Compilation of 1993 Annual Reports of the Navy ELF Communications System Ecological Monitoring Program

Volume 3 of 3 Volumes:
Tabs G-I

Technical Report D06209-2
Contract No. N00039-93-C-0001
April 1994

Prepared for:

Submarine Communications Project Office
Space and Naval Warfare Systems Command
Washington, D.C. 20363-5100

Submitted by:

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"Statement A, unlimited"

IITRI

Printed in the United States of America

This report is available from:

National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	April 1994	Annual Report, 01/93 to 09/93

4. TITLE AND SUBTITLE
Compilation of 1993 Annual Reports of the Navy ELF Communications System Ecological Monitoring Program
Volume 3 of 3 Volumes: Tabs G-I

5. FUNDING NUMBERS
C: N00039-93-C-0001
PE: CLIN 0101

6. AUTHOR(S)
See index J. E. Zapotosky, compiler

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
IIT Research Institute
10 West 35th Street
Chicago, Illinois 60616-3799

8. PERFORMING ORGANIZATION REPORT NUMBER
D06209-2

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Submarine Communications Project Office
Space and Naval Warfare Systems Command
Washington, D.C. 20363-5100

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified/Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

During 1993, the U.S. Navy continued to conduct a program to monitor flora, fauna, and their ecological relationships for possible effects from electromagnetic (EM) fields produced by the Navy's Extremely Low Frequency (ELF) Communications System.

Physiological, developmental, behavioral, and ecological variables for dominant biota in upland and riverine habitats near the Naval Radio Transmitting Facility at Republic, Michigan (NRTF-Republic) have been monitored since 1982. The NRTF-Republic was intermittently energized at low amperages beginning in early 1986. Electric current and periods of energization were then gradually increased until 1989, when the transmitter became a fully operational facility. A split-plot or blocked strategy was used to examine biological variables for possible effects from EM exposure. Reports compiled in this document present the progress of these studies through 1993.

Final results and conclusions are expected after all data have been analyzed in 1994. Investigators for similar studies completed in Wisconsin concluded that there were no EM bioeffects from intermittent or full operation of the transmitter in that state.

14. SUBJECT TERMS
ecology
environmental studies
electromagnetic fields
extremely low frequency
ELF Communications System
ELF Ecological Monitoring Program

15. NUMBER OF PAGES
506

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

FOREWORD

This compendium has been prepared by IIT Research Institute (IITRI) on behalf of the Space and Naval Warfare Systems Command (SPAWAR) to document the results of studies monitoring for possible electromagnetic effects to biota from operation of the U.S. Navy's ELF Communications System.

Monitoring studies have been performed by research teams from Michigan State University, Michigan Technological University, the University of Minnesota-Duluth, the University of Wisconsin-Milwaukee, and the University of Wisconsin-Parkside under subcontract agreements with IITRI. SPAWAR funded these studies under Contracts N00039-81-C-0357, N00039-84-C-0070, N00039-88-C-0065, and N00039-93-C-0001 to IITRI. IITRI, a not-for-profit organization, managed the program and provided engineering support to ecological research teams.

Each report in this compendium (Tabs A through H) presents the results of monitoring research performed near the Naval Radio Transmitting Facility at Republic, Michigan (NRTF-Republic) over the period 1982-1993. The results and conclusions of studies conducted near the Naval Radio Transmitting Facility at Clam Lake, Wisconsin (NRTF-Clam Lake) can be found in previous compilations. Research reports have been prepared annually, and each has been reviewed by at least three scientific peers. Investigators considered and addressed peer critiques prior to providing a final copy to IITRI for compilation. Final reports were compiled without further change or editing by SPAWAR or IITRI.

As was done for all program documents, IITRI has submitted this compilation to the National Technical Information Service for unlimited distribution. Previous compilations and other program documents are listed under Tab I.

Respectfully submitted,
IIT RESEARCH INSTITUTE

John E. Zapotosky, Ph.D.
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Approved:

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ELF Electromagnetic Compatibility Assurance

ELF COMMUNICATIONS SYSTEM
ECOLOGICAL MONITORING PROGRAM

INDEX OF 1993 ANNUAL REPORTS

ELF COMMUNICATIONS SYSTEM ECOLOGICAL MONITORING PROGRAM:

BIRD SPECIES AND COMMUNITIES

ANNUAL REPORT: 1993

SUBCONTRACT NUMBER: DO6205-93-C-008

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Report Number: NRRI/TR-93/47

ELF COMMUNICATIONS SYSTEM ECOLOGICAL MONITORING PROGRAM:

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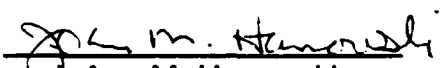

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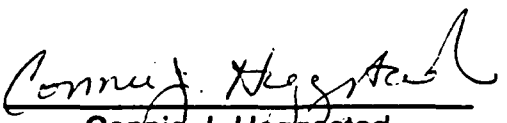

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SUMMARY

This investigation was designed to detect 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, from 1986 onwards. 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 are evident to demonstrate that changes in bird abundance differ between treatment relative to control segments in Michigan after the antenna became operational. No significant interactions found at the community or species level are always repeated in subsequent seasons. In addition, interactions in guild or individual species abundance patterns that exist between treatment and control areas in any season are not repeated in subsequent seasons. Number of significant interactions found at many levels of the analyses were not greater than the number expected by chance alone and are unlikely attributable to electromagnetic fields.

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 areas 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 foraging, nesting, migration, and habitat guilds. Our monitoring program has included bird censuses over a five month period from May to September (1986-1992). Additional data were collected in both states during August and September of 1984 and during June of 1985. Research in Wisconsin was completed in 1989 (Hanowski et al. 1991), but has continued in Michigan.

Here we begin to summarize all of our results of 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.

To investigate possible effects of ELF EM fields, we analyzed changes in species abundances over time on treatment and control segments using a statistical technique repeated measures ANOVA. This analytical technique differs from the standard ANOVA that we used previously to test difference among treatment groups in each year and season. The repeated measures ANOVA incorporates data from all years and compares changes in abundance in bird parameters from pre-treatment to post-treatment conditions. For this test, a significant interaction would indicate that changes in bird abundance over time was not equal in treatment and control areas. Another difference in our statistical analyses was that data were analyzed by season rather than by month. For these analyses we used the May count as spring migration, the maximum value from June and July counts for the breeding season, and the maximum value from August and September for the fall migration season. This method was also used for the final data analyses of data from the Wisconsin study.

We recorded a total of 51,286 birds during the entire study, 27,212 on treatment and 26,774 on control segments. A total of 140 species were observed over all years and seasons; 21 were counted only on controls and 5 only on treatment transects. No species observed either exclusively in control or treatment areas was common in the study area in any season or year (from 1 to 7 total observations).

Numbers of individuals and species observed in all seasons have fluctuated annually. Annual variation in abundance was greatest during both migration periods, the time when birds are moving through the study areas. A significant interaction ($P <$

0.03) was found for both numbers of species and individuals during the fall migration period and for number of species during the spring migration period. Numbers of individuals and species observed during spring migration reflected patterns found during the breeding season; numbers were consistently higher in control than in treatment study areas in all years. Although a significant interaction in number of species observed in the spring migration was found between control and treatment study areas, the trend has been for numbers observed converging over time. Examination of abundance patterns over time did not indicate that changes were due to electromagnetic fields.

Three of nine tests of migration guild parameters (three types X three seasons) indicated a significant interaction ($P < 0.05$) in the repeated measure ANOVA. No consistent patterns emerged for any migration group across seasons, suggesting that difference detected were likely due to chance and not electromagnetic fields. For example, changes in numbers of long-distant migrants over years was not the same ($P < 0.01$) on control and treatment transects during spring migration. A significant interaction ($P < 0.04$) was found for permanent resident species during the breeding season and during fall migration, a difference ($P < 0.04$) in number of short distant migrants.

Examination of birds within five feeding guilds over three seasons (15 total tests) indicated only two significant interactions in changes in numbers over time within treatment and control areas. Numbers of foliage insectivores have declined overall in both control and treatment areas during migration but have fluctuated more widely in treatment areas. Number of bark insect foraging species also showed a significant interaction ($P < 0.03$) in numbers over time during the breeding season, but in contrast overall numbers have increased in both control and treatment areas from 1986 to 1993. No difference could be attributed to electromagnetic fields.

A small percentage of significant tests among nesting guilds was found (2 of 18). Number of birds that nest in cavities were consistently higher in control than treatment areas over all years, but numbers in treatment areas fluctuated more over years, especially from 1990 to 1991. Overall numbers, however have increased from 1986 to 1993 in both control and treatment areas during the breeding season. Number of ground nesting birds observed during fall migration have declined in both control and treatment areas over time, but numbers on treatment transects have fluctuated more widely during this time period than numbers counted in control areas. Examination of these groups abundance patterns over time did not suggest that changes were due to electromagnetic fields.

One of 18 tests among habitat guilds indicated that changes in abundance over time in treatment and control areas differed. For this guild group, numbers of birds that prefer mixed forests showed a significant interaction ($P < 0.01$) during spring migration. Overall, numbers have declined in both treatment and control areas from

1986 to 1993 but the magnitude of declines have been higher in control than treatment areas.

Five of 38 species (13%) species tested in the spring migration season indicated a significant interaction in abundance over years ($P < 0.05$) between control and treatment study areas. Patterns of species abundance over years in treatment and control areas for these five species showed three different patterns. For one species, the Black-and-white Warbler abundance in treatment and control areas have tracked fairly well with treatment transects showing a slightly larger change in abundance over time. Abundance patterns for three species, the Blue Jay, Rose-breasted Grosbeak, and Song Sparrow varied considerably but not consistently in treatment and control areas over years. For these species, however overall abundance has declined more in control than in treatment areas from pre to post-impact years. One species, the Downy Woodpecker has shown the opposite pattern; declines over time have been greater in treatment than in control areas. Given the number of species tested, the number of significant results observed are less than expected by chance alone.

Four of 54 (7%) species tested indicated that changes in abundance over years was significantly ($P < 0.05$) different between reference and treatment study areas in the breeding season. Patterns of changes in abundance for all four species; Red-breasted Nuthatch, Great Crested Flycatcher, Chipping Sparrow, and Brown-headed Cowbird have been highly variable in both treatment and control areas over years. However, relative abundance patterns in pre-treatment years and in post-treatment years on treatment and control areas have been fairly consistent. Suggesting that electromagnetic fields had no negative impact on these bird species.

Nine percent (3 of 33) species tested in the fall migration period indicated a significant difference ($P < 0.05$) in abundance over years in treatment and control study areas. Abundance patterns for two species, Golden-crowned Kinglet and American Woodcock have declined more overall in treatment than control study areas over years. Numbers of Cedar Waxwings have been highly variable among years but fairly consistent in relative abundance among control and treatment study areas.

No consistent patterns are evident to demonstrate that changes in bird abundance differ between treatment relative to control segments in Michigan after the antenna became operational. No significant interactions found at the community or species level are always repeated in subsequent seasons. In addition, interactions in guild or individual species abundance patterns that exist between treatment and control areas in any season are not repeated in subsequent seasons. Number of significant interactions found at many levels of the analyses were not greater than the number expected by chance alone and are unlikely attributable to electromagnetic fields.

INTRODUCTION

Effects of exposure to extremely low frequency (ELF) electromagnetic (EM) fields (other than the earth's) and the mechanism by which bird behavior, reproduction, or migration may be affected by exposure are largely unknown (National Academy of Sciences 1977; Lee et al. 1979). Some birds are known to be able to detect slight changes in magnetic fields (Semm and Beason 1990) and they can use the earth's magnetic field for orientation during migration (Wiltschko and Wiltschko 1988). An ability to detect ELF electric or magnetic fields does not, however, imply an adverse biological effect (American Institute of Biological Sciences 1985). Data obtained from laboratory studies suggest that ELF EM fields may affect animals either by covert biochemical or physiological changes that may alter chances of survival (e.g., mutations, changes in hormone or enzyme levels), or overt behavioral response resulting from detection and reaction to ELF EM fields (American Institute of Biological Sciences 1985). Most previous field investigations have attempted to document overt behavioral responses and to determine how those responses may affect the structure and composition of bird communities; most have analyzed combined effects of habitat alteration and EM fields (Anderson et al. 1977; Anderson 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 rights-of-way (ROW) (Chasko and Gates 1982; Kroodsma 1982), on collision with lines and structures (Avery et al. 1980), and on audible noise generated by a transmission line (Lee and Griffith 1978). To our knowledge, our recently completed study on effects on birds of EM fields produced by the US Navy's ELF transmission facility in Wisconsin (Hanowski et al. 1991), was the first that attempted to separate effects of EM fields on bird species and communities from effects due to habitat changes along the ROW. That study produced no convincing evidence that birds were either attracted to or repelled by EM fields produced by the antenna.

The current investigation in Michigan, and the recently completed Wisconsin study (Hanowski et al. 1993), were designed to isolate effects of EM fields produced by ELF antenna systems on bird species breeding in or migrating through Wisconsin and Michigan. Our goal was to determine if distribution and abundance of bird species differed between areas that were close to the antenna and those that were far enough away to be unaffected by EM fields produced by the antenna. Our study has encompassed spring migration (May), breeding (June and July), and fall migration (August and September). 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.

To assess effects of the ELF antenna on bird communities we can either: (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. The former approach was used in Wisconsin because the antenna already was in operation at the start of our

study. Research in Michigan was, in contrast, initiated before the antenna began operation. By following changes in bird numbers over time on areas affected by the antenna and on unaffected areas, we can separate any effects of the antenna on birds from effects of more regional variables (e.g., annual variation in rainfall) and from effects arising from differences in vegetation structure between control and treatment areas. The Michigan transmitter was tested intermittently, at less than full power during parts of our 1988 field season and at full power during most of our 1989 field season. Continuous operation at full power began on 7 October 1989. We consider 1989 as the first full impact year and therefore, 1993 represents the fifth full impact year (full power and >50% time use) (Figure 1). In the following we summarize our research activities in Michigan where data have been collected for eight years during all seasons.

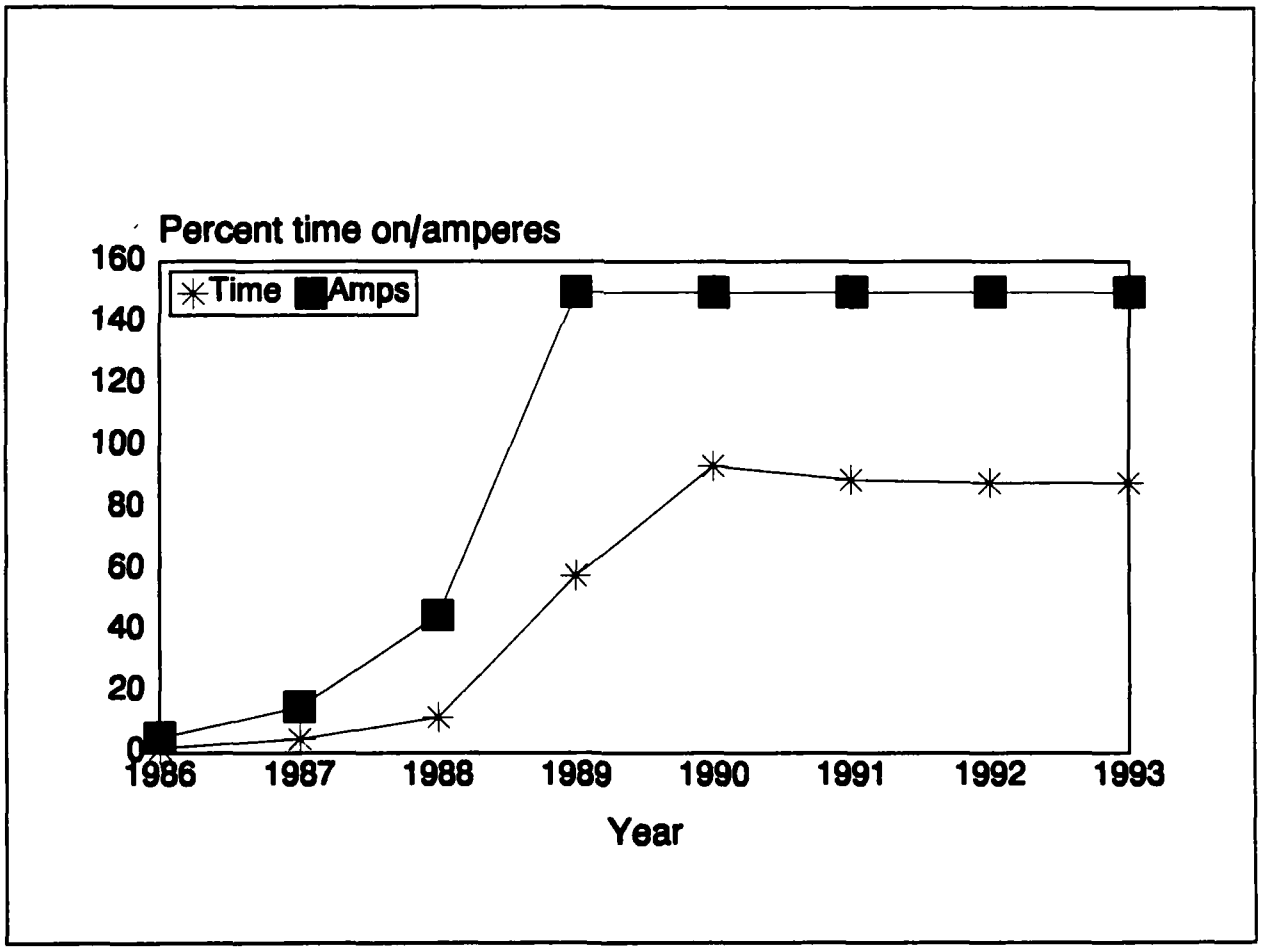

Figure 1. Percent time or amps at which the antenna operated in Michigan from 1986 to 1993.

METHODS

Study areas. Starting points and direction of travel along five treatment and five control transects were randomly determined (see Hanowski et al. 1990) (Figure 2, p 4). Each 4.35 km transect was divided into eight 500 m segments each separated by a 50 m buffer (total N = 40 in each control and treatment group). The 50 m buffer was included to assure that adjacent segments were independent. Spatial autocorrelation tests (Moran's I statistic; Sokal and Oden 1978) indicated that a 50 m buffer was sufficient for considering each 500 m segment as an independent experimental unit (Hanowski et al. 1990). Treatment transects were placed 125 m away from and parallel to the antenna ROW to reduce possible edge effects; the ROW was not sampled. Reference transects were located more than 10 km from the antenna.

Some 500-m transect segments in Michigan have been partially logged since this study started. The Michigan Department of Natural Resources agreed to delay most additional logging until 1994. Analyses of annual variation in bird community composition revealed that segments logged <20% of their total length showed no greater difference in bird populations between years than did unlogged sites. Segments that were logged > 20% 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. Sample sizes used in final analyses were 36 reference transects and 33 treatment transects.

EM Fields. EM fields were measured at the beginning and end of each 500 m segment by IIT Research Institute engineers (Haradem et al. 1989). EM fields produced by the ELF communication system include: (1) essentially identical air and earth magnetic fields generated by the electrical current in the antenna and ground terminals; (2) an electric field in the earth that is the sum of the fields induced by the magnetic field and the current from the buried ground terminals; and (3) an electric field in the air that is produced as a result of the difference in potential between the antenna element and the earth (Haradem et al., 1989). All possible control-treatment pairs (each combination of individual 500 m transects) were required to meet EM exposure criteria that assured that 76 Hz EM fields at treatment sites were at least an order of magnitude higher than those at control sites. In addition, in order to isolate effects of 76 Hz fields from those of 60 Hz fields (i.e., regular power distribution utilities), 76 Hz field intensities at treatment sites had to be at least an order of magnitude greater than EM fields produced by 60 Hz powerlines at both treatment and control sites. Moreover, 60 Hz fields between control and treatment sites could not be significantly different (Haradem et al. 1989).

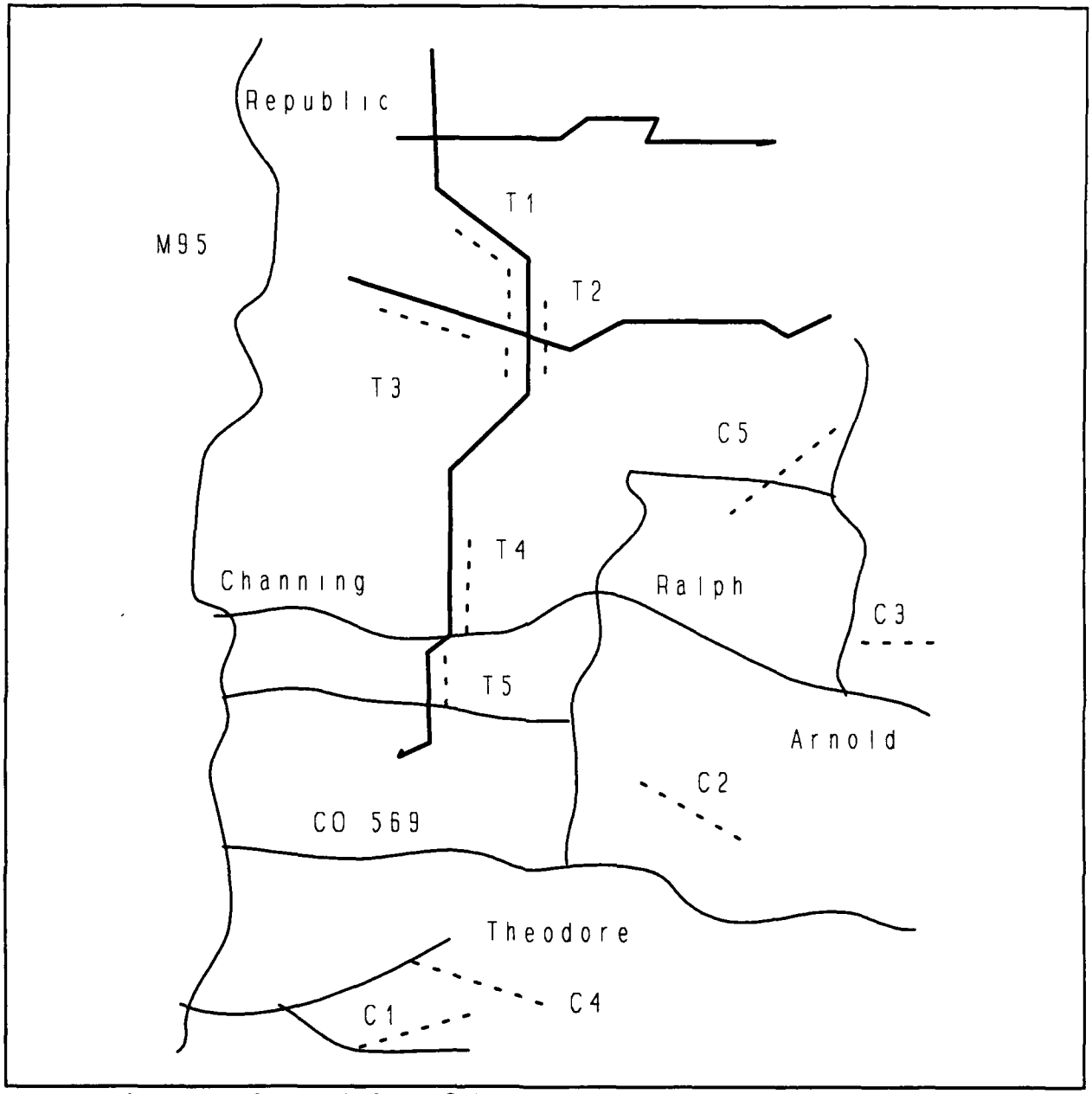

Figure 2. Location of control (C1 to C5) and treatment (T1 to T5) transects in Michigan.

Bird counts. We counted birds on line transects (Järvinen and Väisänen 1975; Hanowski et al. 1990) five times each year (May through September 1986-1993). Censusing was completed between 0.5 hr before and 4.5 hrs after sunrise on days with little wind (< 15 km/hr) and no precipitation. Control and treatment transects were sampled simultaneously by each of two observers to control for possible temporal variation in bird activity between areas. All observers were experienced in the identification of birds by sight and sound; training sessions were conducted prior to censusing to standardize recording methods. Each observer walked at a rate of 1

km/hr and recorded the identity and location on the transect for each bird detected up to 100 m from the transect center line. Birds flying over the canopy were not counted.

We used the maximum number of individuals for each species observed during two breeding (June and July) and two fall migration counts (August and September) along the transect in all data analyses instead of attempting to calculate a density value for that species. We considered the May census as spring migration. With this method we attempted to record the maximum number of breeding or migrating individuals to partially control for annual differnces in phenology of breeding or migration seasons.

Density could be calculated with a variety of formulae (Emlen 1971, 1977; Järvinen and Väisänen 1975; Burnham et al. 1981; Buckland 1985), but there are several assumptions that must be met before these methods can be used. A critical assumption is that distances are measured accurately. These measurements are difficult to obtain when birds are heard but not seen, as is true for most birds recorded during counts. Without accurate distance estimates these methods do not provide valid density estimates. Hence, density estimates may provide an index that may be no better than the actual counts (Wilson and Bart 1985). In addition, absolute density calculations are not needed in most investigations, especially when comparisons of "relative density" are less costly and allow the investigator to meet the objectives of the experiment (see Verner 1985). Here, we assumed that number of birds recorded was related to bird density in an area (see Raphael 1987) and that bird detectability was similar between control and treatment areas.

Bird guilds. We classified each species by (1) nesting area, (2) food or foraging type, (3) breeding habitat preference, and (4) migration strategy (Appendix 1), using published sources (see Hanowski et al. 1993) and personal observations.

Statistical analyses. We used a repeated measures analysis of variance (ANOVA) to test for differences in bird abundance between control and treatment transects within each season. This procedure is relevant when several measurements (e.g., multiple years) are taken on each experimental unit and the measurements are correlated. The test is essentially a multivariate technique which accounts for correlations among the dependent variables while testing for treatment effects (Freund et al. 1986). A two-factor repeated measures ANOVA was done. The between subject factor was area (treatment versus control), the within subject factor was year (1986 to 1993), and the dependent variable was bird abundance. The two-way interaction of area-by-year was also included in the model. Data were examined separately for each species (in each season), provided that at least five individuals were observed in any one year. At total of 54 species were tested in the breeding season, 38 in the spring migration period, and 33 species during fall migration. No between season comparisons were completed.

Annual differences and treatment effects were also examined for each season with repeated measures ANOVA for total number of species observed in a 500 m segment and total number of individuals observed in a 500 m segment. The same model used for individual species (two-factor repeated measures ANOVA, see above) was used for these tests. The only difference was that we used a univariate test for these tests, not the multivariate test that we used for individual species. We did this because we were able to meet assumptions of the univariate test for these variables, and when assumptions are met, it is more powerful than the multivariate test (Freund et al. 1986). All variables were examined for normality and homoscedasticity of variances prior to statistical analyses (Sokal and Rohlf 1981) and were transformed when necessary (e.g., logarithmic, square root) to reduce skewness, kurtosis, and heterogeneity of variances.

One assumption of repeated measures ANOVA (for multivariate test) is that dependent variables in the model have a multivariate normal distribution with a common covariance matrix across the between-subject effects (treatments) (Freund et al. 1986). However, if groups have relatively equal sample sizes, the analysis is insensitive to departures from this assumption (Hand and Taylor 1987). In addition, with the exception of independent sampling, assumptions become less important for larger sample sizes. We have used a large and almost equal sample size in our analyses, therefore we conducted the repeated measures ANOVA (only the multivariate test) on some species regardless of whether the homogeneity assumption was met (see LaTour and Miniard 1983).

RESULTS

The repeated measures analyses includes tests for differences among years, among treatments, and an interaction term. Interpretations of ELF effects in parameters tested here were based on significance of the interaction term. For this analysis we were not interested in whether bird abundance varied annually (year effect) or whether treatment and control sites were different (treatment effect). Because we used a before-and-after design in this study, we were interested in determining whether bird abundance varied over time equally in treatment and control areas. A significant interaction term (interaction effect) would indicate that changes in abundance patterns on treatment and control areas were not the same over time (e.g., before-and-after the antenna was operated).

Electromagnetic fields. Electric field (76 Hz) measured in the earth was 0.99 V/m (range 0.02 - 2.7 mV/m) on control and 62.8 mV/m (range 21 - 112 mV/m) on treatment sites. Mean 76 Hz magnetic flux density was 0.01 mG on control (range 0.001 - 0.07 mG) and 2.9 mG on treatment sites (range 0.9 - 15.0 mG). Transverse (76 Hz) was not measurable on control sites and was 0.16 mV/m on treatment sites (range 0.02 - 0.13 V/m) (Haradem et al. 1993).

Community parameters. We recorded a total of 51,286 birds during the entire study, 27,212 on treatment and 26,774 on control segments (Table 1, p 8). A total of

140 species were observed over all years and seasons; 21 were counted only on controls and 5 only on treatment transects (Appendix 2, 3, 4). Most species counted only on controls were those associated with small ponds or riparian areas (e.g., Great Blue Heron, Pied-billed Grebe, Wilson's Warbler (scientifc names are in Appendix 1). No species observed either exclusively in control or treatment areas was common in the study area in any season or year (from 1 to 7 total observations in all years together).

Numbers of individuals and species observed in all seasons have fluctuated annually. Annual variation in abundance was greatest during both migration periods, the time when birds are moving through the study areas (Figure 3, 4, 5, p 14-16). A significant interaction ($P < 0.03$) was found for both numbers of species and individuals during the fall migration period and for number of species during the spring migration period (Table 2, p 9). Although numbers observed in control areas during fall migration have been fairly consistent over time, numbers observed on treatment transects have varied dramatically, being higher than control areas in three years, lower in three years, and equal to controls in one year (Figure 5). An overall downward trend in numbers is evident in both areas. However, control areas have shown a more negative trend than treatment areas (Figure 5).

Number of individuals and species observed during spring migration reflected patterns found during the breeding season; numbers were consistently higher in control than in treatment study areas in all years. Although a significant interaction in number of species observed in the spring migration was found between control and treatment study areas, the trend has been for number of species observed to converge over time (see Figure 3).

Guild parameters. Examination of birds within five feeding guilds over three seasons (15 total tests) indicated only two significant interactions in changes in numbers over time within treatment and control areas (Table 3, p 10). Numbers of foliage insectivores have declined overall in both control and treatment areas during migration but have fluctuated more widely in treatment areas (Table 3). Overall declines have been greater in magnitude on control than on treatment transects over the years. Number of bark insect foraging species also showed a significant interaction ($P < 0.03$) in numbers over time during the breeding season, but overall numbers have increased in both control and treatment areas from 1986 to 1993 (Table 3).

One of 18 tests among habitat guilds indicated that changes in abundance over time in treatment and control areas differed (Table 3). For this guild group, numbers of birds that prefer mixed forests showed a significant interaction ($P < 0.01$) during spring migration. Overall, numbers have declined in both treatment and control areas from 1986 to 1993 but the magnitude of declines have been higher in control than treatment areas (Table 3).

Table 1. Total numbers of individuals and species observed in treatment (T) and control (C) transects in Michigan, 1986-1993. A combined species total for treatment and control segments is in parentheses.

		Spring Migration			Breeding			Fall Migration		
Parameter	Year	T		C	T		C	T		C
Total individuals	1986	949		1210	1604		1734	682		978
	1987	775		888	1776		1850	1129		936
	1988	815		939	1494		1538	882		882
	1989	570		607	1550		1573	1122		838
	1990	847		858	1324		1378	635		741
	1991	578		778	1371		1557	1001		901
	1992	1045		1060	1638		1700	741		737
	1993	795		836	1412		1516	666		739
Total no. species	1986	54	(76)	69	73	(91)	81	63	(70)	59
	1987	50	(69)	62	80	(95)	86	69	(81)	64
	1988	53	(68)	56	82	(104)	87	63	(81)	67
	1989	44	(62)	46	76	(93)	81	70	(80)	59
	1990	65	(80)	65	79	(90)	76	52	(68)	55
	1991	55	(76)	62	75	(90)	80	61	(78)	61
	1992	66	(83)	69	76	(89)	74	57	(70)	57
	1993	54	(73)	59	72	(87)	76	53	(69)	51

Table 2. Mean number (per 500 m transect) and standard error of total number of species and individuals. A significant interaction (repeated measures ANOVA) was found between control and treatment for numbers of species in the spring and fall migration periods and for number of individuals in the fall migration period.

		Spring Migration				Breeding				Fall Migration			
		Treatment		Control		Treatment		Control		Treatment		Control	
Parameter	Year	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Total individuals	1986	23.39	1.39	30.78	1.37	40.33	1.82	42.83	1.93	16.67	1.58	23.92	2.60
	1987	19.27	1.60	22.11	1.71	45.30	2.30	46.17	2.18	27.00	2.30	23.53	1.81
	1988	19.85	1.56	23.39	1.36	35.82	1.90	37.94	1.71	19.21	1.87	22.06	1.96
	1989	14.03	1.57	15.00	1.21	35.67	1.92	38.64	1.67	27.24	3.01	21.33	2.03
	1990	20.06	1.92	21.11	1.22	32.79	1.97	33.39	1.59	13.58	1.00	18.22	1.31
	1991	14.61	1.54	19.81	1.66	33.33	1.80	38.33	1.59	25.12	2.74	22.36	1.11
	1992	26.03	1.75	26.78	1.79	40.61	1.69	42.58	1.87	18.15	1.53	18.25	1.32
	1993	19.61	1.47	20.75	1.27	34.03	1.78	37.97	1.50	15.91	1.32	18.42	1.07
Total no. species	1986	9.36	0.49	12.97	0.61	15.58	0.73	17.53	0.83	7.42	0.66	9.33	0.65
	1987	8.09	0.59	10.67	0.58	17.70	0.96	20.03	0.93	10.36	0.79	9.92	0.69
	1988	9.42	0.58	11.06	0.59	16.58	0.85	18.56	0.81	8.24	0.53	9.25	0.73
	1989	7.42	0.67	8.11	0.55	15.45	0.73	17.75	0.90	10.18	0.87	9.33	0.54
	1990	9.58	0.76	11.08	0.62	14.18	0.69	16.08	0.67	7.12	0.50	8.89	0.55
	1991	7.67	0.76	9.89	0.73	14.33	0.79	17.06	0.78	8.91	0.74	10.17	0.49
	1992	11.24	0.59	12.22	0.75	16.06	0.76	17.83	0.76	8.03	0.63	8.03	0.50
	1993	9.00	0.59	9.92	0.57	14.36	0.78	16.83	0.76	6.58	0.57	7.25	0.46

Table 3. Mean number (per 500 m transect) and standard error of individuals in habitat, nest, migration, and foraging guilds that showed a significant interaction in abundance over years (repeated measures ANOVA) between treatment and control. Superscript letters indicate season where a difference was detected (S=spring migration, B=breeding, F=fall migration).

		Spring Migration				Breeding				Fall Migration			
		Treatment		Control		Treatment		Control		Treatment		Control	
Guild	Year	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Foliage insects[F]	1986	13.27	1.09	16.44	0.72	21.88	0.97	23.03	1.01	6.79	0.82	10.94	2.19
	1987	10.39	1.15	10.42	1.02	24.55	1.44	22.97	1.07	10.58	1.38	8.92	1.02
	1988	8.00	0.94	9.11	0.90	20.06	1.02	19.58	1.12	7.18	0.91	8.72	0.86
	1989	5.48	0.76	5.39	0.59	19.30	1.05	20.72	0.94	10.55	1.11	8.94	1.06
	1990	11.15	1.15	10.42	0.76	17.97	1.09	18.86	1.09	6.24	0.67	8.28	0.88
	1991	8.39	1.02	10.22	1.24	20.15	1.04	22.44	1.14	6.94	0.71	6.94	0.44
	1992	16.12	1.14	15.81	0.97	25.06	1.25	25.11	1.01	5.88	0.52	6.31	0.63
	1993	8.45	0.70	10.00	0.97	21.15	0.97	23.69	1.31	4.82	0.49	6.11	0.65
Bark insects[B]	1986	1.21	0.21	1.78	0.28	1.30	0.22	1.94	0.28	1.58	0.30	2.69	0.43
	1987	0.48	0.12	1.14	0.24	1.94	0.30	3.14	0.44	3.21	0.54	4.08	0.55
	1988	1.45	0.20	2.14	0.42	1.36	0.26	3.22	0.40	2.64	0.41	3.53	0.52
	1989	0.88	0.20	1.61	0.25	1.61	0.24	2.25	0.29	3.88	0.74	3.42	0.46
	1990	1.42	0.28	2.03	0.28	1.85	0.30	1.81	0.25	1.36	0.22	2.03	0.29
	1991	0.67	0.14	1.78	0.33	1.33	0.28	2.03	0.33	3.76	0.57	3.25	0.39
	1992	1.76	0.29	2.00	0.28	2.91	0.39	3.17	0.48	3.21	0.50	3.36	0.43
	1993	1.52	0.30	1.92	0.29	2.03	0.35	2.39	0.33	2.36	0.32	2.72	0.32

Table 3 (continued)

		Spring Migration				Breeding				Fall Migration			
		Treatment		Control		Treatment		Control		Treatment		Control	
Guild	Year	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Mixed coniferous[S] and deciduous	1986	2.91	0.41	4.81	0.59	4.79	0.37	4.89	0.54	1.09	0.27	1.42	0.27
	1987	1.52	0.25	3.22	0.58	4.85	0.43	5.86	0.56	1.45	0.28	1.42	0.27
	1988	2.27	0.32	2.69	0.45	4.09	0.41	4.92	0.44	1.52	0.28	1.89	0.38
	1989	1.82	0.30	1.42	0.27	4.91	0.57	6.03	0.53	2.64	0.39	2.81	0.32
	1990	2.58	0.45	3.19	0.46	4.55	0.46	5.11	0.48	1.39	0.22	1.50	0.25
	1991	1.18	0.20	3.17	0.56	4.94	0.42	5.17	0.55	1.48	0.29	2.03	0.27
	1992	3.27	0.43	3.36	0.40	5.45	0.56	6.69	0.59	1.39	0.25	1.39	0.26
	1993	2.27	0.36	2.83	0.44	4.79	0.33	5.64	0.63	0.70	0.18	0.86	0.17
Permanent res.[B]	1986	3.00	0.48	3.39	0.43	3.82	0.52	4.25	0.62	5.15	0.70	8.92	1.11
	1987	1.94	0.32	2.86	0.49	5.03	0.61	7.28	0.81	9.67	0.94	10.36	0.83
	1988	4.48	0.51	5.28	0.49	3.58	0.51	5.69	0.75	7.97	1.46	8.19	0.99
	1989	3.85	0.45	3.61	0.48	3.85	0.51	4.69	0.47	11.24	1.74	8.64	1.07
	1990	3.06	0.39	4.19	0.54	4.97	0.71	3.86	0.48	5.42	0.57	7.00	0.69
	1991	2.91	0.45	2.61	0.31	3.79	0.58	4.92	0.54	10.36	1.15	8.64	0.80
	1992	3.58	0.47	3.69	0.40	7.39	1.09	6.25	0.77	7.39	0.68	7.69	0.66
	1993	4.76	0.53	4.86	0.42	5.09	0.68	5.31	0.53	6.42	0.75	7.28	0.63

Table 3 (continued)

		Spring Migration				Breeding				Fall Migration			
		Treatment		Control		Treatment		Control		Treatment		Control	
Guild	Year	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Short-distance migrants[F]	1986	9.39	0.83	11.33	1.11	11.97	1.20	11.75	1.40	6.58	0.88	7.42	1.00
	1987	10.33	1.16	11.25	1.19	14.09	1.78	13.28	1.32	10.61	1.57	6.83	0.89
	1988	11.73	1.20	13.22	1.07	11.36	1.08	10.67	0.91	6.36	0.82	6.69	0.94
	1989	9.94	1.29	11.03	1.02	11.24	1.22	11.14	1.23	9.15	1.49	6.11	0.85
	1990	8.45	1.04	8.64	0.84	9.30	0.98	8.97	1.00	3.58	0.58	4.67	0.70
	1991	7.36	0.95	9.22	0.89	9.64	0.90	10.72	1.08	4.55	0.66	5.61	0.57
	1992	8.45	1.10	8.19	0.86	9.82	0.94	10.14	0.89	4.73	0.79	3.94	0.60
	1993	10.03	1.23	10.03	0.87	9.33	1.13	11.69	1.09	3.21	0.57	3.36	0.41
Long-distance migrants[S]	1986	10.48	0.88	15.44	0.87	23.03	1.18	25.19	1.19	2.76	0.59	4.97	1.11
	1987	6.33	0.74	7.03	0.75	24.09	1.47	23.61	1.26	3.30	0.52	3.58	0.69
	1988	2.70	0.44	4.14	0.51	19.76	1.17	20.42	1.24	2.36	0.34	4.39	0.60
	1989	0.03	0.03	0.22	0.07	19.55	1.28	21.89	1.18	4.70	0.79	4.72	0.59
	1990	8.15	1.08	7.44	0.64	17.73	1.46	19.83	1.21	3.33	0.44	4.81	0.54
	1991	4.06	0.86	7.75	1.54	19.15	1.02	21.97	1.34	3.82	0.55	4.06	0.36
	1992	13.27	1.45	14.08	1.40	22.61	1.27	25.33	1.26	2.85	0.42	3.28	0.48
	1993	3.55	0.59	4.47	0.91	18.82	0.98	20.44	1.24	1.76	0.30	2.67	0.37

Table 3 (continued)

		Spring Migration				Breeding				Fall Migration			
		Treatment		Control		Treatment		Control		Treatment		Control	
Guild	Year	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Ground nest[F]	1986	10.82	1.05	12.39	0.86	17.36	1.22	14.47	1.08	3.24	0.56	4.33	0.87
	1987	9.06	1.07	7.33	0.62	18.27	1.20	14.67	0.95	4.70	0.86	2.47	0.46
	1988	5.76	0.75	6.81	0.71	14.79	1.04	13.53	0.98	3.52	0.49	3.42	0.43
	1989	3.64	0.65	2.83	0.38	16.21	1.23	15.11	0.92	6.21	1.21	3.44	0.42
	1990	8.82	1.30	7.14	0.72	13.30	1.12	11.61	0.84	2.06	0.30	2.83	0.39
	1991	5.58	0.86	6.22	0.79	13.97	1.17	13.31	0.83	3.21	0.46	3.39	0.40
	1992	11.18	1.16	10.28	0.81	15.09	0.90	15.00	0.84	2.27	0.38	2.03	0.36
	1993	6.67	0.88	6.11	0.63	14.97	1.04	13.03	0.76	1.06	0.22	1.33	0.21
Cavity nest[B]	1986	2.48	0.32	3.53	0.60	4.36	0.51	5.03	0.59	5.03	0.72	8.42	1.12
	1987	1.88	0.29	3.81	0.59	4.45	0.53	8.47	0.91	7.82	0.89	10.03	1.01
	1988	4.73	0.41	6.64	0.73	3.70	0.56	6.31	0.70	6.24	0.66	8.47	0.99
	1989	3.94	0.56	5.61	0.50	3.12	0.36	5.39	0.43	8.85	1.17	8.22	1.07
	1990	2.91	0.38	4.50	0.45	4.18	0.66	4.28	0.46	4.09	0.51	5.97	0.58
	1991	2.94	0.39	4.19	0.57	3.67	0.56	5.25	0.51	7.73	0.91	7.61	0.66
	1992	3.24	0.43	4.58	0.49	6.36	0.69	7.33	0.87	6.88	0.67	7.97	0.68
	1993	4.64	0.49	5.31	0.51	4.52	0.62	5.75	0.58	6.33	0.70	7.39	0.67

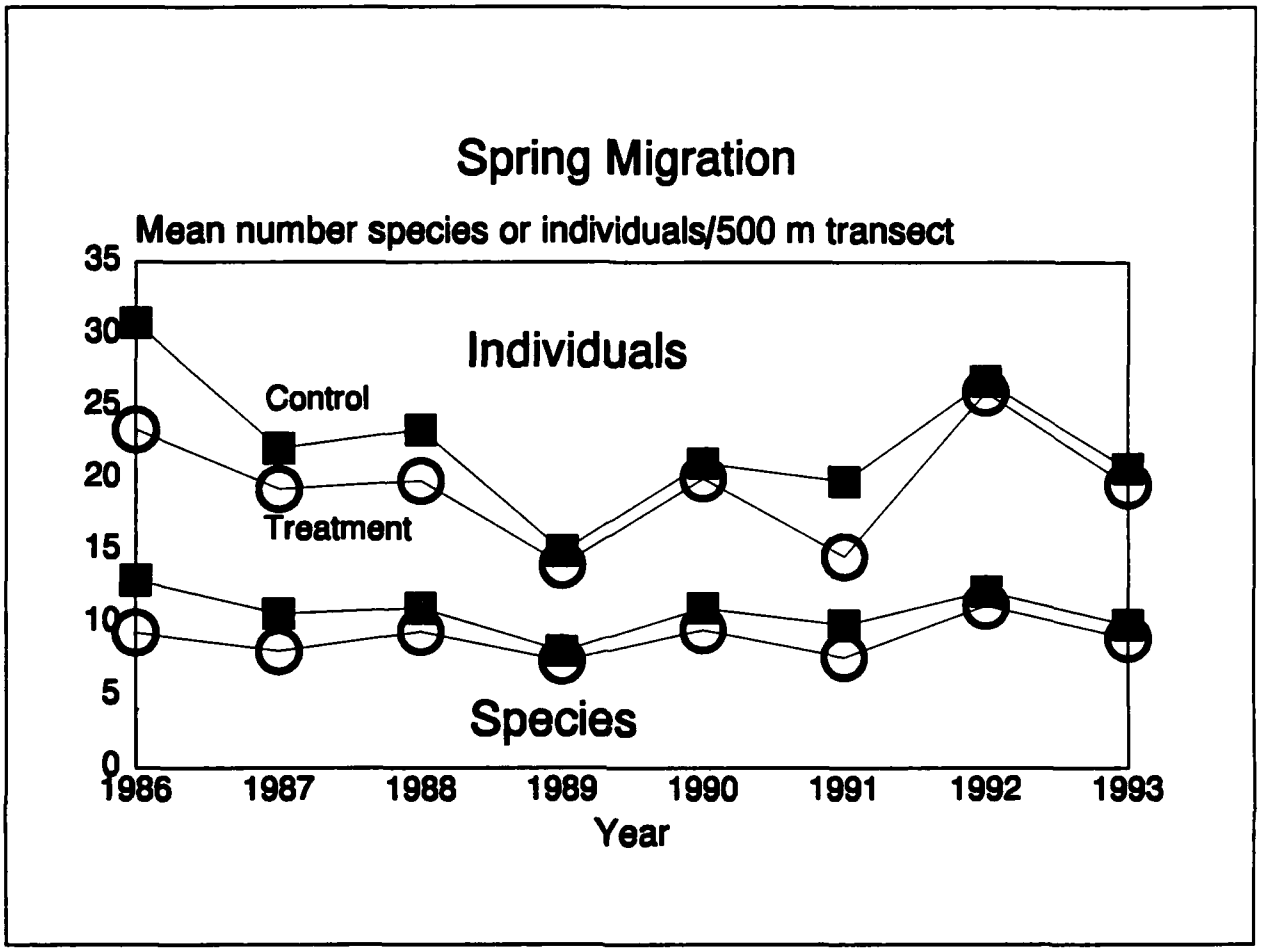

Figure 3. Mean number of species and individuals observed/500 m transect in treatment and control study areas during spring migration 1986 to 1993.

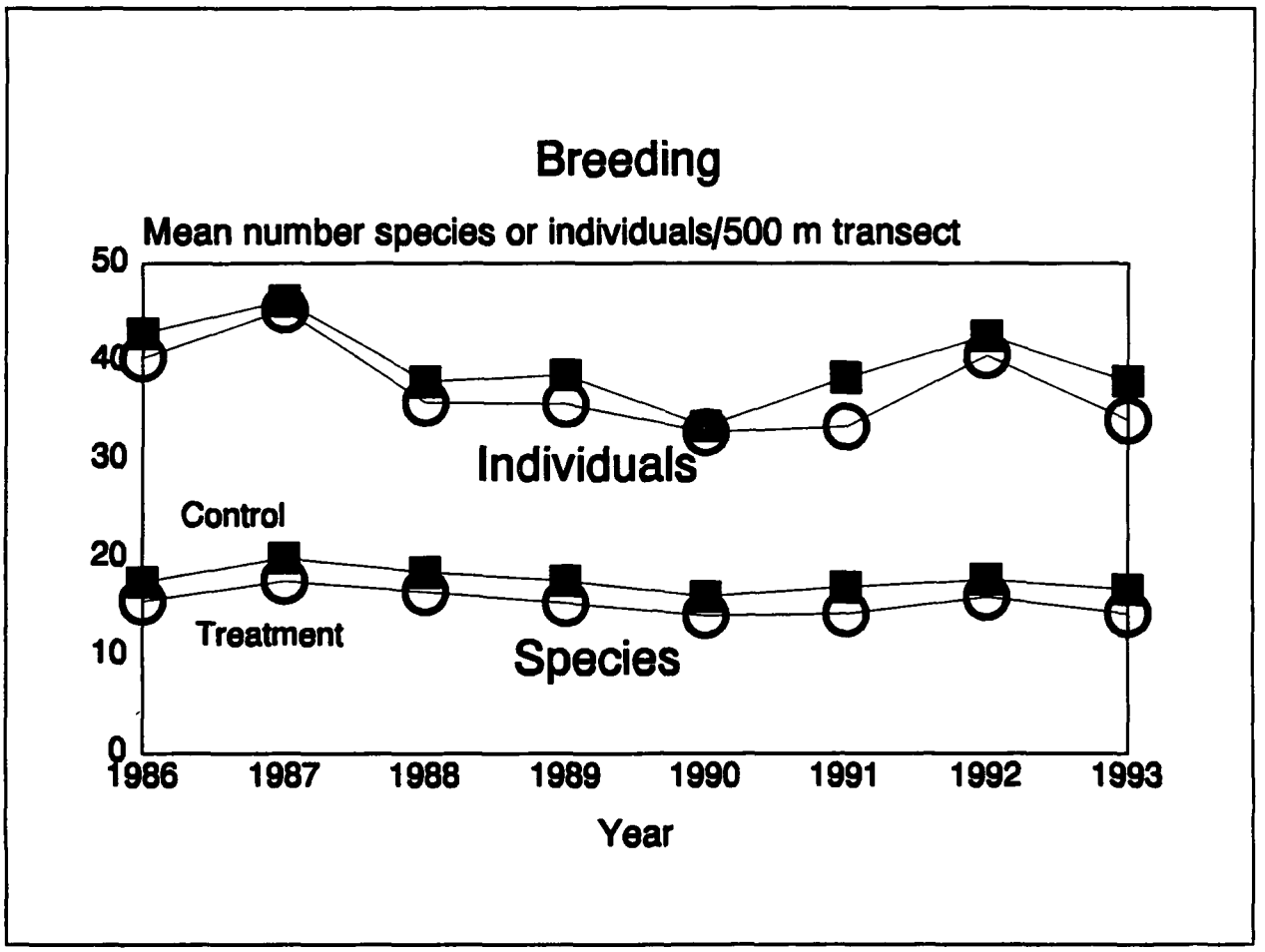

Figure 4. Mean number of species and individuals observed/500 m transect in treatment and control study areas during the breeding season 1986 to 1993.

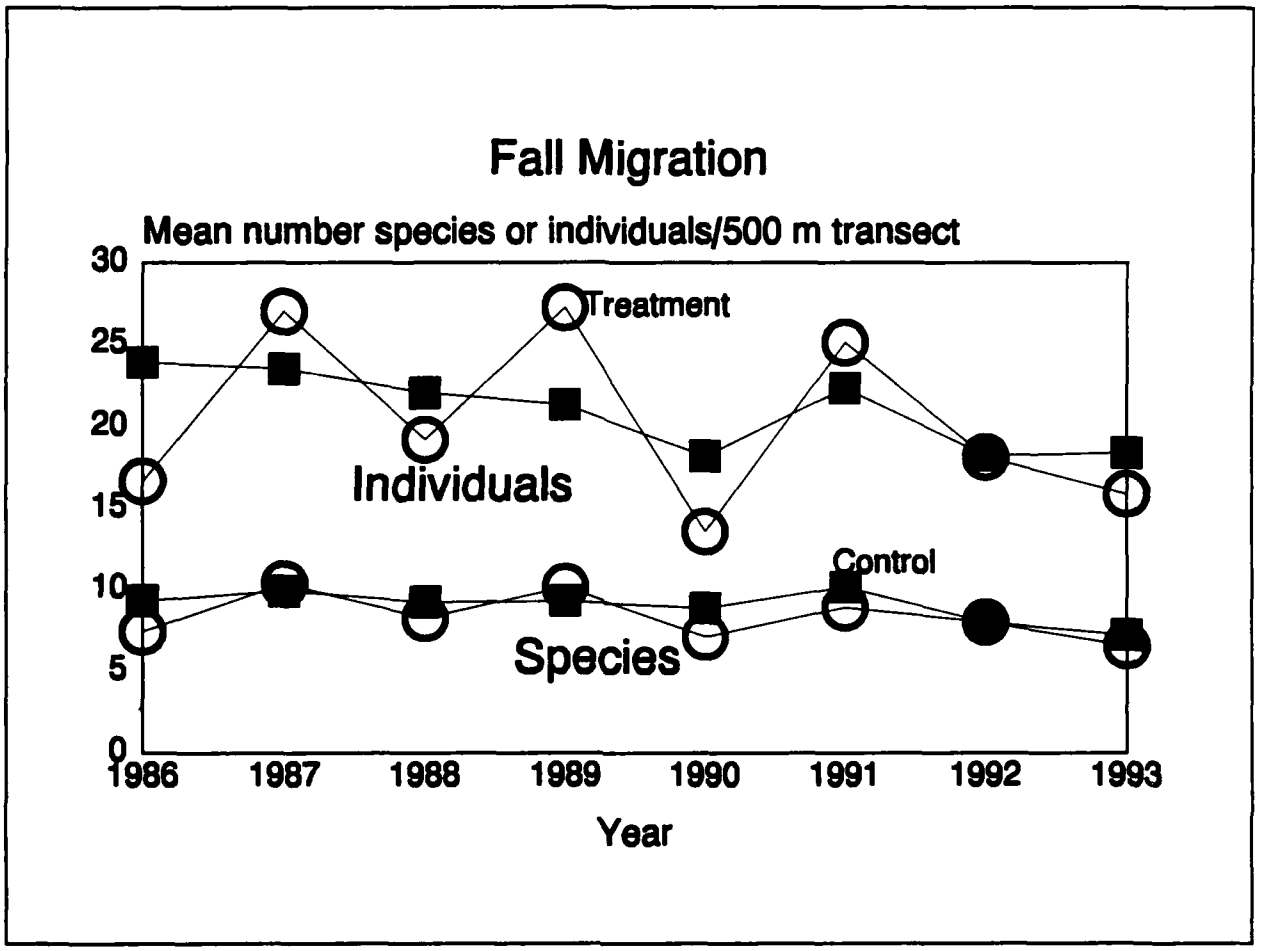

Figure 5. Mean number of species and individuals observed/500 m transect in treatment and control study areas from 1986 to 1993 in the fall migration period.

Three of nine tests of migration guild parameters (three types X three seasons) indicated a significant interaction ($P < 0.05$) in the repeated measure ANOVA (Table 3). No consistent patterns emerged for any migration group across seasons. For example, changes in numbers of long-distant migrants over years was not the same ($P < 0.01$) on control and treatment transects during spring migration. Significant interactions ($P < 0.04$) were found for permanent resident species during the breeding season and during fall migration, for the number of short distant migrants ($P < 0.04$).

A small percentage of significant tests among nesting guilds was found (2 of 18) (Table 3). Number of birds that nest in cavities were consistently higher in control than treatment areas over all years, but numbers in treatment areas fluctuated more over years, especially from 1990 to 1991 (Table 3). Overall numbers, however, have increased from 1986 to 1993 in both control and treatment areas during the breeding season. Number of ground nesting birds observed during fall migration have declined in both control and treatment areas over time, but numbers on treatment transects have fluctuated more widely during this time period than numbers counted in control areas (Table 3).

Individual species. Five of 38 species (13%) species tested in the spring migration season indicated a significant interaction in abundance over years ($P < 0.05$) between control and treatment study areas (Table 4, p 18). Patterns of species abundance over years in treatment and control areas for these five species showed three different patterns. For one species, the Black-and-white Warbler abundance in treatment and control areas have varied similary over time (Figure 6). Abundance patterns for three species, the Blue Jay, Rose-breasted Grosbeak, and Song Sparrow varied considerably but not consistently in treatment and control areas over years (Table 4; Figure 7, p 24). For these species, however the number observed has declined more in control than in treatment areas from pre to post-impact years. One species, the Downy Woodpecker has shown the opposite pattern; declines over time have been greater in treatment than in control areas (Table 4; Figure 8, p 25).

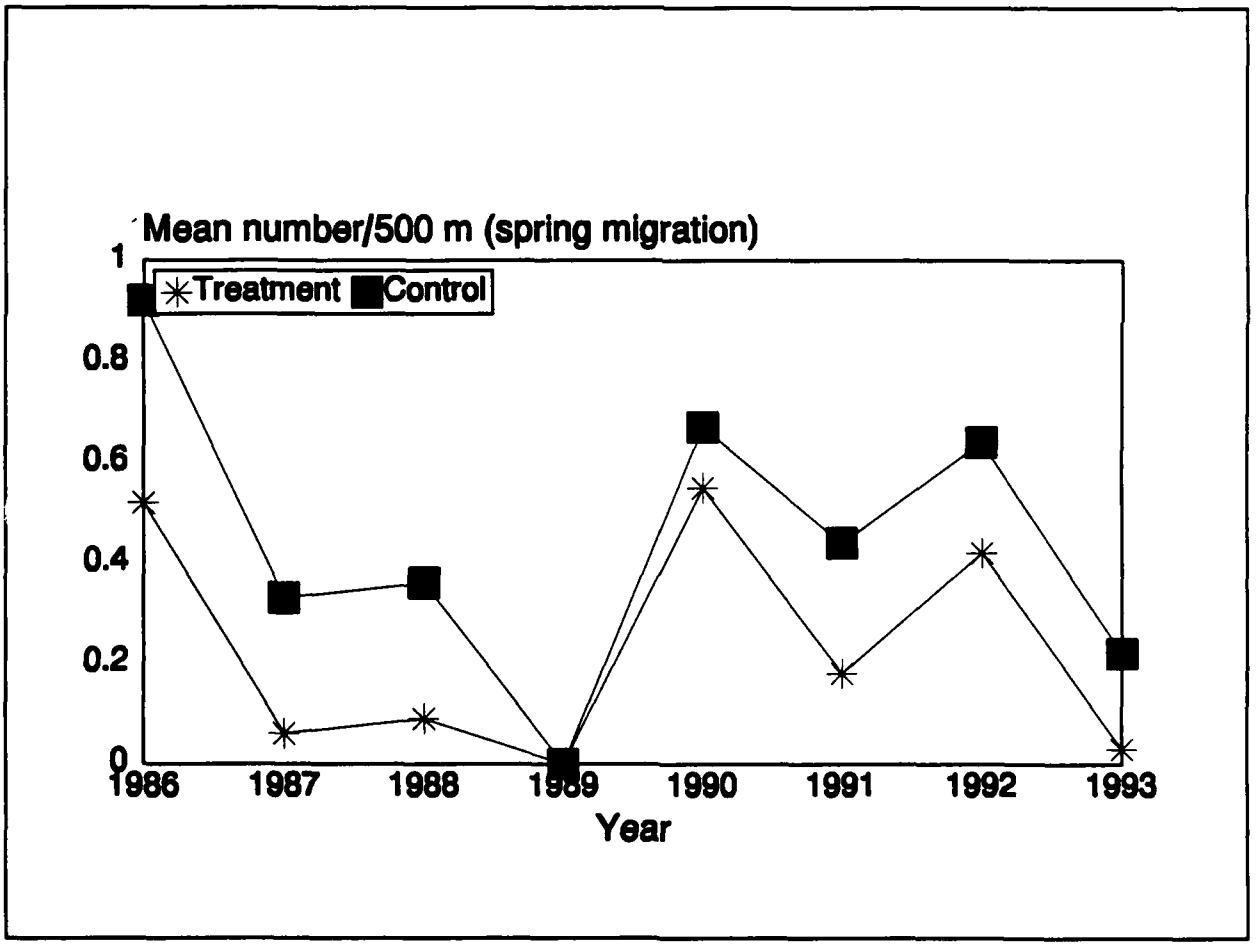

Figure 6. Mean number of Black-and-white Warblers observed/500 m transect in control and treatment study areas during spring migration from 1986 to 1993.

Four of 54 (7%) species tested indicated that changes in abundance over years was significantly ($P < 0.05$) different between control and treatment study areas in the breeding season (Table 4). Patterns of changes in abundance for all four species; Red-breasted Nuthatch, Great Crested Flycatcher, Chipping Sparrow, and Brown-headed Cowbird have been highly variable in both treatment and control areas over

Table 4. Mean number (per 500 m transect) and standard error of species that showed a significant interaction in abundance over years (repeated measures ANOVA) between treatment and control. Superscript letter indicates season where significant difference was found (S=spring migration, B=breeding, F=fall migration).

		Spring Migration				Breeding				Fall Migration			
		Treatment		Control		Treatment		Control		Treatment		Control	
Parameter	Year	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
American Woodcock[F]	1986	0.06	0.04	0.00	0.00	0.06	0.04	0.17	0.09	0.12	0.07	0.00	0.00
	1987	0.00	0.00	0.03	0.03	0.12	0.09	0.28	0.14	0.18	0.08	0.08	0.05
	1988	0.00	0.00	0.00	0.00	0.12	0.06	0.11	0.05	0.36	0.16	0.03	0.03
	1989	0.03	0.03	0.03	0.03	0.15	0.09	0.08	0.06	0.21	0.08	0.14	0.07
	1990	0.12	0.07	0.03	0.03	0.09	0.07	0.00	0.00	0.06	0.04	0.08	0.05
	1991	0.03	0.03	0.00	0.00	0.06	0.04	0.17	0.08	0.03	0.03	0.08	0.05
	1992	0.00	0.00	0.08	0.06	0.03	0.03	0.06	0.04	0.06	0.04	0.03	0.03
	1993	0.06	0.04	0.00	0.00	0.12	0.09	0.03	0.03	0.03	0.03	0.11	0.05
Downy Woodpecker[S]	1986	0.12	0.06	0.17	0.07	0.30	0.10	0.44	0.16	0.24	0.08	0.72	0.18
	1987	0.03	0.03	0.19	0.07	0.24	0.09	0.44	0.14	0.33	0.09	0.39	0.13
	1988	0.27	0.12	0.22	0.12	0.15	0.10	0.31	0.12	0.06	0.04	0.00	0.00
	1989	0.21	0.09	0.19	0.10	0.18	0.08	0.06	0.04	0.09	0.05	0.17	0.06
	1990	0.09	0.05	0.03	0.03	0.12	0.09	0.17	0.10	0.33	0.10	0.14	0.07
	1991	0.06	0.04	0.17	0.06	0.03	0.03	0.19	0.07	0.55	0.15	0.25	0.08
	1992	0.21	0.09	0.11	0.05	0.12	0.06	0.33	0.11	0.27	0.08	0.33	0.10
	1993	0.00	0.00	0.11	0.05	0.12	0.07	0.25	0.11	0.33	0.09	0.33	0.11

Table 4 (continued)

		Spring Migration				Breeding				Fall Migration			
		Treatment		Control		Treatment		Control		Treatment		Control	
Parameter	Year	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Great Crested Flycatcher[B]	1986	0.09	0.05	0.17	0.07	0.39	0.11	0.72	0.13	0.06	0.04	0.08	0.05
	1987	0.00	0.00	0.06	0.04	0.39	0.13	0.92	0.17	0.06	0.06	0.08	0.05
	1988	0.03	0.03	0.19	0.08	0.33	0.09	0.56	0.15	0.03	0.03	0.06	0.04
	1989	0.00	0.00	0.06	0.04	0.12	0.06	0.78	0.14	0.03	0.03	0.06	0.06
	1990	0.09	0.05	0.19	0.07	0.12	0.07	0.53	0.14	0.00	0.00	0.03	0.03
	1991	0.03	0.03	0.11	0.05	0.39	0.14	0.39	0.11	0.03	0.03	0.19	0.07
	1992	0.06	0.04	0.25	0.10	0.18	0.07	0.64	0.16	0.03	0.03	0.14	0.07
	1993	0.03	0.03	0.06	0.04	0.30	0.10	0.36	0.10	0.00	0.00	0.14	0.06
Blue Jay[S]	1986	1.33	0.36	1.56	0.29	0.94	0.23	0.67	0.20	0.97	0.30	1.22	0.24
	1987	0.70	0.17	0.72	0.20	1.42	0.23	1.42	0.25	1.76	0.40	1.28	0.19
	1988	0.48	0.20	1.06	0.23	0.82	0.17	1.03	0.27	1.06	0.26	1.25	0.28
	1989	0.42	0.14	0.25	0.12	0.88	0.23	0.69	0.18	1.21	0.24	0.86	0.27
	1990	0.45	0.16	0.56	0.13	1.12	0.40	0.64	0.20	1.45	0.29	1.47	0.30
	1991	0.64	0.23	0.50	0.15	0.64	0.19	0.64	0.16	1.24	0.21	0.97	0.17
	1992	0.85	0.26	0.33	0.11	1.03	0.28	1.00	0.18	1.03	0.20	0.86	0.16
	1993	0.94	0.24	0.58	0.17	0.64	0.18	0.72	0.17	0.76	0.16	1.08	0.23

Table 4 (continued)

		Spring Migration				Breeding				Fall Migration			
		Treatment		Control		Treatment		Control		Treatment		Control	
Parameter	Year	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Red-breasted Nuthatch[B]	1986	0.27	0.11	0.17	0.07	0.27	0.13	0.25	0.08	0.70	0.18	0.69	0.15
	1987	0.21	0.09	0.31	0.12	0.36	0.10	0.67	0.13	1.58	0.35	2.08	0.30
	1988	0.82	0.17	0.78	0.20	0.52	0.15	0.94	0.18	1.06	0.26	1.61	0.25
	1989	0.21	0.07	0.25	0.10	0.45	0.12	0.83	0.15	2.88	0.61	1.97	0.31
	1990	0.48	0.15	0.69	0.20	0.67	0.18	0.31	0.12	0.45	0.13	0.78	0.19
	1991	0.09	0.07	0.14	0.07	0.30	0.14	0.39	0.13	2.12	0.46	1.39	0.23
	1992	0.67	0.18	0.67	0.13	1.42	0.35	0.94	0.21	1.73	0.31	1.53	0.31
	1993	0.73	0.20	0.78	0.17	0.61	0.16	0.67	0.14	0.58	0.12	0.56	0.14
Golden-crowned Kinglet[F]	1986	1.06	0.37	0.42	0.18	1.15	0.34	0.94	0.27	1.97	0.48	1.78	0.38
	1987	1.45	0.37	1.17	0.26	2.30	0.71	1.03	0.25	3.88	0.87	1.67	0.57
	1988	1.48	0.34	1.78	0.48	1.48	0.37	1.22	0.40	2.15	0.55	1.67	0.43
	1989	1.58	0.41	0.86	0.26	1.36	0.32	0.94	0.31	2.21	0.52	1.44	0.53
	1990	1.06	0.29	1.00	0.31	1.24	0.32	0.83	0.33	0.94	0.27	1.14	0.42
	1991	1.06	0.29	0.83	0.22	1.70	0.37	1.56	0.36	0.61	0.16	0.47	0.16
	1992	1.12	0.45	0.36	0.14	1.73	0.37	0.64	0.21	0.67	0.19	0.31	0.13
	1993	0.30	0.13	0.33	0.11	1.61	0.39	1.50	0.50	0.12	0.07	0.33	0.14

Table 4 (continued)

Parameter	Year	Spring Migration				Breeding				Fall Migration			
		Treatment		Control		Treatment		Control		Treatment		Control	
		Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Cedar Waxwing[F]	1986	0.00	0.00	0.03	0.03	0.33	0.20	0.25	0.15	0.15	0.10	0.31	0.10
	1987	0.00	0.00	0.00	0.00	0.39	0.16	0.31	0.12	0.79	0.22	0.97	0.26
	1988	0.00	0.00	0.00	0.00	0.73	0.27	0.42	0.19	1.76	1.06	0.44	0.19
	1989	0.00	0.00	0.00	0.00	0.52	0.17	0.42	0.15	0.88	0.27	0.39	0.16
	1990	0.00	0.00	0.00	0.00	0.55	0.32	0.17	0.10	0.09	0.09	0.19	0.17
	1991	0.00	0.00	0.00	0.00	0.79	0.24	0.53	0.15	2.21	0.37	1.39	0.34
	1992	0.00	0.00	0.00	0.00	0.82	0.30	0.19	0.10	0.27	0.14	0.06	0.04
	1993	0.00	0.00	0.00	0.00	0.42	0.19	0.53	0.23	0.30	0.13	0.53	0.21
Black-and-white Warbler[S]	1986	0.52	0.17	0.92	0.21	0.45	0.14	0.69	0.17	0.12	0.08	0.08	0.05
	1987	0.06	0.04	0.33	0.09	0.67	0.18	0.97	0.26	0.15	0.08	0.08	0.08
	1988	0.09	0.05	0.36	0.11	0.42	0.13	0.97	0.16	0.06	0.04	0.33	0.14
	1989	0.00	0.00	0.00	0.00	0.48	0.13	0.75	0.15	0.15	0.08	0.14	0.06
	1990	0.55	0.21	0.67	0.14	0.61	0.16	0.72	0.16	0.21	0.08	0.14	0.06
	1991	0.18	0.09	0.44	0.12	0.39	0.15	0.64	0.15	0.15	0.11	0.11	0.05
	1992	0.42	0.12	0.64	0.14	0.45	0.13	0.97	0.18	0.21	0.09	0.11	0.07
	1993	0.03	0.03	0.22	0.08	0.42	0.14	0.47	0.14	0.12	0.07	0.17	0.06

Table 4 (continued)

		Spring Migration				Breeding				Fall Migration			
		Treatment		Control		Treatment		Control		Treatment		Control	
Parameter	Year	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Rose-breasted Grosbeak[S]	1986	0.06	0.04	0.94	0.23	0.94	0.23	1.47	0.27	0.00	0.00	0.11	0.09
	1987	0.12	0.07	0.22	0.08	0.82	0.19	0.67	0.12	0.24	0.10	0.08	0.06
	1988	0.03	0.03	0.03	0.03	1.03	0.18	1.19	0.19	0.03	0.03	0.11	0.07
	1989	0.00	0.00	0.00	0.00	0.67	0.18	1.11	0.22	0.12	0.07	0.08	0.06
	1990	0.39	0.15	0.39	0.11	0.79	0.24	1.00	0.19	0.15	0.09	0.11	0.07
	1991	0.30	0.17	0.47	0.14	0.42	0.12	1.11	0.18	0.12	0.06	0.03	0.03
	1992	1.06	0.30	0.69	0.13	0.97	0.19	1.03	0.18	0.12	0.09	0.00	0.00
	1993	0.06	0.04	0.19	0.10	0.18	0.08	0.42	0.11	0.00	0.00	0.03	0.03
Chipping Sparrow[B]	1986	0.24	0.10	0.81	0.20	0.58	0.18	0.58	0.18	0.12	0.09	0.00	0.00
	1987	0.67	0.25	0.56	0.23	0.39	0.17	0.44	0.19	0.15	0.11	0.03	0.03
	1988	0.52	0.19	0.42	0.17	0.64	0.17	0.33	0.13	0.06	0.06	0.03	0.03
	1989	0.21	0.09	0.25	0.13	0.70	0.20	0.28	0.12	0.36	0.18	0.08	0.08
	1990	0.12	0.07	0.11	0.09	0.48	0.19	0.28	0.13	0.00	0.00	0.06	0.06
	1991	0.12	0.06	0.50	0.27	0.21	0.07	0.36	0.14	0.00	0.00	0.36	0.21
	1992	0.33	0.13	0.50	0.25	0.33	0.12	0.50	0.26	0.06	0.04	0.08	0.06
	1993	0.15	0.08	0.17	0.09	0.64	0.23	0.50	0.19	0.12	0.12	0.08	0.06

Table 4 (continued)

		Spring Migration				Breeding				Fall Migration			
		Treatment		Control		Treatment		Control		Treatment		Control	
Parameter	Year	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Song Sparrow[S]	1986	0.09	0.05	0.19	0.10	0.39	0.13	0.72	0.19	0.09	0.07	0.19	0.10
	1987	0.36	0.15	0.31	0.10	0.39	0.16	0.75	0.22	0.27	0.15	0.11	0.05
	1988	0.52	0.17	0.17	0.09	0.36	0.11	0.28	0.09	0.09	0.05	0.11	0.09
	1989	0.24	0.09	0.42	0.16	0.24	0.10	0.47	0.15	0.39	0.22	0.17	0.07
	1990	0.36	0.10	0.06	0.04	0.15	0.06	0.19	0.07	0.03	0.03	0.00	0.00
	1991	0.00	0.00	0.19	0.08	0.21	0.10	0.39	0.13	0.03	0.03	0.03	0.03
	1992	0.24	0.10	0.22	0.10	0.18	0.09	0.61	0.16	0.03	0.03	0.06	0.04
	1993	0.12	0.06	0.17	0.09	0.12	0.06	0.56	0.18	0.12	0.07	0.06	0.04
Brown-headed Cowbird[B]	1986	0.21	0.09	0.50	0.13	0.06	0.04	0.28	0.10	0.00	0.00	0.00	0.00
	1987	0.09	0.05	0.28	0.10	0.09	0.05	0.25	0.12	0.00	0.00	0.00	0.00
	1988	0.12	0.09	0.28	0.14	0.03	0.03	0.31	0.11	0.00	0.00	0.00	0.00
	1989	0.21	0.07	0.50	0.23	0.09	0.05	0.17	0.07	0.00	0.00	0.00	0.00
	1990	0.06	0.04	0.25	0.10	0.06	0.04	0.17	0.07	0.00	0.00	0.00	0.00
	1991	0.03	0.03	0.11	0.07	0.00	0.00	0.25	0.10	0.00	0.00	0.00	0.00
	1992	0.03	0.03	0.11	0.05	0.00	0.00	0.03	0.03	0.00	0.00	0.00	0.00
	1993	0.12	0.07	0.22	0.10	0.00	0.00	0.06	0.04	0.00	0.00	0.00	0.00

years. However, relative abundance patterns in pre-treatment years and in post-treatment years on treatment and control areas have been fairly similar (Table 4).

Nine percent (3 of 33) species tested in the fall migration period indicated a significant difference ($P < 0.05$) in abundance over years in treatment and control study areas (Table 4). Abundance patterns for two species, Golden-crowned Kinglet and American Woodcock, have declined more overall in treatment than control study areas over years (Table 4). Number of Cedar Waxwings has been highly variable among years but, similar in relative abundance among control and treatment study areas (Table 4).

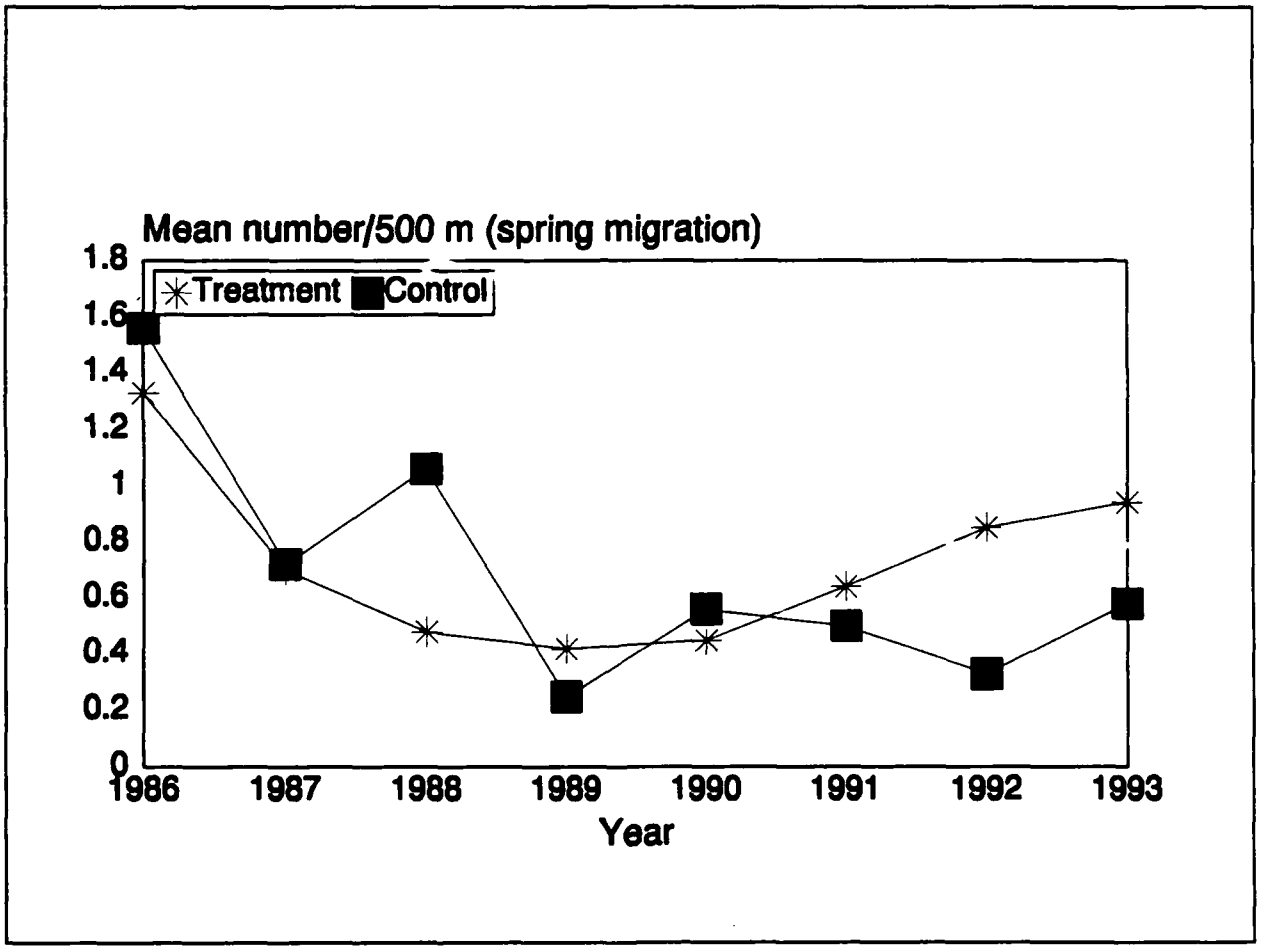

Figure 7. Mean number of Blue Jays observed/500 m transect in control and treatment study areas during spring migration from 1986 to 1993.

DISCUSSION

Bird community abundance patterns. We found no convincing evidence that overall bird distribution or abundance was affected by EM fields produced by the ELF antenna. Breeding bird communities (number of species, number of individuals) varied substantially over the eight years of this study and a similar pattern was found in

northern Wisconsin (Hanowski et al. 1993). Although numbers varied annually, consistent patterns for numbers of individuals and species on treatment and control study areas were evident; control areas had more species and individuals than treatment study areas in most years. Patterns in abundance for birds in the period when they are most stationary and therefore, receive the most exposure to EM fields were the same before and after the antenna was operated.

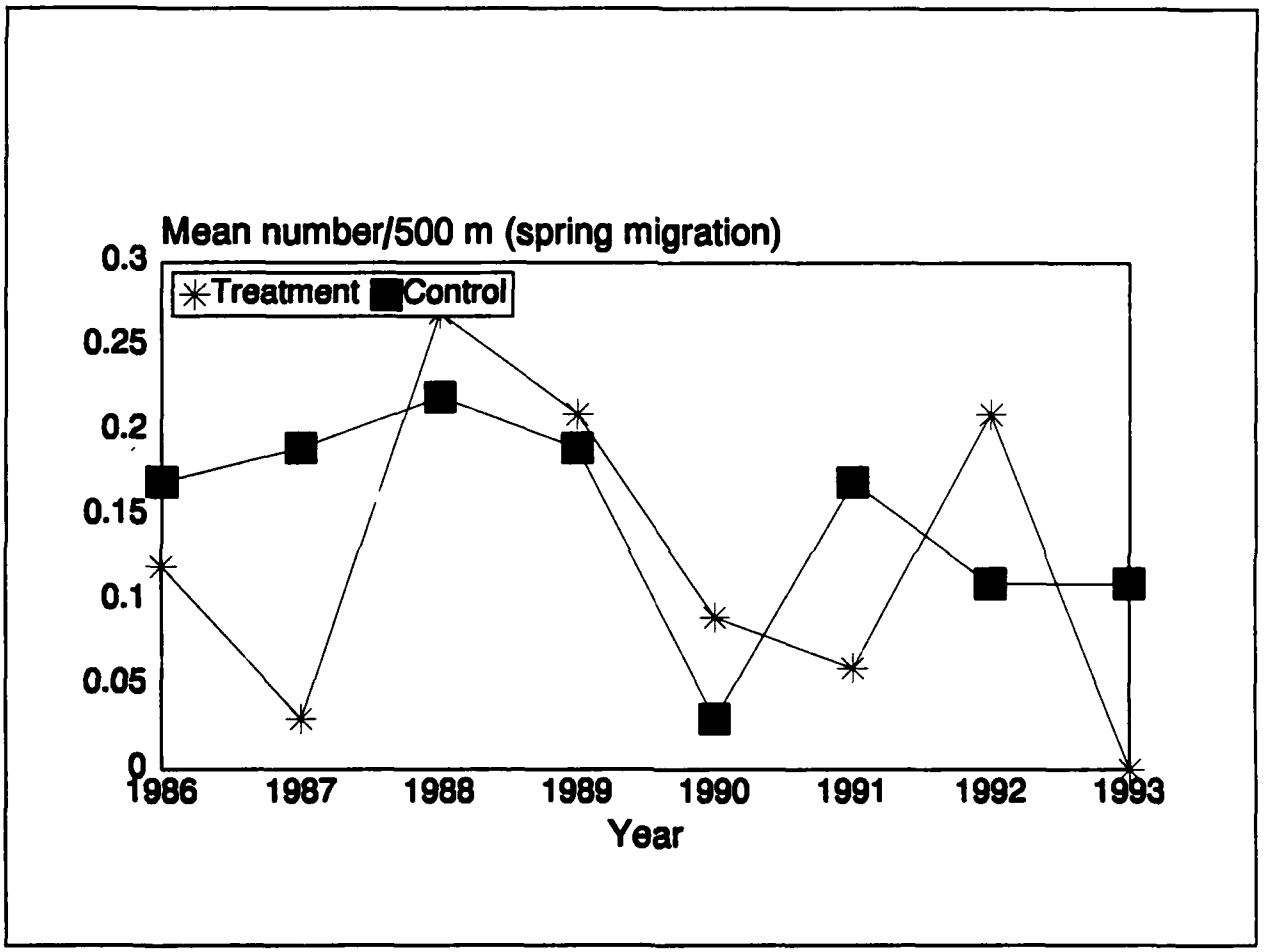

Figure 8. Mean number of Downy Woodpeckers observed/500 m transect in treatment and control study areas during spring migration from 1986 to 1993.

Annual variation in abundance was greatest during both migration periods, the time when birds are moving through the study areas. Number of individuals and species observed during spring migration reflected patterns found during the breeding season; numbers were consistently higher in control than in treatment study areas in all years. Although a significant interaction in number of species observed in the spring migration was found between control and treatment study areas, the trend has been for numbers observed to converge over time (see Figure 3, p 14). Thus, this difference is not likely due to repulsion of birds due to EM fields during spring migration.

Annual variation in abundance patterns for individuals and species was most pronounced during the fall migration period, especially for number of individuals. Although numbers observed in control areas have been fairly consistent over time, numbers observed on treatment transects have varied considerably, being higher than control areas in three years, lower in three years, and equal to controls in one year (Figure 5, p 16). However, because this alternating pattern in abundance has occurred both before and after the antenna was operated, it is unlikely due to EM fields related to the operation of the antenna.

Annual variation in bird abundance may reflect timing of sampling in relation to migration phenology. Weather during migration may profoundly influence abundance of birds in a particular area (Richardson, 1978). Thus, differences in weather from one year to the next may produce apparent (as well as real) differences in bird abundance. If arrival of most migrants was later in one year than in another, we might record substantial variation in abundance between years (particularly in September). We attempted to minimize this by sampling at approximately the same period (calendar date) each year. In addition, we sampled two times during the breeding and fall migration seasons and used the maximum number of individuals observed in our analyses. This method should partially control for annual phenological difference in bird detection. Patterns of annual variation however, were similar on treatments and controls during breeding and spring migration, indicating that birds likely responded to environmental conditions and not to EM fields produced by the antenna (see Rogers, 1981). Reasons for patterns observed for number of individuals on treatment areas during the fall migration period are unclear.

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. It was operated at 150 amperes for 16-24 hr/day during most of the 1989 sampling period and during all of 1991, 1992, and 1993. 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, but declines have occurred on both treatment and control segments, often in concert. Further, major declines occurred before the antenna began operation in 1988. No consistent patterns are yet evident to indicate that changes in abundance on treatment segments have been more pronounced than on control segments since the antenna became fully operational. That is, after the antenna became fully operational in 1989, trends in abundance on treatment and control segments have not been significantly altered.

Results from Wisconsin also showed little consistency among years or seasons in species richness or number of individuals (Hanowski et al. 1993). If the ELF transmitter strongly influenced bird distribution patterns, one might expect that changes in relative abundance of birds on treatment and control segments would be somewhat consistent (within each group) from one year to the next, particularly during the breeding season, and from one season to the next. There was, however, little or no evidence for such a pattern. 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 treatment and control segments in Wisconsin (Hanowski et al. 1991).

Guild distribution patterns. Species that belong to the same "guild" share some biological characteristics. Thus, if the ELF antenna system influenced the distribution patterns of birds, 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. We attributed many differences that we detected in our studies in Wisconsin to differences in amounts and types of habitats present in treatment and control study areas. Because we had no before treatment data, we could not determine whether differences in bird abundance was due to habitat or to EM fields. In this study, however we have before operational data and therefore, we can rule out that differences between control and treatment transects are due to habitat. This assumption appears to be valid for the Michigan study as reflected by results of the guild analyses for habitat. In this analyses, only one of eighteen tests indicated a significant interaction, only slightly more than would be expected by chance. This result indicates that any successional changes in habitats that have occurred in Michigan over the past eight years have been parallel in treatment and control areas and that birds have responded similarly to these changes in both areas.

Guild parameters that have shown significant interactions in the breeding season from three groups, nesting, migration, and foraging are related and are likely driven by similar data sets. For example, numbers of cavity nesters, permanent residents, and bark foragers all showed significant interactions in abundance between control and treatment study areas and also very similar patterns (Figure 9, p 29). Most permanent residents nest in cavities and feed on bark insects. Abundance patterns for these groups indicate that all were more abundant in control than in treatment areas, except in 1990 when slightly more permanent residents and bark insect foragers were observed in treatment areas (Figure 9). Patterns of changes in abundance over time in treatment and control areas, however do not reflect a pattern that would be expected if birds were responding to EM fields and we would expect that permanent residents would receive the largest amounts of exposure to these fields.

Similar patterns (to the breeding season) among guild groups that showed a significant interaction was found for the fall migration season. In this season, numbers of short-distance migrants, ground nesters, and foliage gleaners showed significant interaction amoung years between control and treatment areas (Figure 10). Abundance patterns for these groups are similar because many short-distance migrants are ground nesters and feed on foliage insects and we would expect similar

patterns in abundance. Numbers of individuals within these groups have shown a fairly steady decline in both treatment and control areas over the years, with treatment areas showing more variation from year to year especially before 1990. This pattern of change is not likely due to negative effects of EM fields primairly because in years where the magnitude of fluctuation in treatments was greatest, numbers exceeded the control areas whereas in most other years numbers on controls were higher (Figure 10, p 30).

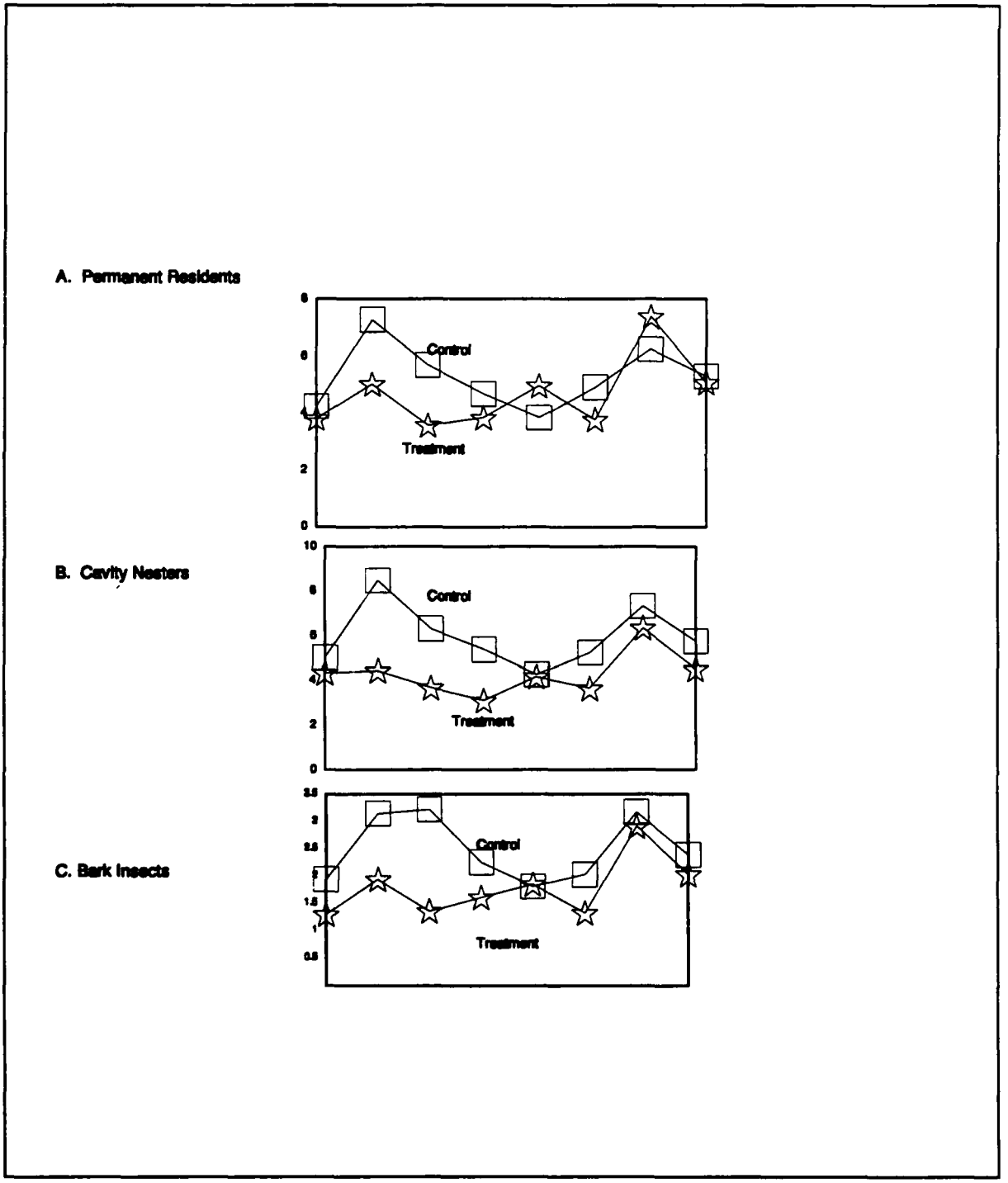

Figure 9. Mean number/500 m transect of cavity nesters, bark foragers, and permanent resident birds during the breeding season on treatment and control study areas from 1986 to 1993.

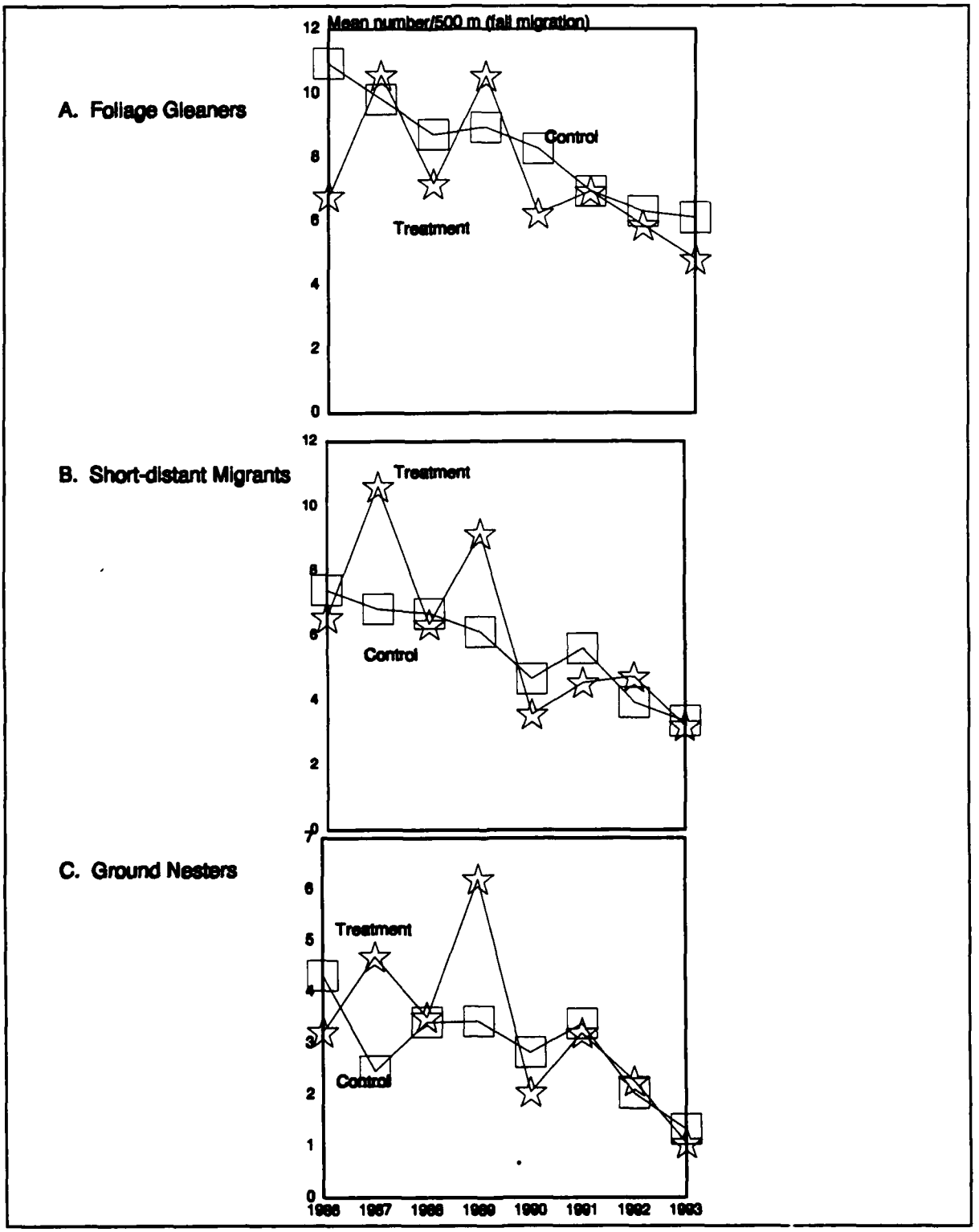

Figure 10. Mean number/500 m transect of short-distant migrants, foliage gleaners, and ground nesting birds during the fall migration period on treatment and control transects from 1986 to 1993.

INDIVIDUAL SPECIES

EM exposure 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 (possible negative response) and others on treatment segments (possible positive response), then such differences might cancel each other, producing nonsignificant results at the community level. If differences between treatment and control segments (related to EM fields) is a primary factor influencing distribution patterns of individual species, then we might expect those species to show similar patterns among years and seasons.

There have, however, been no cases where differences in abundance of a species between treatment and control segments have remained consistently significant among seasons in Michigan. In addition, numbers of significant differences detected were not much greater than what would be expected by chance alone. If the antenna operation adversely affected bird species, we might have expected numbers on treatment segments to decline after operation began. Birds have been sampled during three seasons since 1986. Both 1986 and 1987 can be considered pre-impact years (although the antenna was tested at low power during part of 1987). The antenna was tested at half strength during 1988, at full strength during most of 1989 and all of 1990, 1991, 1992, and 1993. Thus, we consider 1988 a transitional year and 1989-1993 as impact years. If we examine species that showed a significant interaction in abundance in any season (12 total), during 1986-1987, two species showed a change in position in relative abundance between control and treatment areas (one became more abundant on treatments and one less abundant (Figure 11, p 32). (We are not including 1985 here as samples were collected only during June.) During 1989-1993, species became more abundant on treatment than controls 10 times (in any one year to the next, any one species can be counted more than one time) and in 14 instances the opposite pattern was seen. Thus, a similar proportion of changes in relative abundance were noted for species in each group both before and after antenna operation reached full strength.

Most species that indicated a significant interaction in abundance among control and treatment areas over time were rare to uncommon in the study areas; 9 of 12 had means < 1 individual/500 m transect, including American Woodcock, Great Crested Flycatcher, Chipping Sparrow, Brown-headed Cowbird, Downy Woodpecker, Song Sparrow, Rose-breasted Grosbeak, Blue Jay, and Black-and-white Warbler. Because of their low abundance, a rather small shift in relative abundance in treatment and control areas from year to year would indicate a significant interaction in the repeated measures ANOVA (the test is most sensitive to changes in relative abundance). We are currently working on methods to calculate the power of our repeated measures ANOVA for a variety of individual species, guild, and bird community parameters. Results in terms of power and detectable differences will be discussed at greater length in the final report.

EM fields. Growth or navigational abilities of birds exposed to the ELF antenna could be affected by EM fields and are being studied in association with the Michigan antenna with Tree Swallows (Beaver et al., 1990). Many birds use the earth's EM field as an aid in navigation during migration (Wiltschko and Wiltschko, 1988) and Larkin and Sutherland (1979) observed that birds flying over the antenna (in Wisconsin) changed course more often than treatment individuals. Similarly, weak EM fields can cause disorientation in homing pigeons (Wiltschko and Wiltschko, 1988). However, although individuals in homing experiments were momentarily disoriented, all were able to adjust to EM field anomalies and successfully navigate. We detected no consistent differences in overall bird abundance between control and treatment areas during fall or spring migration, suggesting that birds were not attracted to or repelled by the antenna.

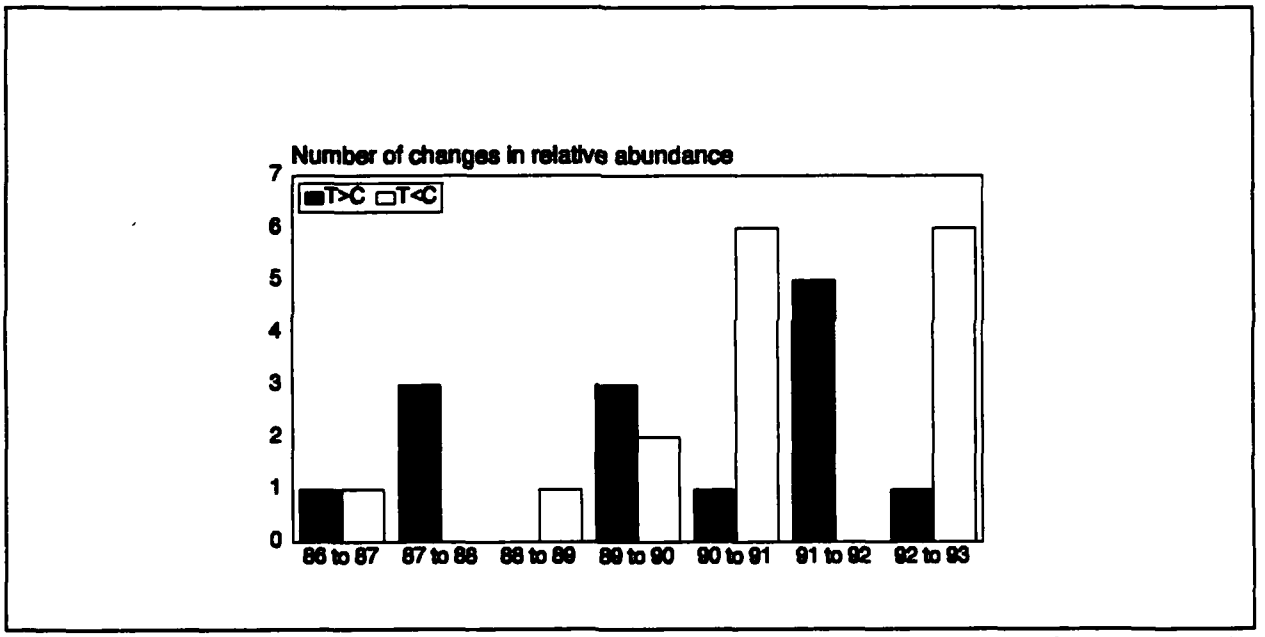

Figure 11. Number of changes in relative abundance from year to year for species that showed a significant interaction in abundance among control and treatment study areas.

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Appendix 1. Scientific name, nesting, feeding, habitat, and migration classification for bird species observed in Michigan (1985-1993).

Appendix 1. Scientific name, nesting, feeding, habitat, and migration classification for bird species observed in Michigan (1985-1993).

Species	Nest	Food	Habitat	Migration
Common Loon Gavia immer	1	1	9	2
Pied-billed Grebe Podilymbus podiceps	1	1	9	2
American Bittern Botaurus lentiginosus	3	1	6	2
Least Bittern Ixobrychus exilis	1	1	8	3
Great Blue Heron Ardea herodias	2	1	9	2
Canada Goose Branta canadensis	1	18	9	2
Wood Duck Aix sponsa	4	18	9	2
Mallard Anas platyrhynchos	1	18	9	2
Blue-winged Teal Anas discors	1	18	9	3
Hooded Merganser Lophodytes cucullatus	4	1	9	1
Red-breasted Merganser Mergus serrator	1	1	9	2
Turkey Vulture Cathartes aura	1	3	3	2

Appendix 1 (continued)

Species	Nest	Food	Habitat	Migration
Bald Eagle Haliaeetus leucocephalus	2	1	9	2
Northern Harrier Circus cyaneus	1	2	5	2
Sharp-shinned Hawk Accipiter striatus	2	2	2	2
Cooper's Hawk Accipiter cooperii	2	2	1	2
Northern Goshawk Accipiter gentilis	2	2	2	1
Broad-winged Hawk Buteo platypterus	2	2	3	3
Red-tailed Hawk Buteo jamaicensis	2	2	5	2
American Kestrel Falco sparverius	4	2	5	2
Merlin Falco columbarius	2	2	2	3
Spruce Grouse Dendragapus canadensis	1	4	2	1
Ruffed Grouse Bonasa umbellus	1	4	1	1
Virginia Rail Rallus limicola	3	19	8	2
Sora Porzana carolina	3	19	8	2

Appendix 1 (continued)

Species	Nest	Food	Habitat	Migration
Sandhill Crane *Grus canadensis*	1	5	8	2
Killdeer *Charadrius vociferus*	1	19	5	2
Greater Yellowlegs *Tringa melanoleuca*	1	1	10	3
Solitary Sandpiper *Tringa solitaria*	2	19	9	3
Spotted Sandpiper *Actitis macularia*	1	19	9	2
Common Snipe *Gallinago gallinago*	1	19	8	2
American Woodcock *Scolopax minor*	1	6	6	2
Mourning Dove *Zenaida macroura*	2	7	5	2
Black-billed Cuckoo *Coccyzus erythropthalmus*	3	10	1	3
Yellow-billed Cuckoo *Coccyzus americanus*	3	10	1	3
Barred Owl *Strix varia*	2	2	1	1
Common Nighthawk *Chordeiles minor*	1	11	3	3
Whip-poor-will *Caprimulgus vociferus*	1	11	1	3

Appendix 1 (continued)

Species	Nest	Food	Habitat	Migration
Chimney Swift Chaetura pelagica	4	11	7	3
Ruby-throated Hummingbird Archilochus colubris	2	17	9	3
Belted Kingfisher Ceryle alcyon	4	1	9	2
Yellow-bellied Sapsucker Sphyrapicus varius	4	17	1	2
Downy Woodpecker Picoides pubescens	4	16	1	1
Hairy Woodpecker Picoides villosus	4	16	1	1
Black-backed Woodpecker Picoides arcticus	4	16	2	1
Northern Flicker Colaptes auratus	4	9	5	2
Pileated Woodpecker Dryocopus pileatus	4	16	1	1
Olive-sided Flycatcher Contopus borealis	2	12	4	3
Eastern Wood-Pewee Contopus virens	2	12	3	3
Yellow-bellied Flycatcher Empidonax flaviventris	1	12	11	3
Alder Flycatcher Empidonax alnorum	3	12	6	3

Appendix 1 (continued)

Species	Nest	Food	Habitat	Migration
Least Flycatcher *Empidonax minimus*	3	12	1	3
Eastern Phoebe *Sayornis phoebe*	5	12	9	2
Great Crested Flycatcher *Myiarchus crinitus*	4	12	1	3
Eastern Kingbird *Tyrannus tyrannus*	2	12	5	3
Tree Swallow *Tachycineta bicolor*	4	11	5	2
Barn Swallow *Hirundo rustica*	5	11	7	3
Gray Jay *Perisoreus canadensis*	2	5	11	1
Blue Jay *Cyanocitta cristata*	2	5	1	1
American Crow *Corvus brachyrhynchos*	2	5		2
Common Raven *Corvus corax*	2	5	2	1
Black-capped Chickadee *Parus atricapillus*	4	10	1	1
Boreal Chickadee *Parus hudsonicus*	4	10	11	1
Red-breasted Nuthatch *Sitta canadensis*	4	16	2	1

Appendix 1 (continued)

Species	Nest	Food	Habitat	Migration
White-breasted Nuthatch *Sitta carolinensis*	4	16	1	1
Brown Creeper *Certhia americana*	4	16	1	2
House Wren *Troglodytes aedon*	4	10	7	3
Winter Wren *Troglodytes troglodytes*	1	10	11	2
Sedge Wren *Cistothorus platensis*	3	10	8	2
Marsh Wren *Cistothorus palustris*	3	10	8	2
Golden-crowned Kinglet *Regulus satrapa*	2	10	2	2
Ruby-crowned Kinglet *Regulus calendula*	2	10	2	2
Blue-gray Gnatcatcher *Polioptila caerulea*	3	10	1	3
Eastern Bluebird *Sialia sialis*	4	12	5	2
Veery *Catharus fuscescens*	1	9	1	3
Gray-cheeked Thrush *Catharus minimus*	3	9	4	3
Swainson's Thrush *Catharus ustulatus*	2	9	11	3

Appendix 1 (continued)

Species	Nest	Food	Habitat	Migration
Hermit Thrush *Catharus guttatus*	1	9	3	2
Wood Thrush *Hylocichla mustelina*	3	9	1	3
American Robin *Turdus migratorius*	2	9	5	2
Gray Catbird *Dumetella carolinensis*	3	13	4	3
Brown Thrasher *Toxostoma rufum*	3	9	4	2
Cedar Waxwing *Bombycilla cedrorum*	2	14	9	1
European Starling *Sturna vulgaris*	4	9	7	1
Solitary Vireo *Vireo solitarius*	2	10	2	3
Yellow-throated Vireo *Vireo flavifrons*	2	10	1	3
Warbling Vireo *Vireo gilvus*	2	10	1	3
Philadelphia Vireo *Vireo philadelphicus*	2	10	1	3
Red-eyed Vireo *Vireo olivaceus*	2	10	1	3
Golden-winged Warbler *Vermivora chrysoptera*	1	10	4	3

Appendix 1 (continued)

Species	Nest	Food	Habitat	Migration
Tennessee Warbler *Vermivora peregrina*	1	10	11	3
Nashville Warbler *Vermivora ruficapilla*	1	10	11	3
Northern Parula *Parula americana*	2	10	11	3
Yellow Warbler *Dendroica petechia*	3	10	6	3
Chestnut-sided Warbler *Dendroica pensylvanica*	3	10	4	3
Magnolia Warbler *Dendroica magnolia*	2	10	2	3
Cape May Warbler *Dendroica tigrina*	2	10	2	3
Black-throated Blue Warbler *Dendroica caerulescens*	3	10	1	3
Yellow-rumped Warbler *Dendroica coronata*	2	13	2	2
Black-throated Green Warbler *Dendroica virens*	2	10	3	3
Blackburnian Warbler *Dendroica fusca*	2	10	2	3
Pine Warbler *Dendroica pinus*	2	10	2	2
Palm Warbler *Dendroica palmarum*	1	10	11	3

Appendix 1 (continued)

Species	Nest	Food	Habitat	Migration
Bay-breasted Warbler *Dendroica castanea*	2	10	2	3
Blackpoll Warbler *Dendroica striata*	2	10	2	3
Black-and-white Warbler *Mniotilta varia*	1	16	3	3
American Redstart *Setophaga ruticilla*	2	12	4	3
Ovenbird *Seiurus aurocapillus*	1	10	1	3
Northern Waterthrush *Seiurus noveboracensis*	1	10	9	3
Connecticut Warbler *Oporornis agilis*	1	10	11	3
Mourning Warbler *Oporornis philadelphia*	1	10	4	3
Common Yellowthroat *Geothylpis trichas*	3	10	6	3
Wilson's Warbler *Wilsonia pusilla*	3	10	6	3
Canada Warbler *Wilsonia canadensis*	3	10	3	3
Scarlet Tanager *Piranga olivacea*	2	10	1	3
Rose-breasted Grosbeak *Pheucticus ludovicianus*	3	13	1	3

Appendix 1 (continued)

Species	Nest	Food	Habitat	Migration
Indigo Bunting *Passerina cyanea*	3	15	5	3
Rufous-sided Towhee *Pipilo erythrophthalmus*	1	8	4	2
Chipping Sparrow *Spizella passerina*	2	8	2	2
Clay-colored Sparrow *Spizella pallida*	3	8	5	2
Vesper Sparrow *Pooecetes gramineus*	1	8	5	2
Savannah Sparrow *Passerculus sandwichensis*	1	8	5	2
Le Conte's Sparrow *Ammodramus leconteii*	1	8	8	2
Song Sparrow *Melospiza melodia*	3	8	5	2
Lincoln's Sparrow *Melospiza lincolnii*	1	8	11	3
Swamp Sparrow *Melospza georgianna*	3	8	6	2
White-throated Sparrow *Zonotrichia albicollis*	1	8	4	2
Dark-eyed Junco *Junco hyemalis*	1	8	11	2
Red-winged blackbird *Agelaius phoeniceus*	3	8	8	2

Appendix 1 (continued)

Species	Nest	Food	Habitat	Migration
Rusty Blackbird *Euphagus carolinus*	3	8	9	2
Brewer's Blackbird *Euphagus cyanocephalus*	3	8	5	2
Common Grackle *Quiscalus quiscula*	3	5	5	2
Brown-headed Cowbird *Molothrus ater*	7	8	5	2
Northern Oriole *Icterus galbula*	2	13	1	3
Purple Finch *Carpodacus purpureus*	2	7	3	2
Red Crossbill *Loxia curvirostra*	2	7	2	1
White-winged Crossbill *Loxia leucoptera*	2	7	2	1
Pine Siskin *Carduelis pinus*	2	15	2	1
American Goldfinch *Carduelis tristis*	3	7	5	2
Evening Grosbeak *Coccothraustes vespertinus*	2	15	3	1
Unidentified woodpecker	4			

Appendix 1 (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 1 (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

Appendix 1 (continued)

D. Migration

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

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 2. Number of individuals and species observed on control and treatment transects in Michigan during May in 1986-1993 on transects used in the final statistical analyses (36 control and 33 treatment).

Appendix 2. Number of individuals and species observed on control and treatment transects in Michigan during May in 1986-1993 on transects used in the final statistical analyses (36 control and 33 treatment).

	1986		1987		1988		1989		1990		1991		1992		1993	
Species	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
Common Loon									0	1						
Pied-billed Grebe															0	1
American Bittern			1	1	1	1					1	1	0	2		
Great Blue Heron	0	1											0	1		
Canada Goose					0	2	0	1	0	1	0	2			0	4
Wood Duck					0	1	0	5	0	1			2	0	0	6
Mallard	1	0			0	1	1	1			1	4	0	4	0	1
Blue-winged Teal			0	4							0	2				
Hooded Merganser					0	2	0	3					0	3		
Turkey Vulture					2	0	2	0								
Bald Eagle							0	1								

Appendix 2 (continued)

	1986		1987		1988		1989		1990		1991		1992		1993	
Species	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
Sharp-shinned Hawk					1	0					0	1	0	1		
Northern Goshawk													1	0		
Broad-winged Hawk	0	1	2	3	3	1			1	3	0	2	2	0	1	0
Red-tailed Hawk					0	2							0	1		
American Kestrel	1	0					0	2	2	0	1	2	2	1	1	0
Spruce Grouse	1	0														
Ruffed Grouse	9	7	12	4	16	17	23	13	16	11	17	10	6	8	12	16
Virginia Rail											0	1				
Sandhill Crane											0	1				
Killdeer			0	2					1	0			1	0		
Greater Yellowlegs											0	1				
Common Snipe			0	1	1	4			0	1	1	0			1	1

Appendix 2 (continued)

	1986		1987		1988		1989		1990		1991		1992		1993	
Species	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
American Woodcock	2	0	0	1	0	1	1	1	5	1	1	0	0	3	2	0
Mourning Dove					0	1					1	0				
Black-billed Cuckoo															1	0
Barred Owl			1	0					0	1						
Whip-poor-will	1	1					0	1								
Belted Kingfisher	0	1	0	1	0	1	0	1								
Yellow-bellied Sapsucker	10	21	12	25	21	55	13	46	15	27	19	42	11	27	13	20
Downy Woodpecker	6	9	1	7	10	8	7	7	3	2	3	7	7	7	0	4
Hairy Woodpecker	7	4	2	2	3	1	2	4	4	5	2	5	3	4	2	6
Black-backed Woodpecker	0	1					1	0			1	0				
Northern Flicker	23	31	15	18	24	28	25	14	10	10	17	14	11	3	19	23
Pileated Woodpecker	1	0	1	1	1	0	1	0	1	3	0	2	4	3	4	3

Appendix 2 (continued)

Species	1986		1987		1988		1989		1990		1991		1992		1993	
	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
Olive-sided Flycatcher	1	0									0	1	0	1		
Eastern Wood-Pewee									1	0	0	1				
Yellow-bellied Flycatcher					1	1			1	1			0	2		
Alder Flycatcher									1	0						
Least Flycatcher	16	42	4	13	13	14			30	28	2	37	40	67	4	7
Eastern Phoebe	1	1	1	1			1	2	2	0	1	1	1	0	4	0
Great Crested Flycatcher	4	6	1	3	1	7	0	2	3	7	1	5	2	12	1	2
Eastern Kingbird	0	2	0	1												
Tree Swallow	0	11	0	9	2	15	1	0	1	8	0	5	0	2	0	2
Gray Jay					3	2	2	0	2	7	2	0	2	1	4	0
Blue Jay	53	58	27	30	21	40	16	11	15	23	24	18	32	15	35	25
American Crow	0	2			2	1	1	0	1	2	1	0			0	1

Appendix 2 (continued)

	1986		1987		1988		1989		1990		1991		1992		1993	
Species	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
Common Raven	0	2	0	3	10	5	2	2	1	3	1	4	5	2	4	1
Black-capped Chickadee	23	26	15	48	56	66	68	75	44	63	50	39	47	71	77	87
Boreal Chickadee	5	0	2	0	2	0	5	0	2	0	6	4	5	2	2	0
Red-breasted Nuthatch	11	8	8	11	32	29	10	10	20	25	3	5	25	24	26	29
White-breasted Nuthatch	3	4	3	2	5	14	1	4	5	4	2	3	1	4	2	2
Brown Creeper	2	10	1	8	1	15	16	35	3	16	9	27	8	11	18	20
House Wren											1	0	1	1		
Winter Wren	15	32	23	27	31	42	13	25	14	23	17	37	20	32	21	41
Sedge Wren	1	6							0	1	0	2	1	8	0	2
Marsh Wren							0	2								
Golden-crowned Kinglet	42	20	58	44	61	67	59	39	42	39	46	36	45	13	11	14
Ruby-crowned Kinglet	10	8	7	7	23	9	24	35	12	11	19	9	11	6	60	60

Appendix 2 (continued)

	1986		1987		1988		1989		1990		1991		1992		1993	
Species	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
Blue-gray Gnatcatcher									0	1						
Eastern Bluebird							1	0							1	0
Veery									0	1	2	0	1	0	0	1
Gray-cheeked Thrush													2	0		
Swainson's Thrush					1	0							3	1		
Hermit Thrush	19	26	18	25	43	38	41	31	32	16	18	27	29	22	48	45
Wood Thrush	1	1	0	1							0	6	5	0		
American Robin	38	42	24	26	48	49	29	39	28	23	29	21	18	27	46	29
Gray Catbird			0	1					0	1					1	1
Brown Thrasher	5	1	3	0			4	0	4	1	8	0	3	0	5	1
Cedar Waxwing	0	1														
European Starling	0	3	1	7	3	4	1	4								

Appendix 2 (continued)

Species	1986		1987		1988		1989		1990		1991		1992		1993	
	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
Solitary Vireo	6	2	8	6	6	2	0	2	9	5	5	9	8	10	3	4
Yellow-throated Vireo	0	1							1	1					0	4
Red-eyed Vireo	8	8	1	6	0	1			3	1	1	0	14	4	1	2
Golden-winged Warbler	3	10	4	1					6	0	2	2	4	1		
Tennessee Warbler	0	2			0	2							2	2	1	0
Nashville Warbler	215	208	179	123	58	74	0	1	90	79	44	47	152	127	43	31
Northern Parula	0	10	0	11					1	7	1	11	3	21	2	1
Yellow Warbler					1	0			2	0						
Chestnut-sided Warbler	7	12	2	3					12	2	4	4	15	13	1	0
Magnolia Warbler	2	10											2	7	0	3
Cape May Warbler	0	5											1	0		
Black-throated Blue Warbler	0	2													0	1

Appendix 2 (continued)

	1986		1987		1988		1989		1990		1991		1992		1993	
Species	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
Yellow-rumped Warbler	62	37	59	45	67	42	43	39	65	48	47	40	65	45	33	29
Black-throated Green Warb.	75	97	18	57	15	39	0	1	24	55	14	57	65	87	23	51
Blackburnian Warbler			1	0					4	0	0	8	3	6	0	2
Pine Warbler	0	1	4	2							1	0	1	0		
Palm Warbler	6	4	2	2			1	0	1	2	2	2	0	4	2	4
Bay-breasted Warbler			0	1					1	0			1	5		
Black-and-white Warbler	17	34	2	13	3	15			24	30	8	16	16	27	2	8
American Redstart													0	3		
Ovenbird	55	100	9	28	1	14			69	55	37	60	102	116	34	36
Northern Waterthrush	0	5	0	4			0	2	0	3	4	3	2	6	1	5
Connecticut Warbler	0	1			0	1			1	3						
Mourning Warbler	1	1			1	0										

Appendix 2 (continued)

	1986		1987		1988		1989		1990		1991		1992		1993	
Species	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
Common Yellowthroat	3	1							4	2			6	6	0	1
Wilson's Warbler													0	1		
Canada Warbler					1	0										
Scarlet Tanager	1	1							0	1	1	6	4	1		
Rose-breasted Grosbeak	2	36	5	9	1	1			13	15	10	17	35	27	2	8
Indigo Bunting													0	1		
Rufous-sided Towhee	5	3	6	2	0	1	2	0	10	2	4	5	5	3	1	0
Chipping Sparrow	11	30	30	20	24	17	7	13	10	5	5	18	14	18	8	6
Clay-colored Sparrow					0	1										
Vesper Sparrow			0	3			2	0	1	0						
Savannah Sparrow															0	1
Le Conte's Sparrow					1	0										

Appendix 2 (continued)

	1986		1987		1988		1989		1990		1991		1992		1993	
Species	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
Song Sparrow	5	7	13	11	23	6	15	16	22	3	0	9	14	9	11	10
Lincoln's Sparrow									0	1			1	0	3	0
Swamp Sparrow	18	11	10	21	10	19	5	9	7	11	9	10	12	11	10	18
White-throated Sparrow	85	55	111	48	91	57	58	35	91	50	54	23	95	50	95	55
Dark-eyed Junco	0	1	6	6	6	0	13	1	10	0	2	0	3	2	13	1
Red-winged blackbird	0	41	10	38	4	30	0	12	2	24	0	10	2	9	0	11
Rusty Blackbird			0	2			0	1								
Common Grackle	1	5	0	9	5	8	9	11	3	12	4	5	5	1		
Brown-headed Cowbird	8	20	3	10	4	11	9	18	4	11	1	4	1	4	4	10
Northern Oriole	0	4	2	1					0	1	0	1	0	1		
Purple Finch	13	18	17	30	9	15	21	20	9	8	2	10	6	3	7	6
Red Crossbill							1	0							0	1

Appendix 2 (continued)

	1986		1987		1988		1989		1990		1991		1992		1993	
Species	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
White-winged Crossbill									2	0					8	10
Pine Siskin	0	1	1	0	4	7	0	4	1	1					6	5
American Goldfinch	2	6	1	1			1	0	3	2	0	2	1	7	5	5
Evening Grosbeak	2	7	0	2	6	2	4	1	4	17	0	2				
Unidentified non-passerine	24	24	21	22	21	20	7	5	11	17	8	10	26	25	43	47
Unidentified sparrow													1	0		
Unidentified woodpecker			7	14	11	9	1	0	5	13	1	2	1	5	6	5
Unidentified passerine					0	1									1	0
Total individuals	949	1210	775	888	815	939	570	607	847	858	578	778	1045	1060	795	836
Total number species	54	69	50	62	53	56	44	46	65	65	55	62	66	69	54	59

Appendix 3. Numbers of individuals and species observed on control and treatment transects in Michigan during the breeding season 1986-1993 on transects used in the final statistical analyses (36 control and 33 treatment).

Appendix 3. Numbers of individuals and species observed on control and treatment transects in Michigan during the breeding season 1986-1993 on transects used in the final statistical analyses (36 control and 33 treatment).

	1986		1987		1988		1989		1990		1991		1992		1993	
Species	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
Pied-billed Grebe					0	2			0	1	0	1				
American Bittern															0	2
Least Bittern					1	0										
Great Blue Heron	0	1	0	1											0	2
Wood Duck							0	2	2	1	0	3	0	2		
Mallard	0	1	11	0	0	2										
Blue-winged Teal					1	0										
Red-breasted Merganser													0	6		
Turkey Vulture									1	0						
Northern Harrier			0	1	1	0										
Sharp-shinned Hawk					0	1	0	2	1	1	0	2	2	2	0	1

Appendix 3 (continued)

Species	1986		1987		1988		1989		1990		1991		1992		1993	
	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
Cooper's Hawk					1	0										
Northern Goshawk					1	0					1	0				
Broad-winged Hawk	3	4	3	2	1	1	0	3	2	4	2	2	2	2	2	1
Red-tailed Hawk	1	0			0	1	0	1	2	0			0	2		
American Kestrel	1	0					2	2	2	1	5	2			4	0
Merlin															1	0
Ruffed Grouse	9	26	6	4	6	26	13	15	8	15	6	15	6	10	9	2
Sora					0	2										
Sandhill Crane											0	2				
Killdeer			1	0	1	0					0	1				
Spotted Sandpiper											0	1				
Common Snipe	0	1	1	0	0	2										

Appendix 3 (continued)

	1986		1987		1988		1989		1990		1991		1992		1993	
Species	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
American Woodcock	2	7	5	12	5	4	7	3	4	2	2	6	1	2	4	2
Mourning Dove					0	2					0	1				
Black-billed Cuckoo			1	1	2	3	1	0	0	1	2	0	4	1		
Yellow-billed Cuckoo			1	1			1	4	0	1			0	1		
Barred Owl			0	3	0	1									0	2
Common Nighthawk	0	1	0	2	0	1							1	0	2	0
Whip-poor-will	1	1			1	0										
Chimney Swift			0	1			0	2					0	2		
Ruby-throated Hummingbird	1	0	3	2			1	2	2	5	1	4	0	2	2	2
Belted Kingfisher	0	3			0	2	0	1	4	2	0	1			0	2
Yellow-bellied Sapsucker	22	22	13	36	14	34	12	26	6	26	12	33	12	36	5	30
Downy Woodpecker	11	16	9	18	6	11	6	3	4	6	1	11	6	13	5	9

Appendix 3 (continued)

	1986		1987		1988		1989		1990		1991		1992		1993	
Species	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
Hairy Woodpecker	4	4	1	11	2	8	6	4	7	5	9	7	6	8	8	10
Black-backed Woodpecker	1	0			1	0	0	3	2	1	1	0	2	0	4	0
Northern Flicker	29	33	13	13	24	15	18	15	28	14	14	7	17	11	12	9
Pileated Woodpecker	0	2	3	1	0	1	2	4	1	2	1	2	3	2	2	2
Olive-sided Flycatcher	5	1	4	6	1	1	3	2			0	1	4	0	1	3
Eastern Wood-Pewee	9	20	14	19	9	14	10	24	16	20	12	17	13	20	14	12
Yellow-bellied Flycatcher	33	16	20	10	24	14	22	12	23	8	22	14	28	18	18	9
Alder Flycatcher	9	12	14	11	14	11	9	12	10	7	13	5	11	7	4	7
Least Flycatcher	28	74	49	63	32	52	36	47	37	51	13	58	14	39	21	27
Eastern Phoebe	0	1	2	1	1	0			1	0	0	1	2	0	2	1
Great Crested Flycatcher	14	27	16	36	13	22	4	31	5	22	14	16	7	25	10	14
Eastern Kingbird	8	7	3	9	6	3	4	2	2	6	4	3	4	3	0	2

Appendix 3 (continued)

Species	1986		1987		1988		1989		1990		1991		1992		1993	
	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
Tree Swallow	1	1	8	7	0	2			4	0			1	0	0	1
Gray Jay	1	0	8	6	1	3	9	2	10	5	2	6	5	0	16	8
Blue Jay	37	29	52	59	33	41	32	26	41	29	26	26	40	36	27	33
American Crow	11	0	12	5	6	3	2	0			2	0	2	4		
Common Raven	1	5	10	14	2	2	2	5	3	6	2	3	5	10	4	7
Black-capped Chickadee	54	61	63	112	42	73	40	68	61	57	55	92	94	109	71	80
Boreal Chickadee	7	0	1	0	4	0	6	1	3	0	3	1	11	1	9	1
Red-breasted Nuthatch	15	9	17	25	27	37	21	32	28	11	13	14	62	36	26	25
White-breasted Nuthatch	0	6	9	8	0	3	0	1	1	7	4	7	3	5	7	6
Brown Creeper	4	9	12	22	9	26	8	17	5	10	9	18	18	20	12	24
House Wren			0	2	3	0			0	2	1	4	1	5	0	3
Winter Wren	23	31	40	46	20	42	22	39	23	23	21	43	21	29	30	56

Appendix 3 (continued)

Species	1986		1987		1988		1989		1990		1991		1992		1993	
	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
Sedge Wren	5	6	2	2	8	6	5	3	1	13	1	9	2	6	1	5
Marsh Wren					4	3							1	0		
Golden-crowned Kinglet	53	37	90	43	64	48	56	35	48	38	71	57	64	25	61	55
Ruby-crowned Kinglet	1	6	2	2	8	1	7	2	6	3	5	2	9	0	4	1
Eastern Bluebird			6	2	5	1	2	1	1	0	3	2			2	0
Veery	27	26	34	42	24	30	28	32	15	17	16	23	21	28	15	9
Swainson's Thrush	0	1			0	3	0	2	0	1						
Hermit Thrush	82	50	79	71	72	64	97	95	70	72	85	74	76	85	81	70
Wood Thrush	4	4	2	5	3	9	2	1	0	6	0	9			2	3
American Robin	45	43	54	45	47	23	32	35	16	26	36	30	29	27	25	33
Gray Catbird	0	1	1	5	2	0	2	1	1	0						
Brown Thrasher	5	0	5	1	6	0	8	2	8	0	7	1	4	0	3	2

Appendix 3 (continued)

	1986		1987		1988		1989		1990		1991		1992		1993	
Species	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
Cedar Waxwing	12	11	13	14	29	21	33	17	22	8	31	23	33	16	24	19
European Starling	0	2	0	6			2	0	1	0			1	0	1	0
Solitary Vireo	3	6	4	2	8	6	12	3	7	7	8	12	11	15	8	6
Yellow-throated Vireo	0	2	0	2	1	1	1	2			2	3	2	2	1	5
Warbling Vireo	0	2														
Philadelphia Vireo	0	1			1	0	1	0					1	0		
Red-eyed Vireo	116	136	108	122	78	90	75	90	74	117	103	112	117	153	85	119
Golden-winged Warbler	7	5	17	5	19	8	7	11	7	5	6	2	2	2	1	2
Tennessee Warbler	1	2	3	5	5	1	0	2								
Nashville Warbler	153	82	156	78	117	89	140	90	119	96	143	102	170	129	182	112
Northern Parula	8	19	12	18	7	23	8	13	7	16	3	11	3	13	2	15
Yellow Warbler	1	0	1	3	1	2	0	1			0	5			0	1

Appendix 3 (continued)

Species	1986		1987		1988		1989		1990		1991		1992		1993	
	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
Chestnut-sided Warbler	71	51	78	46	75	28	64	42	58	37	59	22	53	33	47	15
Magnolia Warbler	1	3			1	2	3	0	1	1	6	1	3	5	5	9
Cape May Warbler	1	7	4	5	1	1			2	1			5	2	1	3
Black-throated Blue Warbler	1	1	0	1	0	1	0	2	0	1					1	0
Yellow-rumped Warbler	24	17	24	14	33	19	30	25	20	31	24	25	50	24	40	39
Black-throated Green Warb.	68	81	56	89	54	62	45	75	45	75	56	70	75	97	57	109
Blackburnian Warbler	9	11	3	17	6	18	12	13	10	12	4	11	10	20	4	18
Pine Warbler			2	3	2	1	4	1	1	0	1	1	0	1	1	0
Palm Warbler			2	0			1	0			3	2				
Bay-breasted Warbler	0	2											1	1	3	1
Blackpoll Warbler			1	0												
Black-and-white Warbler	20	26	30	38	20	37	23	29	24	28	17	24	21	40	16	18

Appendix 3 (continued)

Species	1986		1987		1988		1989		1990		1991		1992		1993	
	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
American Redstart	2	0	1	1	2	3	0	1	0	1			2	1		
Ovenbird	195	214	161	183	137	145	140	188	115	135	129	164	170	200	150	166
Northern Waterthrush	1	1	0	3	0	2	0	8	0	3			0	1	0	3
Connecticut Warbler	5	1	6	0	3	2	2	0	2	0						
Mourning Warbler	20	19	28	25	29	19	38	16	25	21	22	28	17	18	21	17
Common Yellowthroat	9	38	26	33	15	24	13	30	18	23	23	37	21	42	24	41
Canada Warbler	3	8	4	3	0	1	4	11	2	2	1	6	9	9	5	8
Scarlet Tanager	9	16	11	12	6	17	15	19	12	14	12	20	11	20	16	18
Rose-breasted Grosbeak	34	57	28	30	38	47	25	43	26	40	14	47	34	39	6	16
Indigo Bunting	19	20	9	15	16	18	30	22	23	31	26	36	30	20	18	16
Rufous-sided Towhee	7	10	7	2	11	7	14	5	5	3	10	4	9	5	5	2
Chipping Sparrow	26	25	17	17	33	13	30	11	19	11	7	13	13	18	32	18

Appendix 3 (continued)

	1986		1987		1988		1989		1990		1991		1992		1993	
Species	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
Clay-colored Sparrow					0	1										
Vesper Sparrow			0	2			2	0	1	1	1	0				
Song Sparrow	16	31	18	28	17	13	22	20	15	8	14	22	15	26	15	31
Lincoln's Sparrow	1	2									1	0			1	0
Swamp Sparrow	15	24	15	27	7	15	8	17	8	17	11	24	10	13	9	23
White-throated Sparrow	95	59	115	49	94	46	95	57	82	32	59	30	57	30	57	45
Dark-eyed Junco	0	2	0	3	12	0	6	0	6	0	2	0	3	0		
Red-winged blackbird	7	34	8	34	3	19	1	22	1	12	3	6	2	9	0	6
Brewer's Blackbird											0	2				
Common Grackle	0	14	7	18	2	9	4	8	4	5	23	7	4	5	4	2
Brown-headed Cowbird	2	10	3	10	1	11	3	7	2	8	2	9	0	1	0	3
Northern Oriole	0	3	0	5	0	3	4	4	1	1	2	2	0	3	0	2

Appendix 3 (continued)

	1986		1987		1988		1989		1990		1991		1992		1993	
Species	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
Purple Finch	8	9	2	5	0	5	4	4	2	7	4	4	3	3	6	1
White-winged Crossbill							37	0	2	3			16	0		
American Goldfinch	5	2	10	6	3	3	7	3	9	9	5	3	10	8	9	13
Evening Grosbeak			4	2	6	4	0	4			1	0	0	1		
Unidentified non-passerine	55	51	70	56	33	30	40	29	28	24	30	27	22	27	26	15
Unidentified sparrow	0	10	1	0	1	0										
Unidentified thrush			1	0												
Unidentified woodpecker	7	2	10	23	9	15	7	6	3	4	6	3	8	8	3	6
Unidentified vireo			0	1												
Unidentified passerine			0	1												
Total individuals	1604	1734	1776	1850	1494	1538	1550	1573	1324	1378	1371	1557	1638	1700	1412	1516
Total number species	73	81	80	86	82	87	76	81	79	76	75	80	76	74	72	76

Appendix 4. Number of individuals and species observed on control and treatment transects in Michigan during the fall migration season 1986-1993 on transects used in the final statistical analyses (36 control and 33 treatment).

Appendix 4. Numbers of individuals and species observed on control and treatment transects in Michigan during the fall migration season 1986-1993 on transects used in the final statistical analyses (36 and 33 treatment).

	1986		1987		1988		1989		1990		1991		1992		1993	
Species	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
Common Loon									0	1						
American Bittern											0	1				
Great Blue Heron					0	1										
Wood Duck					0	2	0	1			0	3			0	3
Mallard	0	9											0	2		
Turkey Vulture													0	2		
Northern Harrier							0	1								
Sharp-shinned Hawk			0	1	2	0	1	2	0	2	0	2	0	1	3	0
Cooper's Hawk			1	0												
Broad-winged Hawk	5	3	2	2	4	2	0	1	0	4	5	0	3	4	1	0
Red-tailed Hawk	2	0	1	0	1	1	3	0			1	1	0	1		

Appendix 4 (continued)

Species	1986		1987		1988		1989		1990		1991		1992		1993	
	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
American Kestrel			2	0	5	0	3	0	1	1	6	0			1	0
Merlin											0	1	0	2		
Spruce Grouse							0	1								
Ruffed Grouse	15	24	18	10	17	13	25	7	3	18	11	11	6	12	3	9
Sandhill Crane	1	0			0	2										
Solitary Sandpiper	0	2														
Spotted Sandpiper											0	1				
American Woodcock	4	0	9	5	13	1	8	5	2	4	2	3	3	1	2	4
Mourning Dove													1	0		
Black-billed Cuckoo			0	1							0	1			0	1
Yellow-billed Cuckoo											0	1	1	1		
Barred Owl	1	0					0	1					1	1		

Appendix 4 (continued)

	1986		1987		1988		1989		1990		1991		1992		1993	
Species	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
Common Nighthawk			1	0	0	3										
Whip-poor-will					1	0	1	0								
Ruby-throated Hummingbird	1	3					2	4	1	1						
Belted Kingfisher	1	1	2	2	1	4					1	1			2	0
Yellow-bellied Sapsucker	20	27	4	18	8	26	5	15	6	21	1	8	5	12	1	9
Downy Woodpecker	10	28	13	17	2	1	4	7	13	5	20	11	9	12	12	12
Hairy Woodpecker	7	9	6	10	18	9	6	10	6	8	12	5	9	10	7	8
Black-backed Woodpecker	2	6	1	2	2	2	2	2	1	2	0	1	2	0		
Northern Flicker	23	20	23	27	18	22	27	13	19	14	36	20	17	13	21	19
Pileated Woodpecker	2	5	2	3	2	9	4	0	2	8	3	14	3	6	2	2
Olive-sided Flycatcher					2	0	3	2			1	0			0	2
Eastern Wood-Pewee	12	17	9	25	15	18	11	28	13	17	8	15	14	16	11	15

Appendix 4 (continued)

Species	1986		1987		1988		1989		1990		1991		1992		1993	
	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
Yellow-bellied Flycatcher	1	4	6	2	3	3	1	0	0	1	2	2	1	0	2	0
Alder Flycatcher			2	1	0	1	6	6			5	1	4	5	3	0
Least Flycatcher			1	1	1	1	2	4	2	4	1	4	2	1	1	2
Eastern Phoebe	2	1	1	1	1	1	1	1	2	0			1	0	2	0
Great Crested Flycatcher	2	3	3	3	2	2	1	2	0	2	1	8	1	6	1	5
Eastern Kingbird	5	0	3	2	0	3	6	8	0	5	1	3	3	4	1	1
Barn Swallow															0	2
Gray Jay	10	10	12	3	5	7	13	8	11	9	6	11	9	9	8	5
Blue Jay	35	48	66	54	45	49	43	38	77	69	53	36	40	34	29	41
American Crow	1	1	9	2	2	1	0	1	0	4	0	1	1	2	0	2
Common Raven	1	8	4	9	0	6	2	4	3	2	4	0	1	2	1	1
Black-capped Chickadee	88	180	142	172	115	139	148	154	91	117	112	119	109	138	131	148

Appendix 4 (continued)

Species	1986		1987		1988		1989		1990		1991		1992		1993	
	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
Boreal Chickadee	3	0	4	1	5	2	10	2	5	1	4	0	10	2	4	1
Red-breasted Nuthatch	28	29	65	76	45	61	104	76	22	30	82	59	66	62	24	24
White-breasted Nuthatch	3	5	3	13	5	5	3	8	3	13	2	16	4	17	18	16
Brown Creeper	6	23	31	35	34	36	14	25	2	7	14	21	17	24	24	43
House Wren									1	0	1	0				
Winter Wren	1	10	19	9	9	9	14	12	4	14	4	13	7	16	2	3
Sedge Wren	2	1	0	1	3	7	2	0	1	2	0	8	2	1		
Marsh Wren							0	1							0	1
Golden-crowned Kinglet	79	69	161	63	98	64	86	53	42	42	22	17	30	11	4	12
Ruby-crowned Kinglet	1	6	9	1	1	2	8	1	3	13	1	0	5	0	1	0
Eastern Bluebird			3	0					7	0	3	0	4	0		
Veery	0	2	2	2	3	1	3	0	0	1	1	2				

Appendix 4 (continued)

	1986		1987		1988		1989		1990		1991		1992		1993	
Species	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
Gray-cheeked Thrush	1	1	3	0					1	0						
Swainson's Thrush	2	4	7	0	0	2			0	3	0	3				
Hermit Thrush	21	25	23	12	33	29	55	52	19	21	33	53	17	19	7	9
Wood Thrush			0	3	0	1					0	1	0	1		
American Robin	16	14	28	27	23	17	24	13	24	10	19	19	30	10	30	12
Gray Catbird			2	0	1	1	2	0	1	0						
Brown Thrasher	1	0	3	0			3	0	1	0						
Cedar Waxwing	7	16	38	39	69	20	42	15	4	9	92	53	9	2	17	21
European Starling							5	0								
Solitary Vireo			0	3	1	0	2	2	0	2	4	3	0	1	1	0
Yellow-throated Vireo					2	2							0	1	1	0
Red-eyed Vireo	15	21	23	24	11	16	38	49	45	57	50	58	31	38	29	38

Appendix 4 (continued)

	1986		1987		1988		1989		1990		1991		1992		1993	
Species	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
Golden-winged Warbler			2	0	0	1										
Tennessee Warbler	5	13	2	0			2	0	3	2	1	0	1	1		
Nashville Warbler	8	25	14	6	6	16	21	14	16	22	5	5	9	2	3	4
Northern Parula			2	3			1	1	0	2	3	3				
Yellow Warbler					0	1	1	0			1	0				
Chestnut-sided Warbler	1	3	3	4	3	10	8	5			2	0	3	2	0	1
Magnolia Warbler	1	3			2	6	1	0	0	1					1	1
Cape May Warbler	2	0							2	0					1	0
Black-throated Blue Warbler	3	0	0	1			1	0					0	1		
Yellow-rumped Warbler	20	36	7	16	17	4	0	5	10	2	16	1	6	2	1	1
Black-throated Green Warb.	1	10	5	15	12	10	12	16	10	11	1	5	7	9	0	1
Blackburnian Warbler	3	6	0	2			2	0							0	1

Appendix 4 (continued)

	1986		1987		1988		1989		1990		1991		1992		1993	
Species	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
Pine Warbler													1	0		
Palm Warbler	1	6	0	1	1	0										
Bay-breasted Warbler	4	4	1	2	0	3			0	5						
Black-and-white Warbler	4	5	7	5	4	13	5	5	8	5	5	4	8	5	4	6
American Redstart	1	20	0	3	2	5	1	1			1	3	0	1	2	0
Ovenbird	17	25	19	14	21	36	20	17	9	19	23	19	10	11	2	13
Northern Waterthrush					0	2									0	1
Connecticut Warbler					3	0									0	1
Mourning Warbler	5	2	2	1	1	0			1	0	5	0				
Common Yellowthroat	2	10	10	9	5	7	10	5	6	7	11	16	13	12	4	10
Canada Warbler	1	2	1	1			3	3					0	1	1	1
Scarlet Tanager	2	0			0	2	1	1	0	2	1	3				

Appendix 4 (continued)

	1986		1987		1988		1989		1990		1991		1992		1993	
Species	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
Rose-breasted Grosbeak	0	4	9	4	2	4	5	5	5	5	4	1	4	0	0	1
Indigo Bunting	0	1	3	4	2	0	15	0	2	16	3	2	1	4	1	0
Rufous-sided Towhee	1	3	4	2	4	0	11	2	1	0	2	1	2	0	3	1
Chipping Sparrow	4	0	5	1	2	1	12	3	30	2	0	14	2	3	4	3
Vesper Sparrow											1	0	1	1	1	0
Song Sparrow	3	8	13	4	8	4	18	6	1	0	2	1	5	2	6	2
Lincoln's Sparrow	0	1									1	0				
Swamp Sparrow	3	8	4	5	2	9	8	5	2	13	3	3	1	5	0	5
White-throated Sparrow	49	24	76	27	42	20	80	20	31	12	28	23	30	12	19	7
Dark-eyed Junco	0	1	0	1	3	0	3	0	3	0					2	0
Red-winged blackbird			1	0	0	1										
Common Grackle			1	0	1	1	1	0			0	1				

Appendix 4 (continued)

	1986		1987		1988		1989		1990		1991		1992		1993	
Species	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
Purple Finch			8	0	3	0	3	0			2	0			1	0
White-winged Crossbill			8	1			29	7					4	0		
Pine Siskin			2	0							0	1				
American Goldfinch	8	9	8	8	5	7	16	5	5	3	13	12	19	28	5	6
Evening Grosbeak					0	4	1	1			1	1	3	0	0	3
Unidentified non-passerine	94	101	124	101	91	100	80	69	50	61	228	141	123	106	180	176
Unidentified sparrow			8	1	1	0			1	2	0	1	2	7	6	6
Unidentified thrush			1	0	0	1					1	2	0	1		
Unidentified woodpecker	2	9	11	12	7	10	7	7	1	5	7	16	8	17	3	6
Unidentified vireo													0	2	0	1
Unidentified warbler			1	0	3	0					6	9			9	7
Unidentified duck	0	4			1	0										

Appendix 4 (continued)

	1986		1987		1988		1989		1990		1991		1992		1993	
Species	T	C	T	C	T	C	T	C	T	C	T	C	T	C	T	C
Unidentified raptor							1	0								
Unidentified passerine											0	2			0	3
Total individuals	682	978	1129	936	882	882	1122	838	635	741	1001	901	741	737	666	739
Total number species	63	59	69	64	63	67	70	59	52	55	61	61	57	57	53	51

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.

Collins, P.T. 1990. Birds and invertebrates in northern Wisconsin forests: Are they related?
- University of Minnesota, Duluth; May 1991.
- American Ornithologists' Union; McGill University, Montreal; September 1991.

Blake, J. G., J. M. Hanowski, and G. J. Niemi. 1992. Annual variation in bird populations of mixed conifer-northern hardwood forests. American Ornithologists Union, Ames, Iowa; June 1992.

Blake, J. G. 1992. Temporal and spatial variation in migrant bird populations. Department of Ecology, Ethology, and Evolution, University of Illinois; April 1992.

Helle, P.J. 1992. Bird community dynamics in boreal forests. IUFRO Centennial Meeting (International Union of Forestry Research Organizations), Berlin, Germany; September 1992.

Hanowski, J. M. 1993. Seasonal abundance and composition of forest bird communities adjacent to a right-of-way in northern forests USA. Fifth International Symposium on environmental concerns in rights-of-way management. Montreal, Canada; September 1993.

Helle, P.J. 1993. Bird community response to forest fragmentation: A holarctic view. International Union of Game Biologists. Halifax, Nova Scotia; August 1993.

Publications

Hanowski, J. M., J.G. Blake, and G. J. Niemi. In press. Seasonal abundance and composition of forest bird communities adjacent to a right-of-way in northern forests USA. Proceedings from Fifth International Symposium on environmental concerns in rights-of-way management. Montreal, Canada.

Blake, J. G. J. M. Hanowski, G. J. Niemi, and P. T. Collins. Annual variation in bird populations of mixed conifer-northern hardwoods forests. Condor: in press.

Hanowski, J. M., J. G. Blake, G. J. Niemi, and P. T. Collins. 1993. Effects of extremely low frequency electromagnetic fields on breeding and migrating birds. American Midland Naturalist 129:96-115.

Collins, P. T. 1992. Length-biomass relationship for terrestrial gastropods and Oligochaetes. American Midland Naturalist 128:404-406.

Blake, J.G., G.J. Niemi, and J.M. Hanowski. 1992. Drought and annual variation in bird populations. pgs. 419-430. In J. Hagan and D. W. Johnston, eds., Ecology and conservation of neotropical landbird migrants. Smithsonian Institution Press, Washington, DC.

Blake, J.G., J.M. Hanowski, G.J. Niemi, and P.T. Collins. 1991. Hourly variation in transect counts of birds. Ornis Fennica 68:139-147.

Collins, P.T. 1991. Relationships between invertebrate biomass and bird abundance in northern Wisconsin forests. MS thesis, University of Minnesota.

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.

Manuscripts (in review)

Helle, P. and G. Niemi. Bird community dynamics in boreal forests. Submitted to: R. M. DeGraaf (ed.), Wildlife conservation in forested landscapes. Elsevier Publishing.

Manuscripts (in preparation)

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

Hanowski, J. M., J. G. Blake, and G. J. Niemi. Effects of extremely low frequency electromagnetic fields on breeding and migrating birds.

I. COVER PAGE

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

B. SUBCONTRACT NUMBER: D06205-93-C-007

C. TITLE OF REPORT: ELF COMMUNICATIONS SYSTEM ECOLOGICAL MONITORING PROGRAM ANNUAL REPORT FOR AQUATIC ECOSYSTEMS- TASKS 5.8, 5.9, 5.10

D. REPORTING YEAR: 11/1/92 - 9/30/93

E. REPORT IDENTIFICATION NUMBER: AE-142

II. FRONTISPAGE

A. Subcontractor: Michigan State University
East Lansing, Michigan 48824

B. Subcontract Number: D06205-93-C-007

C. Title of Report: ELF Communications System Ecological Monitoring Program Annual Report for Aquatic Ecosystems - Tasks 5.8, 5.9, 5.10

D. Reporting Year: 11/1/92 - 9/30/93

E. Report Identification Number: AE-142

F. Prepared by:

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Approved by: Thomas M. Burton 11/19/93

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Contract and Grant Administration

III. TABLE OF CONTENTS

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 esentially 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 - length of fish at previous age estimated from 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 fish stock, or of some defined portion of it.

Body-scale relationship - method of backcalculation where length is determined from the distance between annuli.

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 (^{o} C) above a pre-set threshold value (in our study the threshold was 2^{o} 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 silaceous 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 Progammable 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).

FCD-N - Ford Control Downstream New - a periphyton monitoring site located 130 m downstream of FCD.

FCU - Ford Control Upstream

FEN - Ford Experimental New - a fyke net site 400m upstream of FEX used to monitor fish movement past the antenna.

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).

FEX-Line - Ford Experimental Line - an insect studies site located 35 m downstream of FEX (about 5 m downstream of the point where the antenna crosses the river).

FEX-N - Ford Experimental New - a periphyton monitoring site located 40 m downstream of FEX (about 10 m downstream of the point where the antenna crosses the river).

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 One - one of the original study sites. 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 - portable passive gear used at FCD and FEX. Nets are set in tandem, one capturing upstream migrants the other capturing downstream migrants. Nets block entire width of stream and are 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, $\log_e$ (% remaining/100)/ 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 (Wr) - 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 - Randonmized 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 (Ws) - mean weight at length values calculated from a number of populations from the literature. Wr 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; a weir site.

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.

VI Tag - Visible implant tag. A tag implanted in the clear tissue posterior to the eye of a fish, so that the code on the tag is visible.

Weir - semi-permanent traps used to capture fish. Made of hardware cloth held in place with rerod. Applied at beginning of study season and extracted at the end of the season. Weirs have removable weir boxes which, when in place, deter fish movement. When boxes are removed, weir is negotiable by all fish.

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. 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. The ELF exposure rate at FEX under full antenna power represents a five-fold increase in exposure over the exposure at FCD. In order to obtain the desired ten-fold difference in exposure rate, two new periphyton sites (FEX-N and FCD-N), one new insect study site (FEX.LINE), and one new fish movement site (FEN) were added in May, 1990. 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. Power analyses indicated that the best parameters for detecting ELF effects included summer season data for AFDW-biomass, cell volume, species diversity, and species evenness. Significant differences between FEX and FCD for AFDW-biomass, AFDW-biomass accrual, chlorophyll a, chlorophyll a accrual, cell density, species diversity and evenness were detected using paired t-tests. Most biological parameters at FCD-N and FEX-N did not differ significantly, between FCD and FEX, respectively. A before and after, control and impact statistical procedure (BACI) and Randomized Intervention Analysis (RIA) demonstrated that differences do exist between the before and after data for chlorophyll a, chlorophyll a accrual, AFDW-biomass, AFDW-biomass accrual, cell density, and biovolume. These differences may be due to ELF effects.

Data collected for aquatic insect communities in substrate samples at FEX and FCD, and at FEX.LINE include nine structural and functional community parameters and growth rates for six target taxa. Leaf processing rates of fresh tag alder leaves at FEX, FCD, and FEX.LINE were computed. 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. B.A.C.I. tests were performed on the nine biotic parameters for each of the three seasons (27 tests). They failed Tukey's tests for nonadditivity six times, twice in the spring (H' and J'), twice in the summer (numbers of individuals and insect total mass), and twice in the fall (numbers of individuals and chironomid numerical dominance). R.I.A. tests showed that there were no significant before versus after differences for H' or J', but significant differences were found for the remaining four parameters. Total insect mass in the summer had lower coefficient of variation values than the remaining three parameters. Analyses using physical factors as covariates

could not support the contention that factors other than E.L.F. fields were highly correlated with total insect mass in the summer. Growth rates of the taxa found in the substrates were not associated with E.L.F. activation. Processing rates of fresh leaves were not significantly different between the sites over the years. Coefficient of variation values for six biotic parameters for insects colonizing leaves for 24 to 28 days each year was low. Although Two-Way ANOVA tests often showed significant years differences seldom were there site differences. Separate ANCOVA tests, using cumulative degree days as the independent covariate, showed no differences in slope between FEX and FCD for the four biotic parameters that were linear over time. Growth rates for three target species of insects on leafpacks were not shown to be affected by E.L.F. activation. However, FEX and FEX.LINE often showed significant differences in slopes and/or adjusted mean values. It appears that FEX.LINE is not very similar to FEX from the few data we have for those site comparisons.

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 1993 while thirteen 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 numbers or biomass, 3) mean daily brook trout movement rates, or 4) brook trout condition or length/weight regression.

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 were conducted simultaneously at two primary 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 added in 1990 for periphyton, insect, and fish movement studies. 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 three year before period, a 3.5 year transition period, and four years 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 a slight increase in a downstream direction. This trend of slight increase from the upstream site to the downstream site for hardness, alkalinity, tubidity, and in some years for nitrate, and ammonium 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 initiated 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.

Chloride 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 prior to 1991. The differences that did occur were slight and should have little impact on site productivity.

Element 2 - Periphyton Studies

1. Comparisons between the original and new sites

Two new sites were included in 1990 to increase the exposure to electromagnetic fields so that the antenna site receives 10.3 times more exposure than the control site. There was only a 5 fold difference between the original control and antenna sites. The differences between the old and new control sites were not significant for any parameters except species diversity and evenness (the old site had higher values). The old and new antenna sites were not significantly different for any parameters except chlorophyll a standing crop and AFDW organic biomass accrual rate (the old site had higher values).

2. 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. "Before" (6/83-4/86) and "after" (6/89-8/93), control (FCD) and impact (FEX) (BACI), and Randomized Intervention Analysis (RIA) indicate that the between site relationship in chlorophyll a has changed since the antenna began operating at full power. The paired t-tests indicate that this change has been a reversal of the pre-operational pattern when the control site was characterized by significantly higher levels of chlorophyll a than was the antenna site. After testing of the antenna began in 1986, this pattern reversed, and there were significantly higher levels of chlorophyll a standing crop and rates of accrual at the antenna site. Thus, ELF electromagnetic radiation may have stimulated chlorophyll production under the antenna.

3. Organic Matter

Organic matter (AFDW-biomass) standing crop and accrual rates showed considerable year-to-year variability similar to chlorophyll a. 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. These parameters showed significant differences between the control site (FCD) and experimental site (FEX) for the time period after antenna operation. BACI analyses and RIA showed that a difference had occurred in AFDW-organic matter standing crop since the testing of the antenna began in 1986 for the periods when Cocconeis placentula was dominant. When the ice-free standing crop data set was analyzed using BACI and RIA the results were more equivocal. BACI and RIA analyses gave conflicting results for organic matter accrual rates for both ice-free and Cocconeis dominant periods. In the case of the Cocconeis dominant data set low sample size make the RIA results difficult to interpret. Taken as a whole, these data are clearly not as robust as the chlorophyll a data but suggest that ELF antenna operation may be stimulating additional accumulation of organic matter biomass on the rock surface biofilm at the antenna site.

4. Diatom Cell Density

Diatom cell density was not statistically different between FEX and FCD sites according to paired t-tests of the time period after antenna operation. The removal of a single potential "outlyer" data point however, resulted in a statistically significant difference ($p<0.01$). BACI analyses and RIA indicated that data collected before antenna operation in 1983-86 were significantly different from data collected after the antenna starting operating at full power in 1989. Data for diatom density suggest the possibility that operation of the antenna has led to increased standing crop of diatoms in the river, especially during the summer months.

5. Total Biovolume and Individual Cell Volume

Individual cell volume and biovolume comparisons of diatoms between the control (FCD) and experimental (FEX) sites showed no significant differences for the time period after antenna operation. BACI analysis and RIA detected no significant changes in the inter-site relationship for cell volume. For the ice-free period, BACI analysis showed a significant difference between the "before" and "after" biovolume data but this finding was not supported by RIA analysis. Neither BACI or RIA tests were significant when the Cocconeis dominant biovolume data set was considered. 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 cell density. The total diatom biovolume data are highly variable leading to less power to detect changes than is desirable. Nevertheless, trends for biovolume are in the

same direction as are those for chlorophyll a, AFDW organic matter, and cell density. Since all of these parameters are related to increased algal biomass and production and have increased at the antenna site after antenna operation began, the conclusion that antenna operation may be stimulating algal growth appears to be warranted.

6. Species Diversity and Evenness

Diatom species diversity and evenness are the least variable parameters that are monitored. Differences of less than 10 % can be statistically detected with these parameters. Diversity and evenness were significantly different between FEX and FCD during the time after antenna operation using paired t-tests, but not for the period prior to antenna operation. Annual trends showed a high diversity and evenness during winter (except winter of 1986-87) and lower values during the summer periods. Neither diversity or evenness for the diatom community has been significantly affected since operation of the ELF antenna began according to the paired BACI and RIA analyses.

7. Changes in abundance of individual diatoms

In 1993, 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 1993 summer period. During the 1991 summer, Cocconeis reached its highest abundances ever observed since 1983. Three species achieved dominance during the winter of 1989. BACI analyses were presented for four dominant and two non-dominant species of diatoms and showed that no significant differences have occurred before and after antenna operation began for any of these 6 species.

8. Photosynthesis-Respiration Studies

Net primary production, respiration, and gross primary production of the community on rock surfaces did not differ greatly between sites for the time period after antenna operation, however paired t-tests suggest there is a significant difference between FCD and FEX. BACI analysis 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 of Periphyton Communities

This element was eliminated following the 1989 field season, since effects were determined to be too variable and inconsistent from year to year to be useful in detecting ELF effects. Efforts previously spent on this element were used for the periphyton studies at two additional sites for Element 2.

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

Structural and functional community parameters were grouped into seasonal datasets, **Spring**, **Summer**, and **Fall**, after coefficient of variation values showed high variance in the Spring (April, May) and Fall (September through November) transition years. There was lower variance in the Summer stable period. In the spring and fall seasons, dramatic changes in water temperatures as well as potentials for high discharges can affect the biotic community. Because the summer season is more stable and has low variability, any E.L.F. effects on biotic parameters could best be detected in that season (June through August).

Seasonal data were first analyzed with 2-Way ANOVAS. Then, multiple linear regressions were used to determine the physical factors that were most correlated with the nine biotic parameters each season. Discharge was the most important independent covariate in the spring. In the summer and fall, discharge and/or cumulative degrees were the most important covariates.

Of the twenty-one biotic datasets that passed Tukey's test for nonadditivity in the parametric intervention analysis test, the B.A.C.I., only chironomid numerical dominance in the spring showed significant before versus after differences. Chiromomid numerical dominance before E.L.F. activation had always been higher at FCD. After full power for E.L.F., dominance increased at both sites; however, in April of 1992, dominance was higher at FEX. The nonparametric analog, the R.I.A., was used for six datasets that failed Tukey's test or lacked homogeneous variances. Four of the six showed significant before versus after differences. They were: numbers of individuals in the summer and fall, chironomid numerical dominance in the fall, and total insect mass in the summer. Only the latter posed a real question as to possible E.L.F. effects because the other parameters had very high coefficient of variation values. A series of multiple linear regressions were performed, adding one year of data for each test to see whether we could detect a change at one site that was not matched at the other site. The three

physical variables were: Cumulative degree days, discharge, and E.L.F cumulative ground field exposure values. If a difference was detected and E.L.F. cumulative exposure was linked to the change at FEX, this would support results from the R.I.A test for summer insect mass. Over the years, R^2 values did not increase. Of the three independent variables, discharge was consistently the most important factor at FEX. When E.L.F. cumulative ground field exposure did explain more of the variation, it was at the reference site, FCD. It appears to us that factors other than E.L.F. activation accounted for the variation in insect mass during the summer months, even though R.I.A. test results suggested otherwise. Because R.I.A. tests are insensitive and are vulnerable to low sample sizes, we hope that a more sophisticated intervention analysis technique will be devised to verify whether of not total insect mass in in the summer months was related to E.L.F. fields.

Discharge and water temperatures were both highly correlated with taxon richness and insect mass. This was especially true in May of each year, with r^2 values being as high as 0.85 for richness versus water temperature.

ANCOVAS showed that there were no statistical differences between sites with respect to mean dry weight values per individual (MDW/IND) and physiological time (cumulative degree days) for the collector-gatherer mayfly, Paraleptophlebia mollis. Five additional taxa were also monitored for changes in MDW/IND values. Graphical analyses revealed no obvious differences between the sites for those species as well.

Two-way ANOVA tests comparing FEX, FCD, and the new site, FEX.LINE from 1990 through 1993 were performed for the summer dataset, which showed the lowest coefficient of variation values. Five of the nine parameters tested showed no site differences (H', S', numbers of individuals, total insect mass, and collector gatherer percent dominance. There were always significant year differences, and there were significant interaction terms in five of the nine cases (H', J', numbers of individuals, chironomid numerical dominance, and collector gatherer percent dominance). The long-term FEX and FCD comparisons give a better view of changes over the years before and after ELF activation than would any FEX.LINE and FCD comparisons.

Element 5 - Movement Patterns of Ophiogomphus colubrinus

A paper for this Element was published in December of 1992 in the Journal of Aquatic Ecology. We found no differences in movement patterns attributable to E.L.F.

effects. This Element was deleted from our studies in 1990.

Element 6 - Leaf Litter Processing

Fresh leaves were processed at statistically similar rates at FEX and FCD from 1984 through 1992. A new site, FEX.LINE, showed no differences with FEX or with FCD for processing rates as well. However, those data cover only three years.

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. Although Two-Way ANOVA tests often showed significant year differences, they seldom showed significant site differences, suggesting that ELF activation did not differentially affect the experimental site. Multiple linear regressions were performed for linear data to determine whether there were relationships with mean discharge and/or cumulative degree days, as leaves had been put in the river in mid-August through mid-September over the years. Cumulative degree days accounted for more of the variability than discharge for the six biotic parameters tested. Coefficient of multiple determination values were always higher at FCD that at FEX. The higher r^2 values at FCD may be related to the sandier conditions there, which may make the animals more vulnerable to spating events. ELF fields could not be shown to affect taxon diversity, evenness, richness, chironomid numerical dominance, number of individuals, or insect mass adjusted to leaf mass.

B.A.C.I. tests could not be performed on these data, as there was only one mean value for any given year for processing rates and for any collection date. The samples were non-independent from the date they were placed in the river and so B.A.C.I. tests could not be run for data from four weeks' incubation in the river.

ANCOVAS showed that growth rates (MDW/IND) for two species of mayflies and one species of stonefly were generally not significantly different between FEX and FCD for each year of the studies. (Only four of 25 tests showed significant differences.) Comparisons between FEX and the new experimental site FEX.LINE showed that FEX.LINE was not as similar to FEX as was FCD to FEX. There were significant differences between the two experimental sites in four of the six ANCOVA tests. Usually, increases in growth rates were higher at FEX than at than at FEX.LINE.

A paper on growth rates of specific taxa found on leaves and in substrates is being written.

Element 7 - Fish Community Composition and Abundance

1. Species Composition

Fourteen species from six orders and ten families were collected at FEX in 1993. This represents a net decrease of one species from the previous year. Thirteen species from nine families and four orders were collected at FCD in 1993, representing a net decrease in two orders and two family and a net decrease of four species from 1992. Overall, the species composition was similar at the two sites with only minor variation in the catch of uncommon species.

2. Species Abundance

Numerically and by biomass, the catch was dominated by five species (brook trout, common shiners, creek chubs, white suckers, and burbot). Numerically, white suckers were most numerous at FEX, followed by common shiners, creek chubs, brook trout, and burbot. At FCD common shiners were most abundant then creek chubs, white suckers, brook trout, and burbot. A one-way ANOVA detected no differences in percent catch by numbers among the pre-operational, transitional, and fully-operational time periods.

Percent catch by biomass differed little from percent catch by number. At FEX, biomass was distributed (in decreasing magnitude) among white suckers followed by brook trout, common shiners, creek chubs, and burbot. White suckers also had the highest percentage at FCD followed by creek chubs, brook trout, common shiners and burbot. Cyprinid biomass continued to be higher at FCD than at FEX. Due to an apparent error in calibration of the weighing scales, absolute biomass values from 1993 can not be compared with the values of previous years at this time. A Chi-square test showed that over the first 10 years of the study FEX and FCD had similar catch by biomass patterns. A one-way ANOVA revealed a significant difference among periods in the percent catch by biomass of burbot. There were no significant differences among pre-operational, transitional, and post-operational periods for any of the other species.

Shannon-Weaver diversity values for 1993 were similar to the lower values observed from 1988 through 1992. A Spearman Rank Correlation test indicated a similar pattern in the Shannon-Weaver index for FEX and FCD from 1983-1993.

Spearman Rank Correlation and BACI analysis detected no significant differences in index values between years and the three time periods.

3. Catch Statistics

The mean length of most species in 1993 showed no consistent year to year trends at either FEX or FCD. Overall changes in mean length have been slight, which indicates that the size structure is consistent from year to year within the mobile fish communities at FEX and FCD. The two sites continue to be similar in mean length and trends in mean length.

4. Fish Community Mobility

Most non-salmonid fish species with adequate sample sizes demonstrated site to site movement. Recapture percentages for burbot, common shiners, creek chubs, and white suckers increased in 1993 compared to previous 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. Fish condition was examined using relative condition factors. Standard weight formulas were derived for common shiners, creek chubs and white suckers from literature data. Condition factors were not analyzed in 1993 as a result of biased biomass data. In 1992, white sucker condition factor was below the species literature means. Common shiner and creek chub condition factors both rose well above the literature means with creek chubs reaching an all-time high in 1992.

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 in 1984, 1985, 1987 and 1988 were not seen in 1986, 1989, or 1990. Brook trout catches in 1992 remained high until mid July. The greatest catch occurred in late May and diminished into early June. In 1993, brook trout catches peaked in mid to late May, and also increased slightly in early July. 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 water 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 mm) moved from FEX and FCD upstream toward the TM site based on a total of 1230 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 in 1986 and little in 1987, 1988 and 1990. Movement was observed in 1989 although not at 1984-1985 levels. Recapture rates were highest in 1991, when 29 fish marked at FEX and 29 fish marked at FCD were recaptured at TM. In 1992, however, only 2 recaptured brook trout passed upstream under the antenna, and 3 moved downstream under the antenna. Recapture rates were higher for both upstream and downstream movements in 1993. Five recaptured brook trout moved upstream under the antenna from FCD to FEN, as well as four more from FEX to FEN. Fifteen recaptured brook trout moved downstream from FEN to FEX.

Movement rates over all all years were found to range between 0.67 to 12.7 km/day. Rates from FEX to TM were similar among 1984, 1985, 1987, 1989, and 1991 with no catches among these sites in 1986, 1988, and 1990. Brook trout movement rates from FCD to TM were greater in 1989 and 1985 than in 1984 and 1991. No movement was detected between any sites in 1986 and very little between site movement was detected 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, transitional periods, and post-operational periods were compared. The low numbers of recaptured fish that passed under the antenna during the transitional period and 1990 could have been due to an increase in the number of beaver dams, coupled with low water conditions. However, the movement of 45 brook trout from FCD and FEX to TM, and the direct observation of two radio-tagged brook trout passing under the antenna

indicates that the antenna's electromagnetic field does not block passage.

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 young of the year (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. 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. Differences in slopes of the regression lines between FCD and FEX in each year revealed significant differences only in 1984, 1986, and 1988. Covariance analysis detected a significant difference between the slopes of the regression lines among pre-operational (1983-1985), transitional (1986-1989), and post-operational (1990-1991) periods. The slopes of the regression lines were greater at FCD for all periods. Brook trout condition was examined using relative weight condition factors (Wr) 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 (Wr 89 - 104). Condition factors declined from 1983 to 1986 and improved from 1987 to 1990 and then declined again in 1991 and 1992. Condition factors were not analyzed in 1993 as a result of biased biomass data. Length/weight regression analysis revealed no significant differences in the slopes of the regression lines between sites in all years except in 1985. In addition, covariance analysis detected no significant differences in the slopes of the regression lines among pre-operational, transitional, and post-operational years.

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 were 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 monitored fish movement using the other sites indicated on Fig. VII.1 (FCU, and TM).

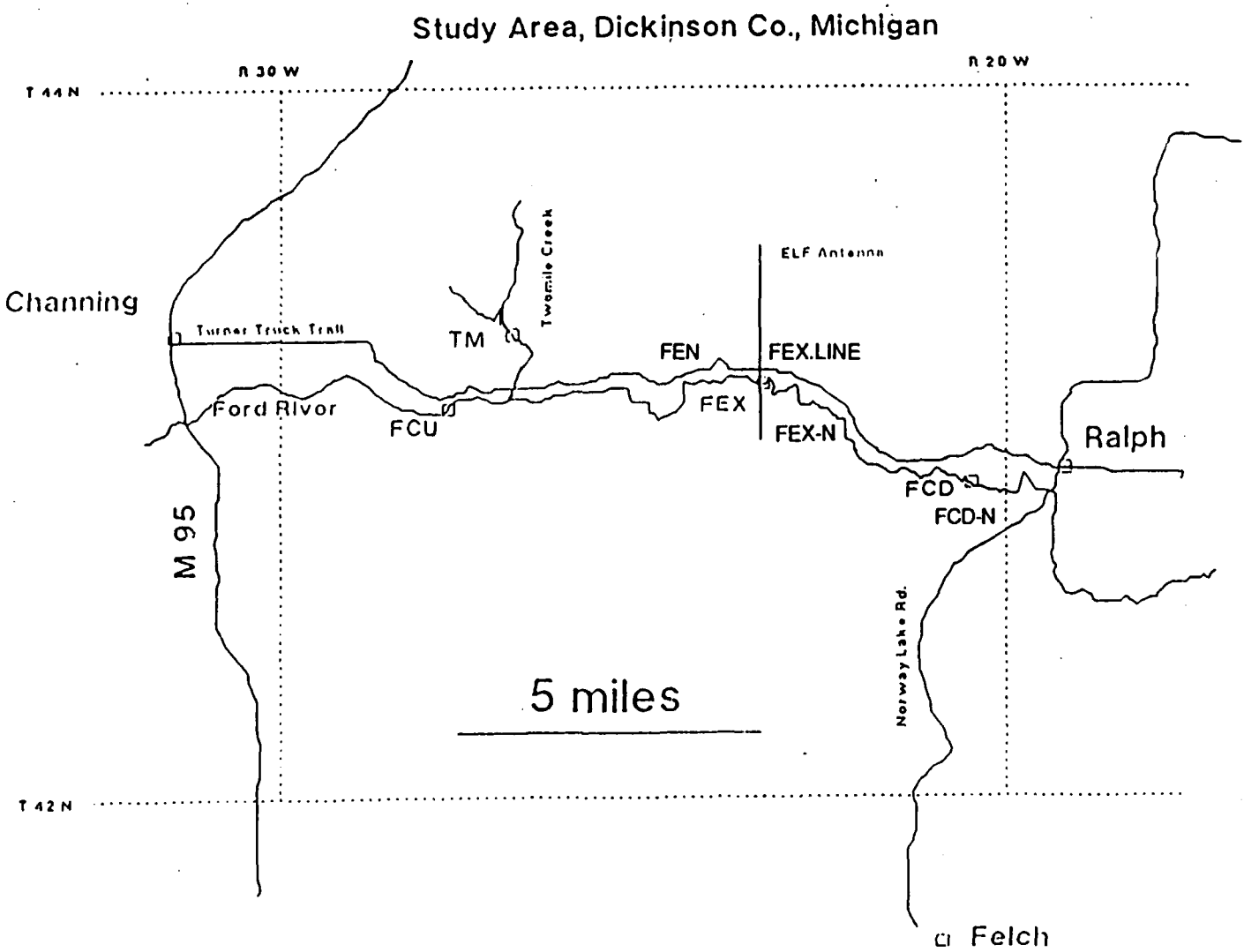

Figure VII.1 ELF Research Sites on the Ford River, Dickinson County, Michigan.

Land use in the Ford River Watershed was analyzed in 1992 to determine what the major land uses were and if significant land use changes had occurred during the course of this study. Land use changes were extracted from the Michigan Resource Information System (MRIS) using Geographic Information Systems (GIS) technology. The MRIS included land use inventory data for 1979 and 1986. Results of this analysis show that forests are the predominant land use in the Ford River Watershed in Dickinson County with almost 90 % of land use being in deciduous, coniferous, or wetlands forest (Table VII.1). There were few changes from 1979 to 1986 in most categories with the largest decrease in land area being in coniferous forest and the largest increase in land area being in cleared land (Table VII.1). Even these changes were relatively minor. Personal observations suggest that the area is subjected to a large amount of timber harvest but that the harvested area quickly revegetates from stump sprouting. There has been little change in land use over the course of the study. Thus, any changes in the biota are unlikely to be related to changes in land use in the watershed.

For the two primary sites (FEX and FCD, see Fig. VII.1), we continuously monitored stream velocity and water depth so the discharge could be calculated. Water temperatures, dissolved oxygen, pH, and solar radiation at the surface and at the stream bottom were also continuously monitored. We also sampled 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.

Table VII.1 Land use changes in the Ford River watershed in Dickinson County from 1979 to 1986 obtained from BSTATS in ERDAS.

Land Use	Percent Cover 1979	Percent Cover 1986	Change
Deciduous Forest	41.40	40.80	-0.60
Coniferous Forest	38.30	37.25	-1.05
Wetlands Forest	10.36	10.26	-0.10
Herbs/Shrubs	5.89	5.73	-0.16
Agriculture	1.27	1.10	-0.17
Non-Forested Wetlands	0.91	0.91	0.00
Barren, Open, or Cleared	0.14	1.55	1.41
Other Terrestrial*	0.32	0.31	-0.01
Aquatic	2.11	2.10	-0.01

* = Residential, Commercial, Utility, and Extractive

VIII. PRESENTATIONS AND PUBLICATIONS FOR 1992-1993

Burton, T. M., D. M. Mullen, and S. L. Eggert. 1992. Effects of extremely low frequency (ELF) electromagnetic fields on the diatom community of the Ford River, Michigan, p. 17-25. In: T. P. Simon and W. S. Davis. Proceedings of the 1991 Midwest Pollution Control Biologists Meeting. Environmental Indicators: Measurement and assessment endpoints. EPA 905/R-92/003, U. S. Environmental Protection Agency, Region 5, Chicago, IL.

Eggert, S. L. 1992. A comparison of Acroneuria lycorias (Plecoptera) production and growth rates in northern Michigan hard and soft water streams. M.S. Thesis, Michigan State University, East Lansing, MI. 132 pp.

Eggert, S. L., T. M. Burton, and D. M. Mullen. 1992. A comparison of RIA and BACI analysis for detecting pollution effects on stream benthic algal communities, p. 26-34. In: T. P. Simon and W. S. Davis. Proceedings of the 1991 Midwest Pollution Control Biologists Meeting. Environmental Indicators: Measurement and assessment endpoints. EPA 905/R-92/003, U. S. Environmental Protection Agency, Region 5, Chicago, IL.

Muzzall, P. M., G. E. Whelan, and W. W. Taylor. 1992. Host-parasite relationships of Longnose Dace, Rhinichthys cataractae, from the Ford River, Michigan. J. Parasitology 78(5):837-844.

Stelzer, R. S. 1993. Growth and abundance of the crayfish Orconectes propinquus in a hard water and soft water stream. J. Freshwater Ecology 8 (4):329-340.

Stout, R. J. 1992. Responses to extremely low frequency electromagnetic fields by a dragonfly naiad (Ophiogomphus colubrinus) in a northern Michigan stream: a five year study. J. Freshwater Ecology 7 (4):343-352.

Treml, M. K. 1992. An evaluation of the influence of temperature on growth of brook trout in the Ford River, Dickinson County, MI from 1984-1991. M.S. Thesis, Michigan State University, East Lansing, MI. 63 pp.

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.

IX. 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 previous annual reports). Total phosphorus, chloride and organic nitrogen were removed from the study in the 1992 field season, as negotiated as part of the phase down of these studies.

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. We continued to use water quality and other environmental data from these two sites only since they are within 150 meters of the new sites (FEX-New or FEX-N and FCD-New or FCD-N). This distance is not great enough to significantly affect water chemistry, temperature, etc., since riparian vegetation does not change appreciably over this distance nor does any new tributary or obvious source of ground water enter between the old and new sites. Note that our FCD-N and FEX-N are within 10-15 meters of FEX-LINE and the new position of FCD sampling for the aquatic insect portion of the study.

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. In 1992 and 1993, monitoring began in mid-May and ceased at the end of August as negotiated as part of the limited phase-down of these studies.

The stations 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. No funds were in the budget for equipment replacement and this, coupled with the expected relative constancy of solar input between the two sites, led to the decision to cease

measurement of solar radiation at one of the sites. This station was repaired for the 1988 season. All four quantum sensors were sent to LI-COR, Inc. for calibration during spring, 1991 and returned to the field in late June.

(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 to replace it, the dissolved oxygen data used for this report came from the twice weekly samples taken in the field at both sites. The 28 day mean dissolved oxygen at FEX using this field data was 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 felt that there was no serious loss of data resulting from the temporary loss of the meter. Since the ambient monitoring equipment provided more detailed data (every 30 minutes throughout the season) than the manual field sampling, we replaced the D.O. meter before the start of the 1990 field season, and 30 minute interval data for the field seasons have been collected since that time.

(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 have been able to obtain consistent data since 1988. Periods of poor meter performance resulted in some gaps in the data; these gaps were filled by twice-weekly manual sampling.

(4) Air and water temperature were monitored using thermistors. The ambient monitoring data were supplemented early in the spring in 1992 and 1993 and late in autumn in 1992 with Ryan Model J temperature recorders submerged in the river. 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 R2 values greater than 0.96 for FEX and 0.97 for FCD.

All automatically acquired data were checked and calibrated by manually determining each parameter 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 in the years prior to 1992 (mid-May to end of August in 1992 and 1993). 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 3-5 hours of collection. Twice per week, samples were taken and frozen for later determination of total phosphorus, soluble reactive phosphorus (samples were placed on ice after collection and were filtered within 3-5 hours of collection), nitrate-N, nitrite-N, ammonium-N, organic-N (total Kjehldahl 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 1988-89 and 1989-90, since

the expense of taking the samples is prohibitive given the minimal amount of biological data collected during the winter months. Winter sampling was discontinued completely following October 1991 due to financial and logistical constraints. Total P, Cl and total N analyses were eliminated as part of the negotiated phase back of these studies in 1991 and 1992. Hardness was also supposed to be eliminated, but it was kept because of the limited extra time required for this analysis.

All chemical analyses followed procedures outlined in Standard Methods (APHA 1985) 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.

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 $p<0.05$.

Procedures for calculating ELF exposures to earth electric fields and to magnetic flux were explained in the 1990 annual report. Essentially, these data were calculated on the basis of hours of operation from the logs of the antenna operation and from site measurements of earth electric fields and magnetic flux data from IITRI. These data are reported as total cumulative exposure over the 28 day, or longer, intervals used in the periphyton studies (i.e. each data point represents a 28 day total exposure time).

Results and Discussion

A. Field Chemistry

The dissolved oxygen (DO) data for 1993 (Table 1.1, Fig. 1.1) generally corroborated the predictable pattern observed at both sites for all previous years of the project. However, mean dissolved oxygen at FCD and FEX for the June, 1993 28 day sampling period was generally 2-3 mg/L higher than past years. Since cold water contains more dissolved oxygen at saturation than does warm water, one would expect the type of longterm pattern found if the water in the river is near saturation throughout the year. The Ford River was typically 5-15 % undersaturated at each site, and DO has shown high negative correlations with temperature at each site ($r = -0.93$ and -0.95 at FCD and FEX respectively, $p<0.01$

Table 1.1 pH and Dissolved Oxygen (mg/L) for the Ford River for 1993. Values are Means ± S.E., N in Parentheses.

Date	pH		Dissolved Oxygen	
	Experimental (FEX)	Control (FCD)	Experimental (FEX)	Control (FCD)
9/26/92	8.17 ± 0.05 (4)	8.23 ± 0.04 (4)	9.11 ± 0.09 (4)	9.06 ± 0.09 (4)
10/24/92	8.15 ± 0.01 (5)	8.18 ± 0.02 (5)	9.47 ± 0.40 (5)	9.44 ± 0.38 (5)
6/7/93	7.93 ± 0.03 (8)	7.91 ± 0.05 (8)	12.41 ± 0.65 (9)	12.04 ± 0.44 (9)
7/6/93	7.99 ± 0.05 (8)	8.00 ± 0.03 (8)	9.50 ± 0.20 (7)	9.29 ± 0.21 (7)
8/2/93	8.17 ± 0.03 (9)	8.15 ± 0.02 (9)	8.99 ± 0.13 (9)	8.84 ± 0.11 (9)
8/27/93	8.13 ± 0.03 (8)	8.05 ± 0.05 (8)	8.93 ± 0.20 (10)	9.04 ± 0.29 (10)

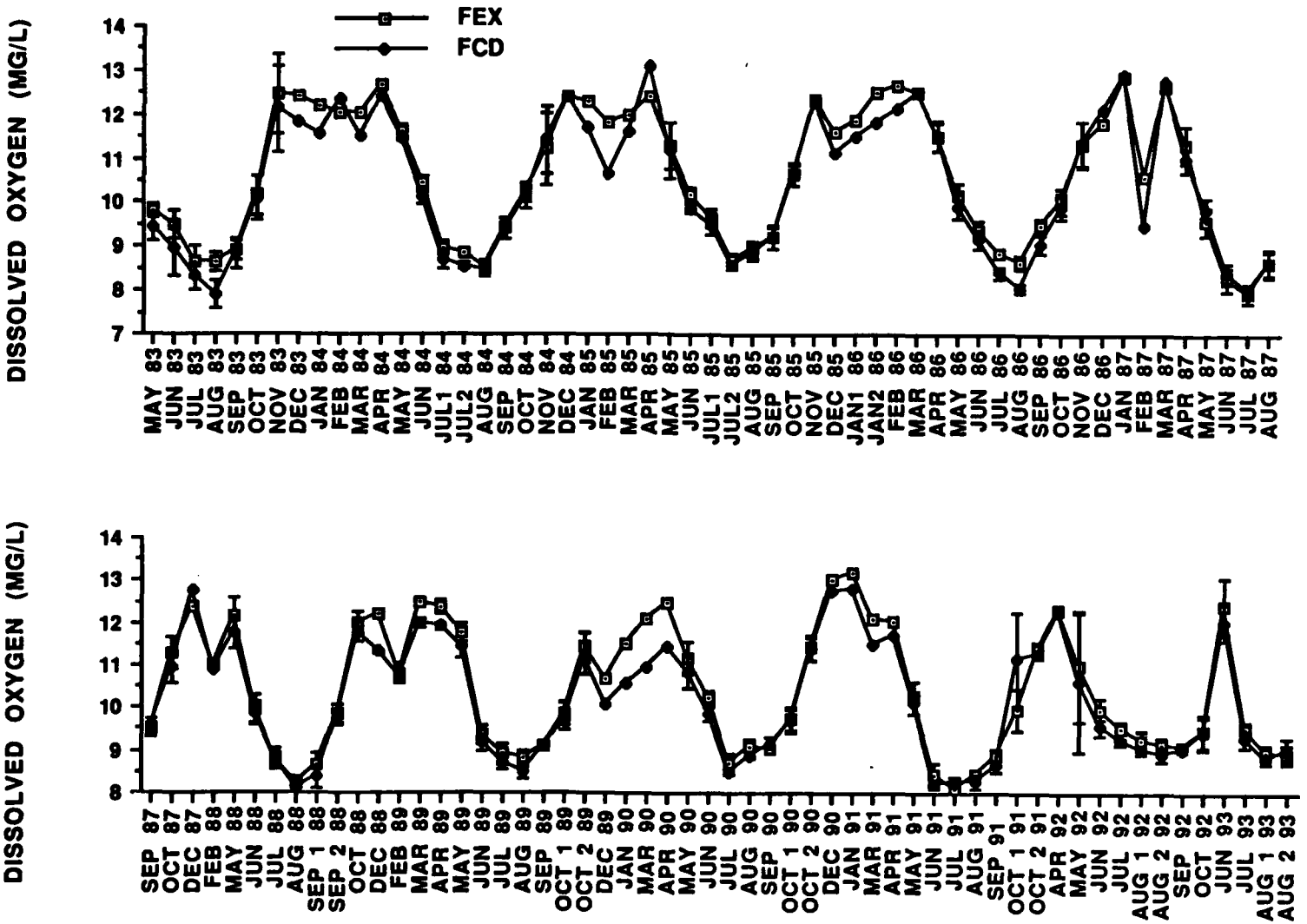

FIGURE 1.1 MEAN DISSOLVED OXYGEN LEVELS (±S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1993.

at both sites). The high dissolved oxygen concentrations in June, 1993 may be related to the colder water temperatures during this period relative to all past years. The mean water temperatures at FCD (10.00 C) and FEX (9.81 C) during June, 1993 were much lower than the average June water temperatures in the Ford River based on the 1983-1992 interval (FCD = 14.19 C, FEX = 14.28 C). There was a significant ($p<0.01$) correlation ($r = 0.99$) in dissolved oxygen values between the two sites for 1992-93 (Table 1.2) as illustrated by Fig 1.1 and Table 1.1. This high degree of correlation was also characteristic for all data collected from 1983 through 1993 ($r = 0.97$) (Table 1.3, Fig. 1.1). In 1993, there was no significant difference in dissolved oxygen between the two sites (Table 1.2) continuing the trend reported in the last annual report for 1992. Slight but significant differences do occur in dissolved oxygen between the two sites when all data collected since 1983 are examined (Table 1.3). In the 1988 report, we hypothesized that differences in dissolved oxygen between the sites reported prior to 1988 were due to a researcher bias for consistently visiting one site first during the sampling trip. Altering the site that was visited first seemed to eliminate this difference in 1988, 1992 and 1993, but not for other years since 1988. In all years in which there has been a difference between the 2 sites, FEX has had the higher D.O. (Fig. 1.1). The reason for this difference is not known but may be caused by many factors (e.g. turbulent water is present a short distance upstream of the FEX ambient monitoring station but is not present at FCD). Regardless of the cause, when differences have occurred between the two sites in the past, they have been 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 1992-93 pH data for the two sites was for the most part consistent with the previous pattern of summer highs (Fig. 1.2), probably related to higher levels of primary production in the warmer months (see Element 2) coupled with lower stream discharge, and higher values for alkalinity (pH was significantly ($p<0.05$) correlated with all these parameters). The most highly correlated parameters with pH were water temperature with r's greater than 0.72 at both sites and discharge with r's greater than -0.67 at both sites. The pH values at the two sites were significantly correlated with each other in 1992-93, and there were no significant differences between sites (Table 1.2) as has been true for all data collected over the course of the study (Table 1.3). Automatically acquired data for the two sites since 1988 has been 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 from 1988 through 1993.

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 1992-1993.

Parameter	df	Paired t-value	Significance	Correlation coefficient	Significance
Conductivity	5	0.766	NS	0.977	P<0.01
Hardness	3	-0.825	NS	1.000	P<0.01
Alkalinity	5	-0.344	NS	0.999	P<0.01
Turbidity	5	0.701	NS	0.949	P<0.01
pH	5	1.113	NS	0.928	P<0.01
Dissolved Oxygen	5	-1.229	NS	0.987	P<0.01
Water Temperature	5	4.030	P<0.01	0.999	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 May 1983 to August 1993.

Parameter	df	Paired t-value	Significance	Correlation coefficient	Significance
Conductivity	109	-0.170	NS	0.924	P<0.01
Hardness	108	-4.923	P<0.01	0.983	P<0.01
Alkalinity	110	-2.969	P<0.01	0.961	P<0.01
Turbidity	109	-2.227	P<0.05	0.747	P<0.01
pH	102	0.023	NS	0.935	P<0.01
Dissolved Oxygen	107	6.998	P<0.01	0.973	P<0.01
Water Temperature	107	2.070	P<0.05	0.995	P<0.01

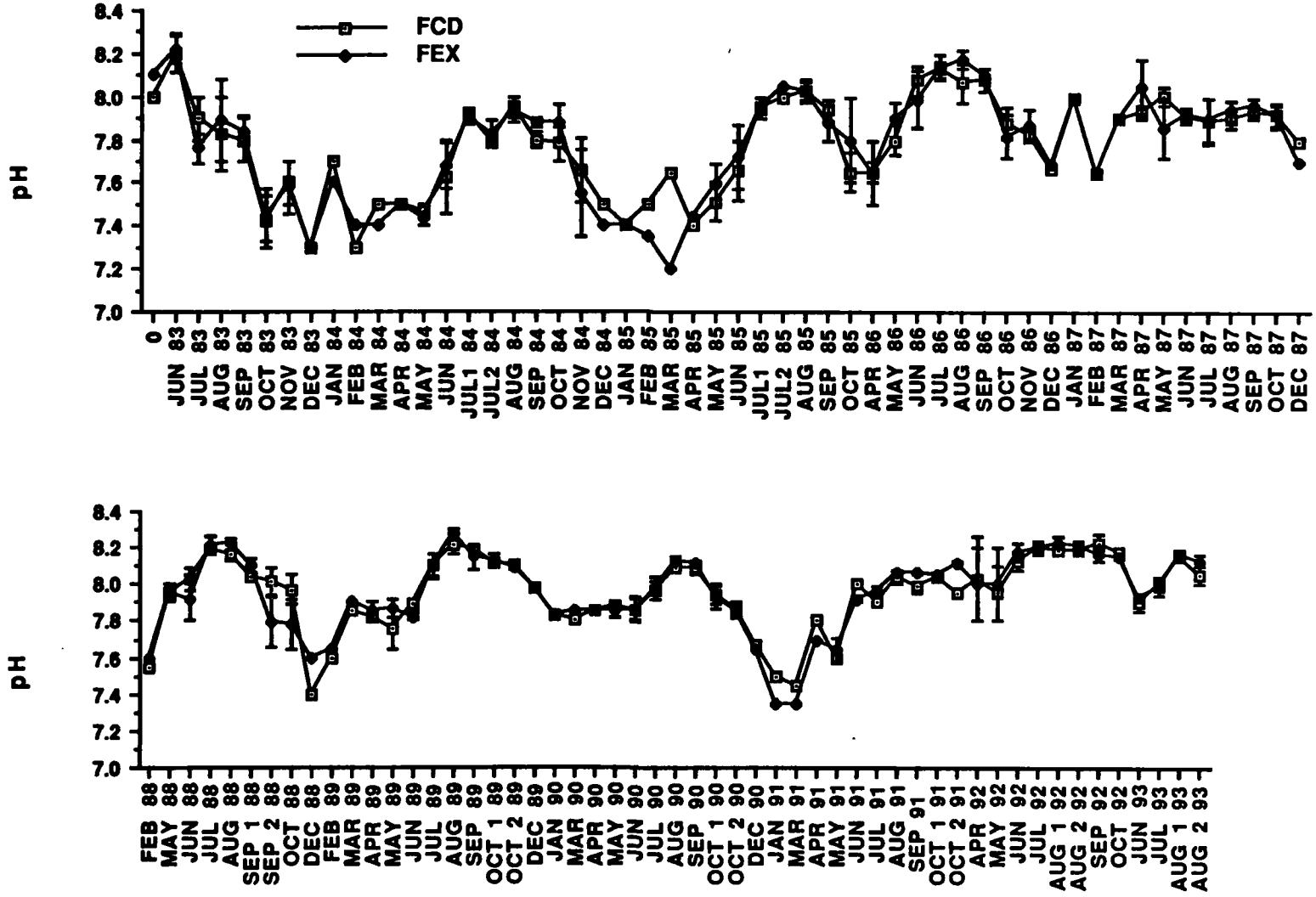

FIGURE 1.2 MEAN pH LEVELS (±S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1993.

Alkalinity and hardness followed similar trends for the two sites (Table 1.4 and 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). These parameters are significantly ($p<0.01$) positively correlated with specific conductance ($r = 0.74$ or greater). As expected, hardness and alkalinity are highly correlated with each other ($r=0.99$, $p<0.01$) at both sites. Alkalinity at FCD was highly correlated with alkalinity at FEX both in 1992-93 ($r=0.99$, $p<0.01$) and when all data since 1983 are included ($r=0.96$, $p<0.01$). There was a significant difference ($p<0.01$) between the sites for the period since 1983 but not for the 1992-1993 interval (Table 1.2, Table 1.3). Hardness was highly correlated between the sites for both the 1983-1993 and 1992-1993 periods. Hardness was significantly different between the sites for the cumulative period since 1983 but not for the 1992-1993 period (Table 1.2, Table 1.3). Hardness and alkalinity at FCD were slightly, but significantly, greater than at FEX for the 1983-1993 period. This increase may be related to the expected increase in cations in a downstream direction.

Conductivity (Fig. 1.7, Table 1.5) follows the same seasonal pattern as alkalinity (Fig. 1.3) and hardness (Fig. 1.4), with high conductivities occurring in months with low flows and lower conductivities occurring in the months with high discharge. Conductivity values at FEX were highly correlated ($r=.98$, $p<0.01$) with conductivity values at FCD during 1992-93 (Table 1.2) and for all data collected since 1983 ($r=0.92$) (Table 1.3). There were no significant differences between sites (Tables 1.2, 1.3).

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 FCD for 1992-1993 ($r=.95$, $p<0.01$) and 1983-1993 ($r=.75$, $p<0.01$). There was no significant difference between turbidity between the two sites for 1992-93 (Table 1.2) but a significant difference existed for the 1983-1993 period ($p<0.05$) (Table 1.3).

B. Nutrient Chemistry

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 1987-89 were much more consistent between sites (with a few exceptions) than had previously been the case. We have no explanation for this increase in consistency. In 1990, values between the two sites returned to some inconsistency with FCD values being

Table 1.4 Alkalinity and Hardness (mg $CaCO_3$/L) for the Ford River. Values are Means ± S.E., N in Parentheses.

Date	Alkalinity		Hardness	
	Experimental (FEX)	Control (FCD)	Experimental (FEX)	Control (FCD)
9/26/92	148 ± 3 (4)	148 ± 3 (4)	---	---
10/24/92	143 ± 2 (5)	143 ± 2 (5)	---	---
6/7/93	101 ± 5 (4)	105 ± 6 (4)	118 ± 5 (4)	123 ± 7 (4)
7/6/93	118 ± 8 (5)	119 ± 7 (5)	143 ± 8 (4)	145 ± 7 (4)
8/2/93	159 ± 5 (5)	157 ± 5 (5)	177 ± 4 (5)	177 ± 4 (5)
8/27/93	160 ± 4 (4)	158 ± 2 (4)	181 ± 4 (4)	180 ± 3 (4)

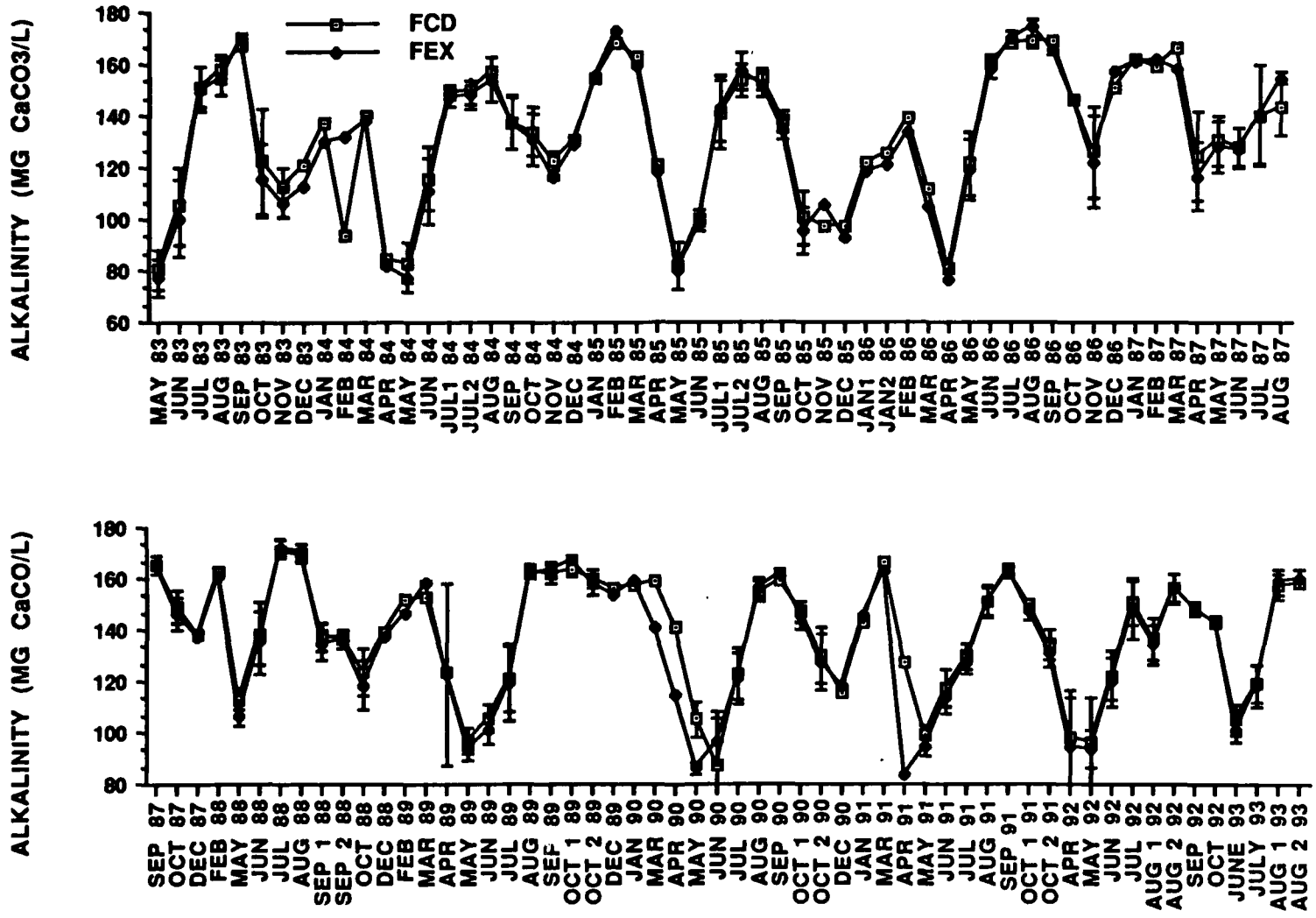

FIGURE 1.3 MEAN ALKALINITY LEVELS (±S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1993.

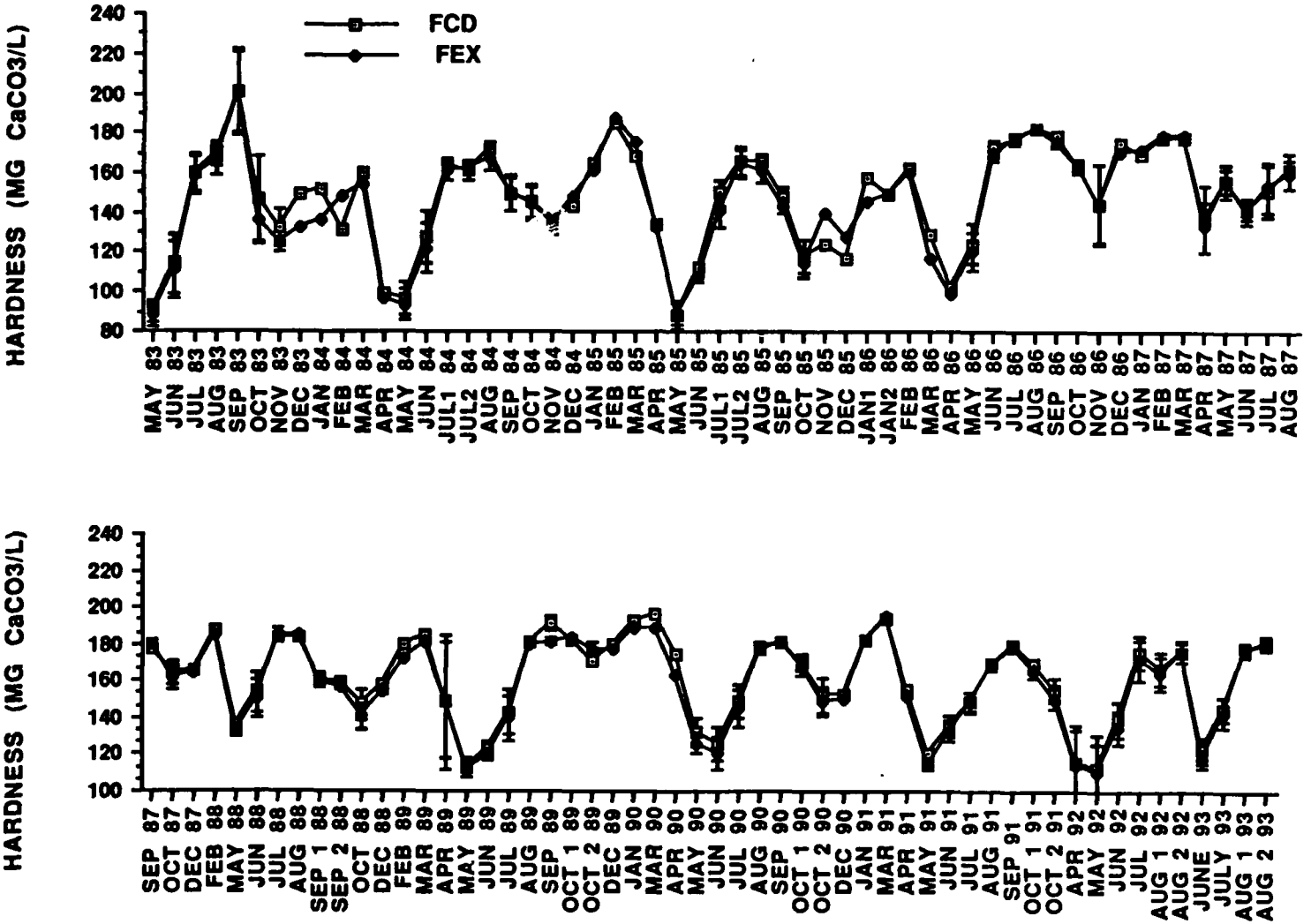

FIGURE 1.4 MEAN HARDNESS LEVELS (±S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1993.

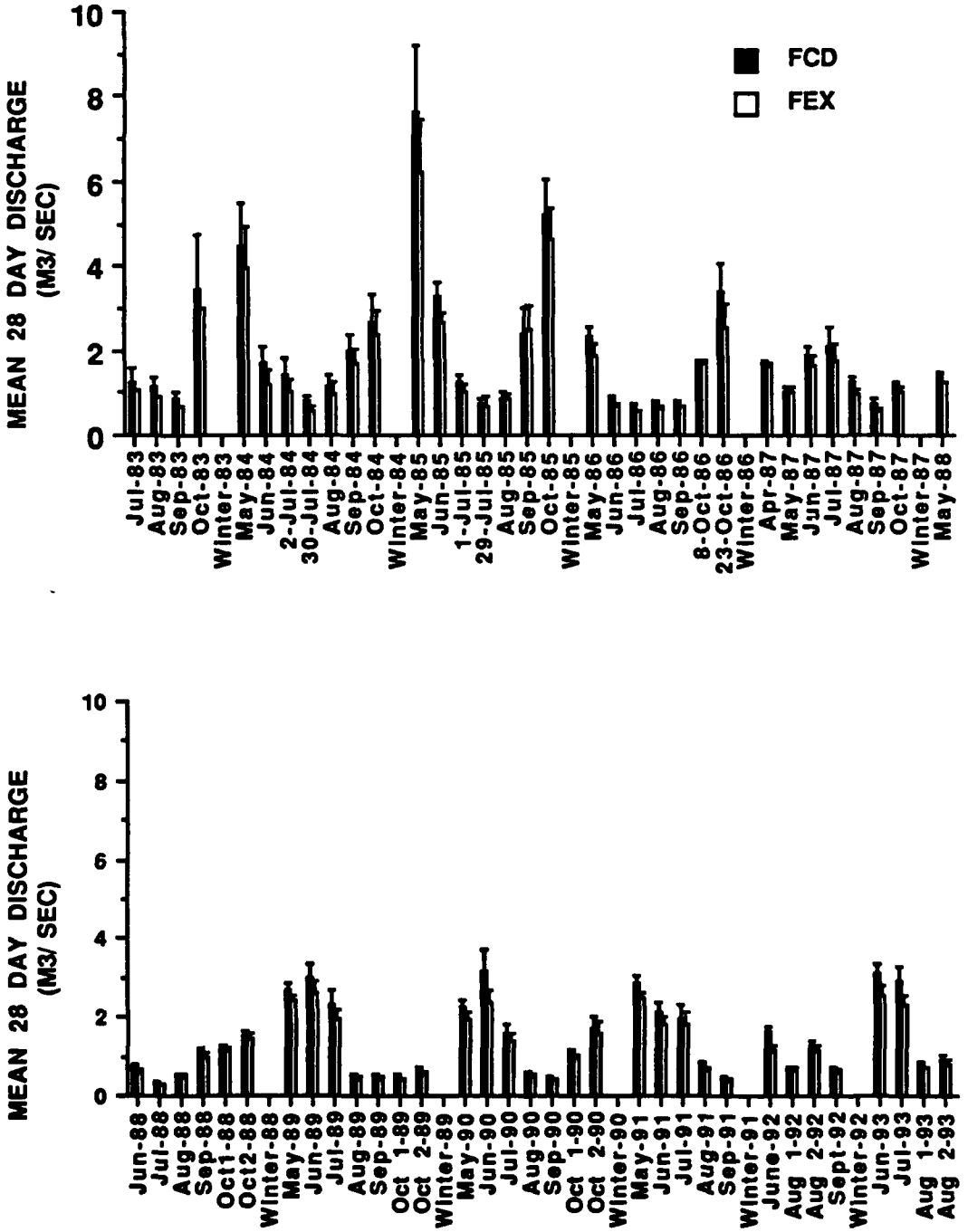

FIGURE 1.5 MEAN DISCHARGE LEVELS (±S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1993.

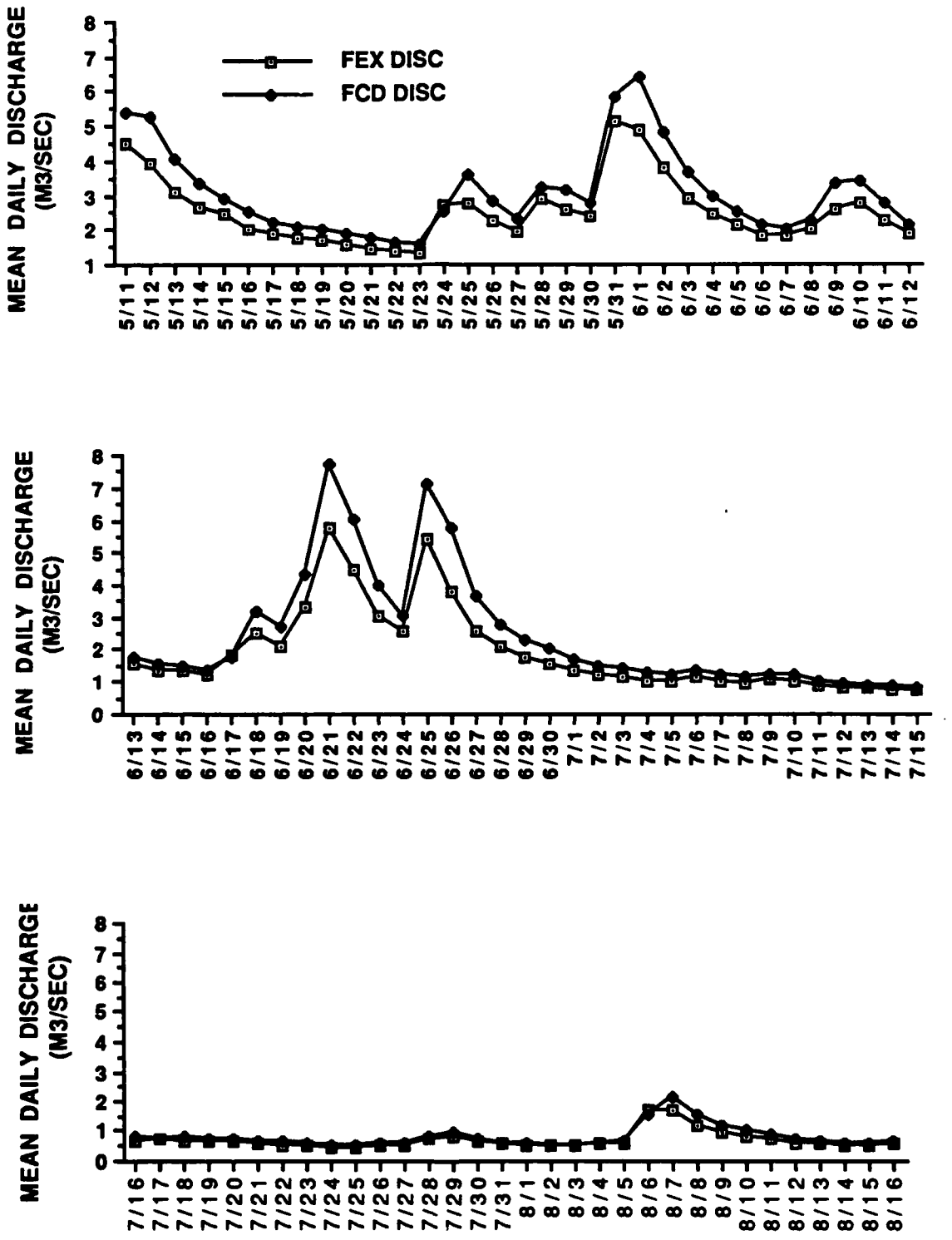

FIGURE 1.6 DAILY DISCHARGE MEANS FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES FOR 1993.

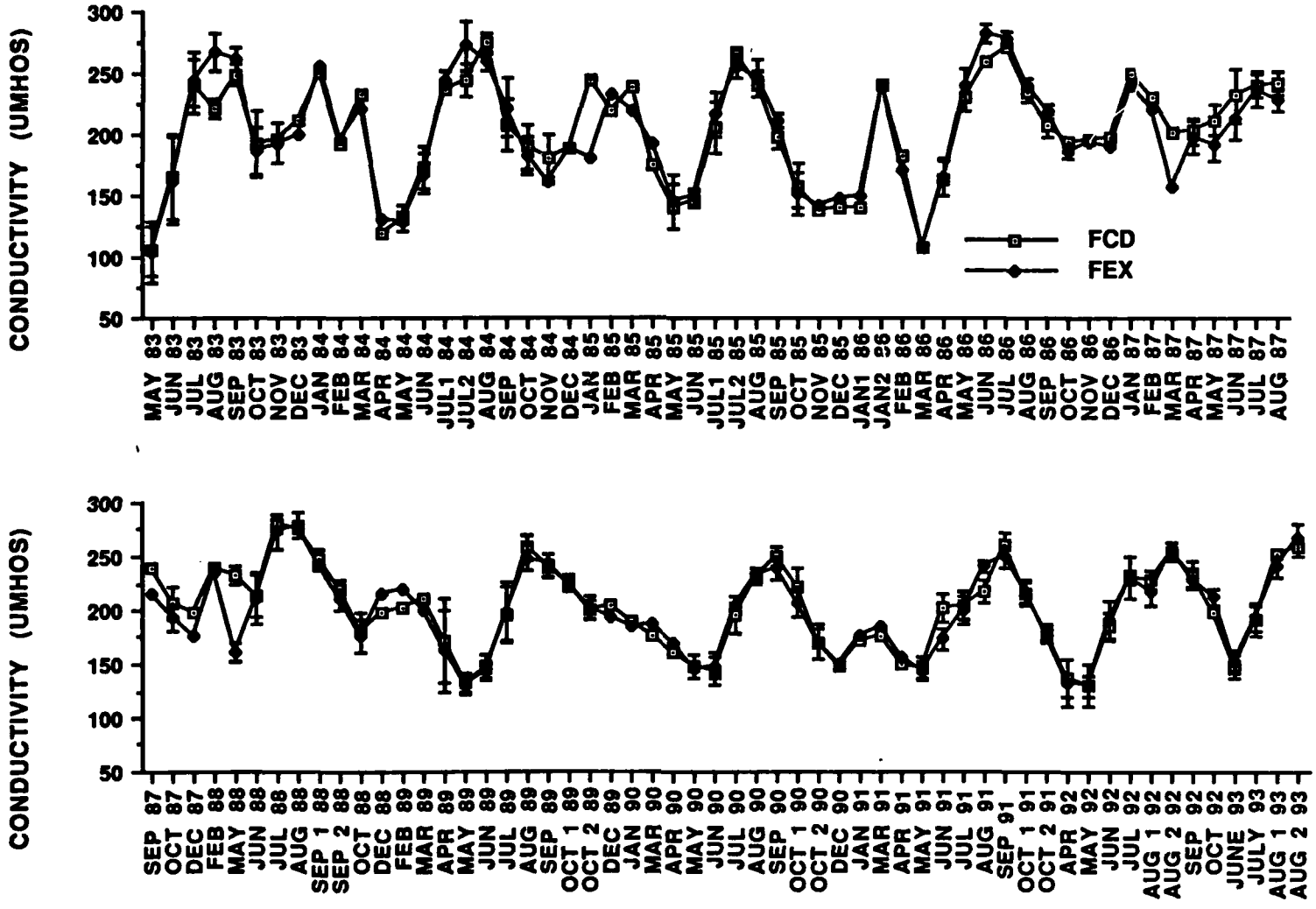

FIGURE 1.7 MEAN CONDUCTIVITY LEVELS (±S.E) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1993.

Table 1.5 Conductivity (µmhos/cm) and Turbidity (NTU's) for the Ford River. Values are Means ± S.E., N in parentheses.

Date	Conductivity		Turbidity	
	Experimental (FEX)	Control (FCD)	Experimental (FEX)	Control (FCD)
9/26/92	229 ± 10 (4)	233 ± 12 (4)	2.5 ± 0.1 (4)	2.2 ± 0.2 (4)
10/24/92	212 ± 7 (5)	198 ± 2 (5)	1.6 ± 0.3 (5)	1.4 ± 0.2 (5)
6/7/93	152 ± 10 (4)	147 ± 11 (4)	1.1 ± 0.1 (4)	1.3 ± 0.1 (4)
7/6/93	193 ± 12 (5)	191 ± 15 (5)	1.3 ± 0.1 (5)	1.2 ± 0.1 (5)
8/2/93	241 ± 10 (5)	252 ± 5 (5)	1.4 ± 0.1 (5)	1.4 ± 0.1 (5)
8/27/93	268 ± 13 (4)	258 ± 9 (4)	1.4 ± 0.1 (4)	1.5 ± 0.0 (4)

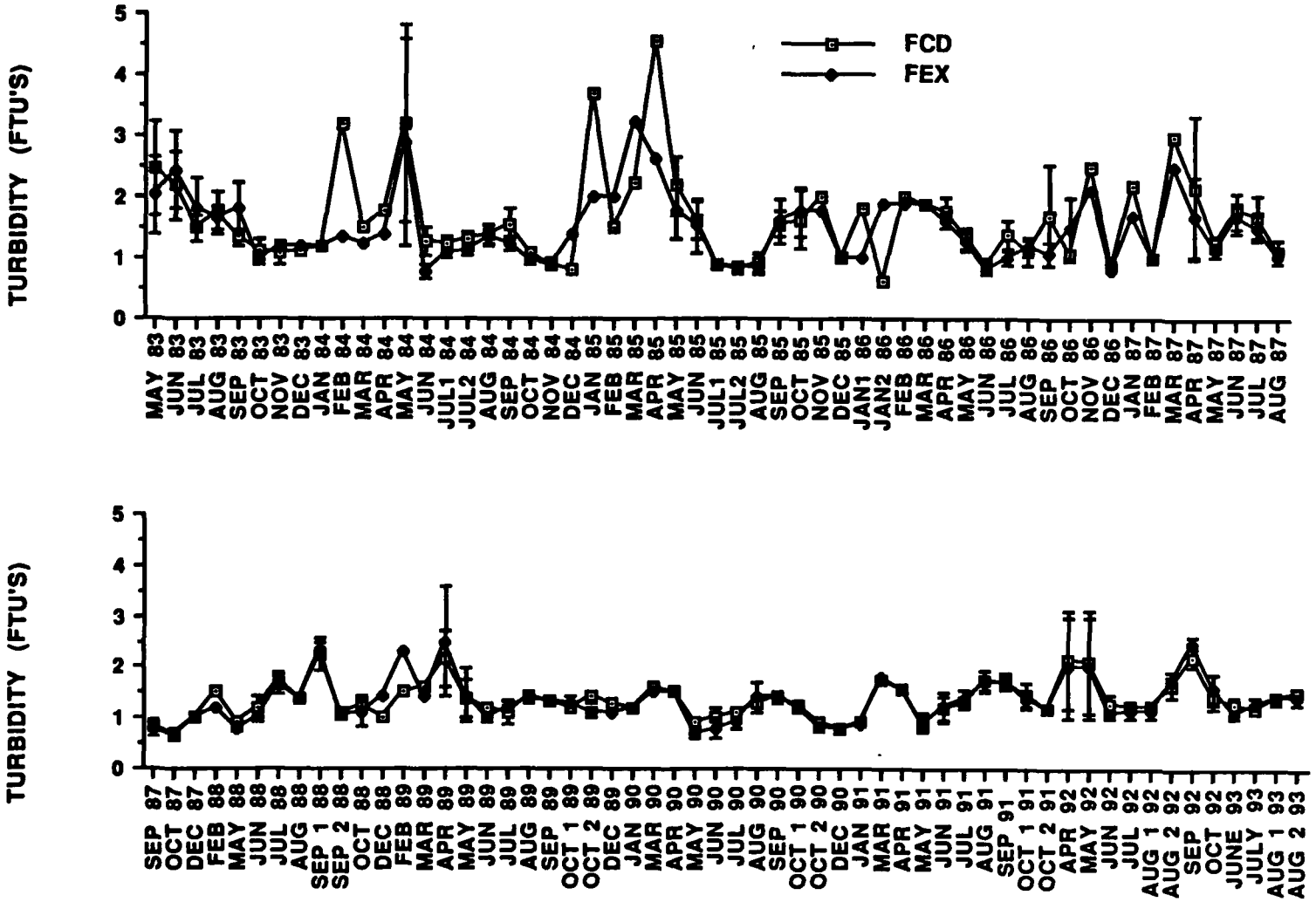

FIGURE 1.8 MEAN TURBIDITY LEVELS (±S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1993.

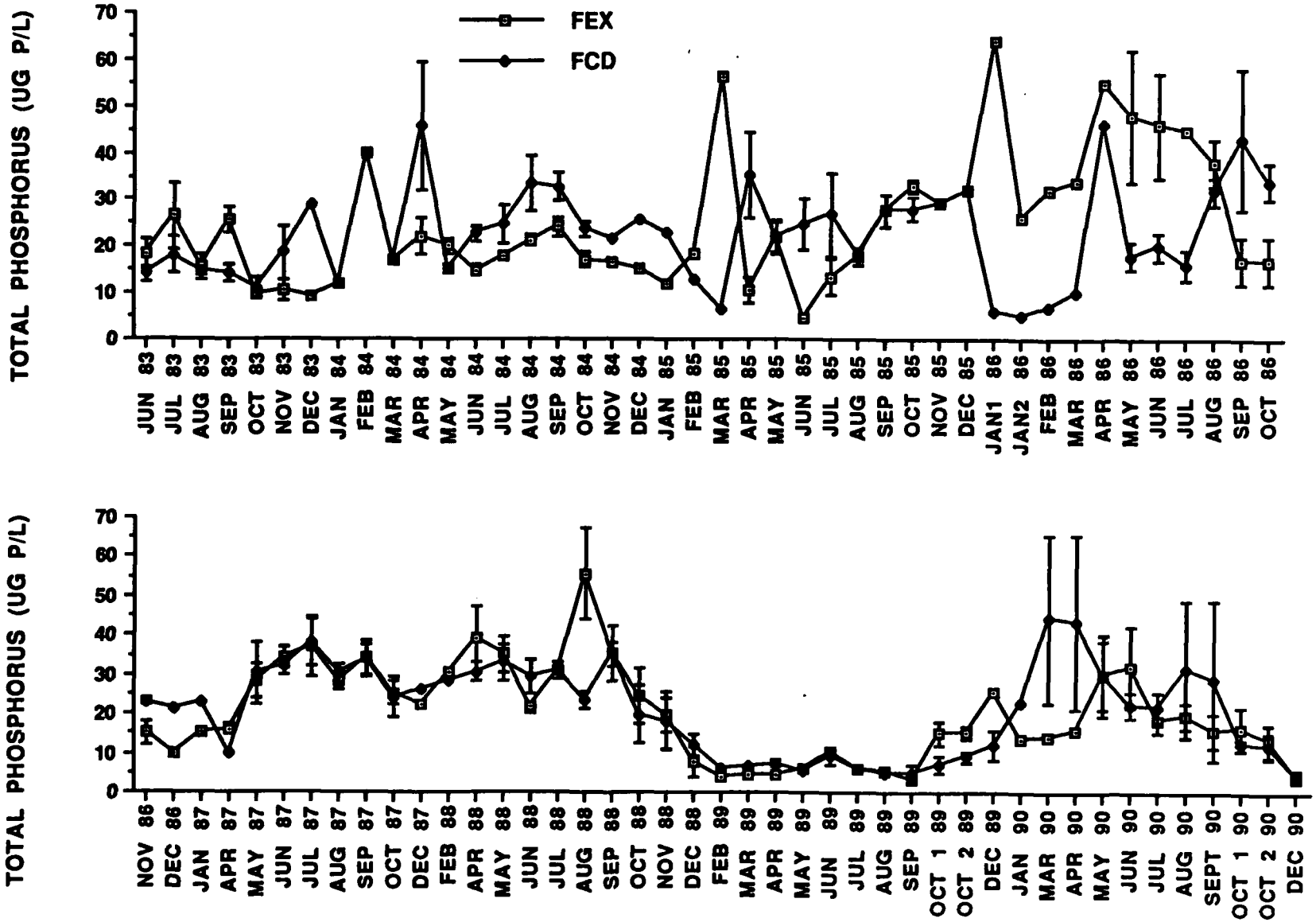

FIGURE 1.9 MEAN TOTAL PHOSPHORUS CONCENTRATION (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1990.

higher than FEX values on some occasions (Table 1.6, Fig. 1.9). Even with the inconsistencies, the concentrations at both sites are relatively low and are characteristic of values of total P for the eastern U.S. reflecting land use that is 50 to 90 % forest (see Omernik 1977, he 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. There were no significant differences between the two sites for the data from 1983 through 1990 (Table 1.7). Total P is positively correlated with organic N ($r=0.45$ for FEX and 0.37 for FCD) and negatively correlated with Si ($r = -0.34$ and -0.38 for FEX and FCD) ($p<0.05$). These correlations are not very robust but are reasonable, since both total P and organic N are primarily associated with particulates which are usually directly correlated with discharge while Si is usually inversely correlated with discharge. Determination of total phosphorus was discontinued after 1990.

Soluble reactive phosphorus (SRP) consistently stayed below 10 ug 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 has not occurred again for data collected through 1993. In 1993 there was no significant difference in SRP between sites ($p>0.05$, Table 1.8). For the 1983-1993 period overall, there remains no significant difference in SRP between sites (Table 1.7). Soluble reactive phosphorus was not significantly correlated between sites for 1993 (Table 1.8), but remained highly correlated over the 1983-1993 period (Table 1.7). As with total phosphorus, soluble reactive phosphorus has been more consistent between the sites since 1986, although some inconsistencies occurred in the spring of 1989 and in December 1990 (Fig. 1.10). 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). Land use in the Ford River watershed is 88-90% forested according to Geographic Information System analyses completed in 1992.

Nitrate-N and nitrite-N values have been reasonably similar at FEX and FCD since 1983, and this trend continued in 1993 (Figs. 1.11, 1.12, Tables 1.7, 1.8, and 1.9). However, there was a slight, yet significant ($p<0.05$) divergence in nitrite values between the two sites for the 1983-1993 period (Table 1.7). 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. Ammonium-N was somewhat variable across time and between sites in 1993, and there was no significant difference between sites (Fig. 1.13, Table 1.8, 1.9). Considering the

Table 1.6 Soluble Reactive Phosphorus (µg P/L) for the Ford River for 1993. Values are Means ± S.E.,N in Parentheses.

DATE	Soluble Reactive Phosporus Experimental (FEX)	Control (FCD)
6/7/93	6.21 ± 0.17 (8)	5.85 ± 0.13 (8)
7/6/93	6.57 ± 0.20 (9)	6.58 ± 0.45 (9)
8/2/93	5.67 ± 0.52 (9)	5.92 ± 0.80 (9)
8/27/93	5.98 ± 0.34 (9)	5.77 ± 0.24 (9)

Table 1.7 Results of Paired t-tests and correlations between Experimental (FEX) and Control (FCD) sites for nutrient chemisty parameters from June 1983 to August 1993.

Parameter	df	Paired t-value	Significance	Correlation coefficient	Significance
Organic Nitrogen	70	-2.710	P<0.01	0.712	P<0.01
Inorganic Nitrogen	95	-1.031	NS	0.806	P<0.01
Ammonium-N	105	1.072	NS	0.496	P<0.01
Nitrite-N	106	2.763	P<0.01	0.825	P<0.01
Nitrate-N	106	-1.121	NS	0.854	P<0.01
Total Phosphorus	85	0.256	NS	0.271	P<0.05
Soluble Reactive Phosphorus	99	-1.721	NS	0.397	P<0.01
Silicate	108	1.233	NS	0.942	P<0.01
Chloride	95	5.188	P<0.01	0.906	P<0.01

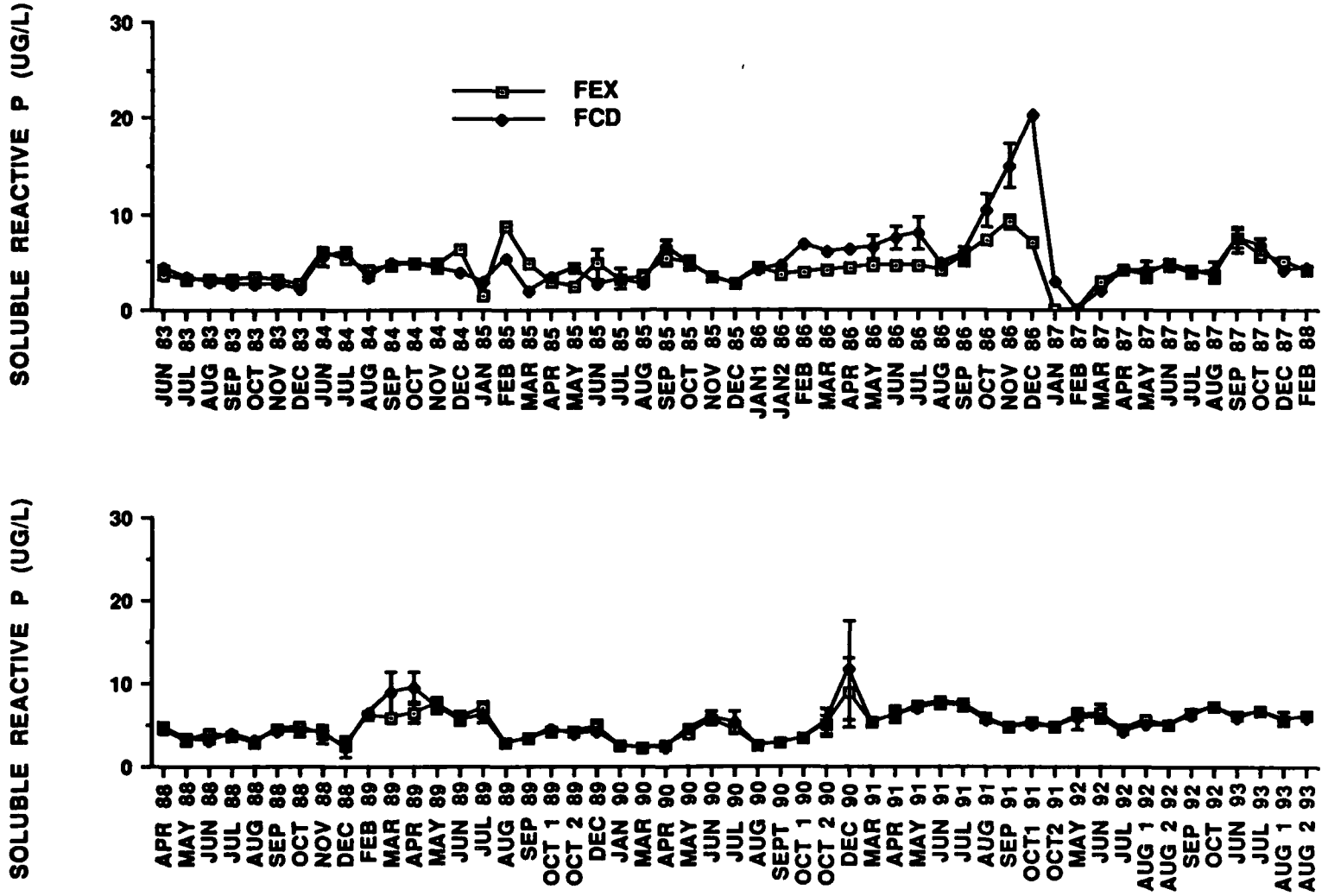

FIGURE 1.10 MEAN SOLUBLE REACTIVE PHOSPHORUS CONCENTRATION (±S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1993.

Table 1.8 Results of Paired t-tests and correlations between Experimental (FEX) and Control (FCD) sites for nutrient chemistry parameters for 1993.

Parameter	df	Paired t-value	Significance	Correlation coefficient	Significance
Ammonium-N	3	0.436	NS	0.635	NS
Nitrite-N	3	0.278	NS	0.996	P<0.01
Nitrate-N	3	-0.461	NS	0.998	P<0.01
Soluble Reactive Phosphorous	3	0.583	NS	0.749	NS
Silicate	3	-0.728	NS	0.996	P<0.01

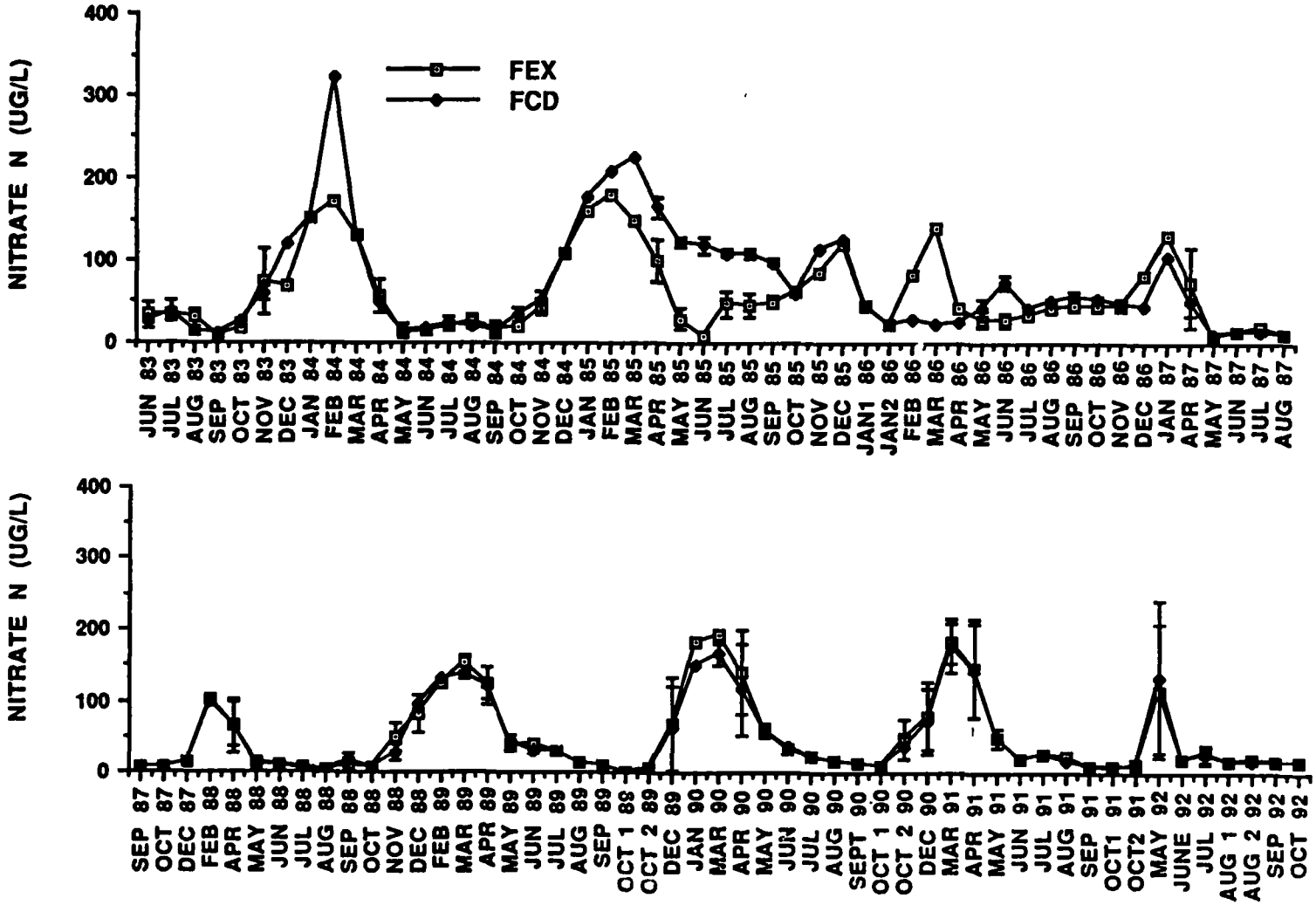

FIGURE 1.11 MEAN NITRATE-N CONCENTRATION (±S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1993.

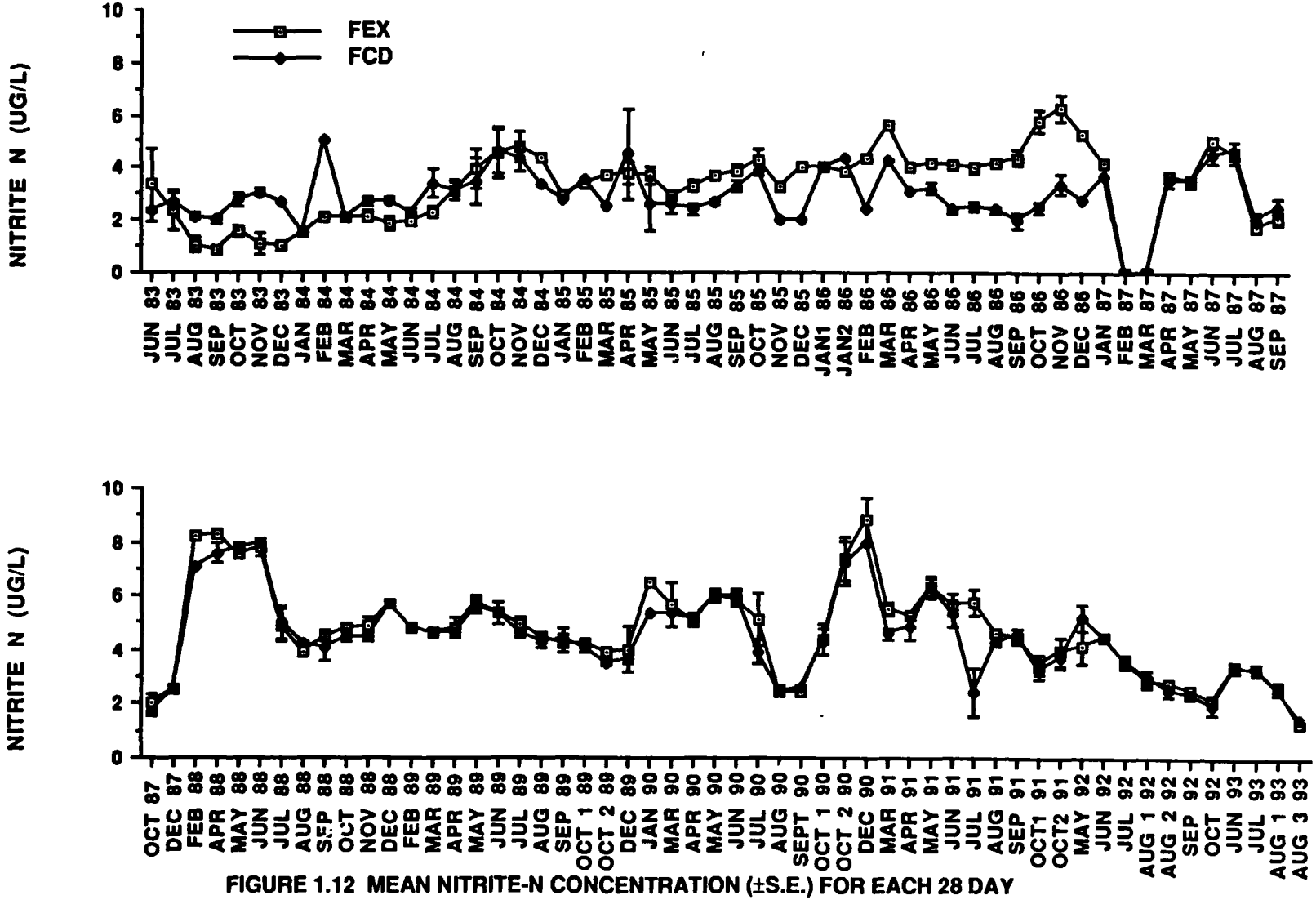

FIGURE 1.12 MEAN NITRITE-N CONCENTRATION (±S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1993.

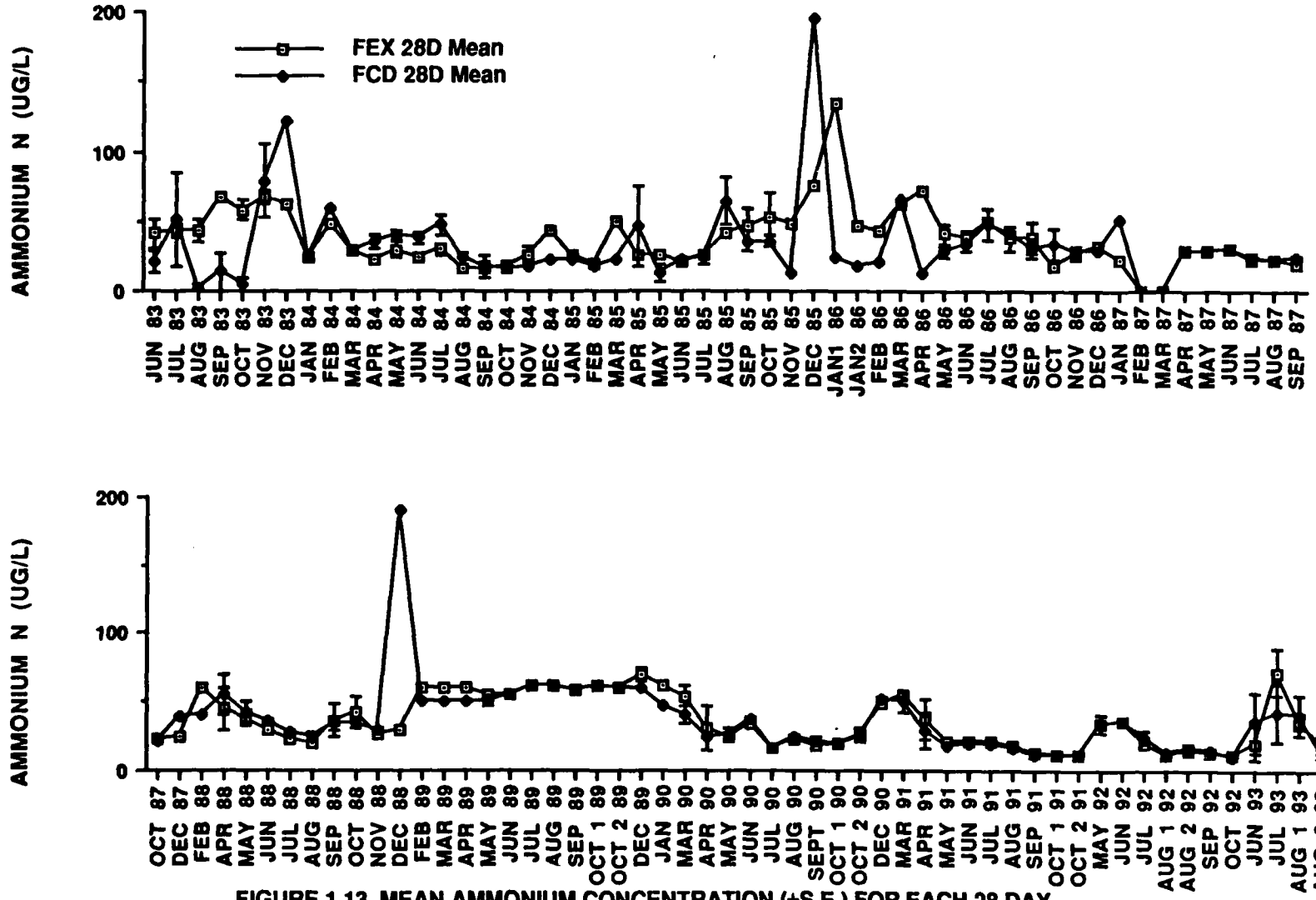

FIGURE 1.13 MEAN AMMONIUM CONCENTRATION (±S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1993.

Table 1.9 Ammonium (µg N/L),Nitrate-N(µg N/L) and Nitrite-N(µg N/L) for the Ford River for 1993. Values are Means ±S.E.,N in parentheses.

Date	Ammonium-N	Nitrate-N	Nitrite-N
		Experimental Site (FEX)	
6/7/93	20.32 ± 12.57 (3)	33.45 ± 3.87 (7)	3.41 ± 0.18 (7)
7/6/93	72.12 ± 17.64 (3)	30.71 ± 1.54 (8)	3.29 ± 0.09 (8)
8/2/93	36.18 ± 5.73 (8)	19.39 ± 2.69 (9)	2.61 ± 0.23 (9)
8/27/93	19.47 ± 6.74 (7)	7.57 ± 0.36 (9)	1.32 ± 0.09 (9)
		Control Site (FCD)	
6/7/93	35.27 ± 21.87 (3)	35.26 ± 5.06 (7)	3.31 ± 0.16 (7)
7/6/93	42.22 ± 20.78 (3)	30.29 ± 0.98 (8)	3.33 ± 0.18 (8)
8/2/93	40.47 ± 15.21 (8)	19.83 ± 2.66 (9)	2.50 ± 0.17 (9)
8/27/93	13.41 ± 4.39 (7)	6.80 ± 0.70 (9)	1.43 ± 0.07 (9)

entire 1983-1993 period, FCD and FEX were fairly similar in Ammonium-N concentrations (Fig 1.13, Table 1.7). One possible explanation for the difference in Nitrate-N between FCD and FEX in 1985 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 the forests along the Ford River (Bormann and Likens 1979, Vitousek et al. 1982). In order to better document the effect of watershed changes on nutrient losses, we have prepared an analysis of land use changes in the watershed using aerial photographs and a geographic information system. Base maps and overlays of land use changes were prepared. These analyses showed that overall land use in the watershed changed less than 2% from 1979-1986. Our on-the-ground observations suggest that substantial portions of the watershed have been harvested for pulpwood since the start of the project. However, rapid regeneration of forest from sprouts result in no overall change in classification using GIS-aerial photograph interpretation.

Nitrate is the predominant form of inorganic nitrogen present in the Ford River. Thus, calculation of inorganic-N from the three components (Figs. 1.11, 1.12, 1.13) results in trends for inorganic-N very similar to those for nitrate-N (Fig. 1.14, Table 1.10). The patterns for inorganic-N and nitrate-N 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).

Concentrations of inorganic-N and nitrate-N at FEX were significantly correlated with concentrations at FCD for the cumulative data set (Table 1.7). In 1985-87, nitrate-N concentrations were significantly different between the two sites. This has not occurred since 1988 and did not occur in 1993 (Table 1.8), probably indicating a return to the patterns and levels exhibited prior to the 1985 clearcutting discussed above (Fig. 1.11). Nitrite-N exhibited a strong inter-site correlation in 1993, and did not show a significant difference between sites (Tables 1.8)(Note that there is an overall difference in nitrite from 1983-93 (Table 1.7) related primarily to large differences between the sites in 1986 (Fig. 1.12)). Nitrite levels have always been near limits of detection as is expected for unpolluted water. Ammonium-N did not show a significant correlation between sites in 1993, but was significantly correlated between sites for 1983-1993 (Table 1.7, 1.8).

Organic nitrogen at FEX was slightly, but significantly, different from organic-N at FCD prior to 1987 (Fig. 1.15), but these differences disappeared after 1987 (Fig. 1.15).

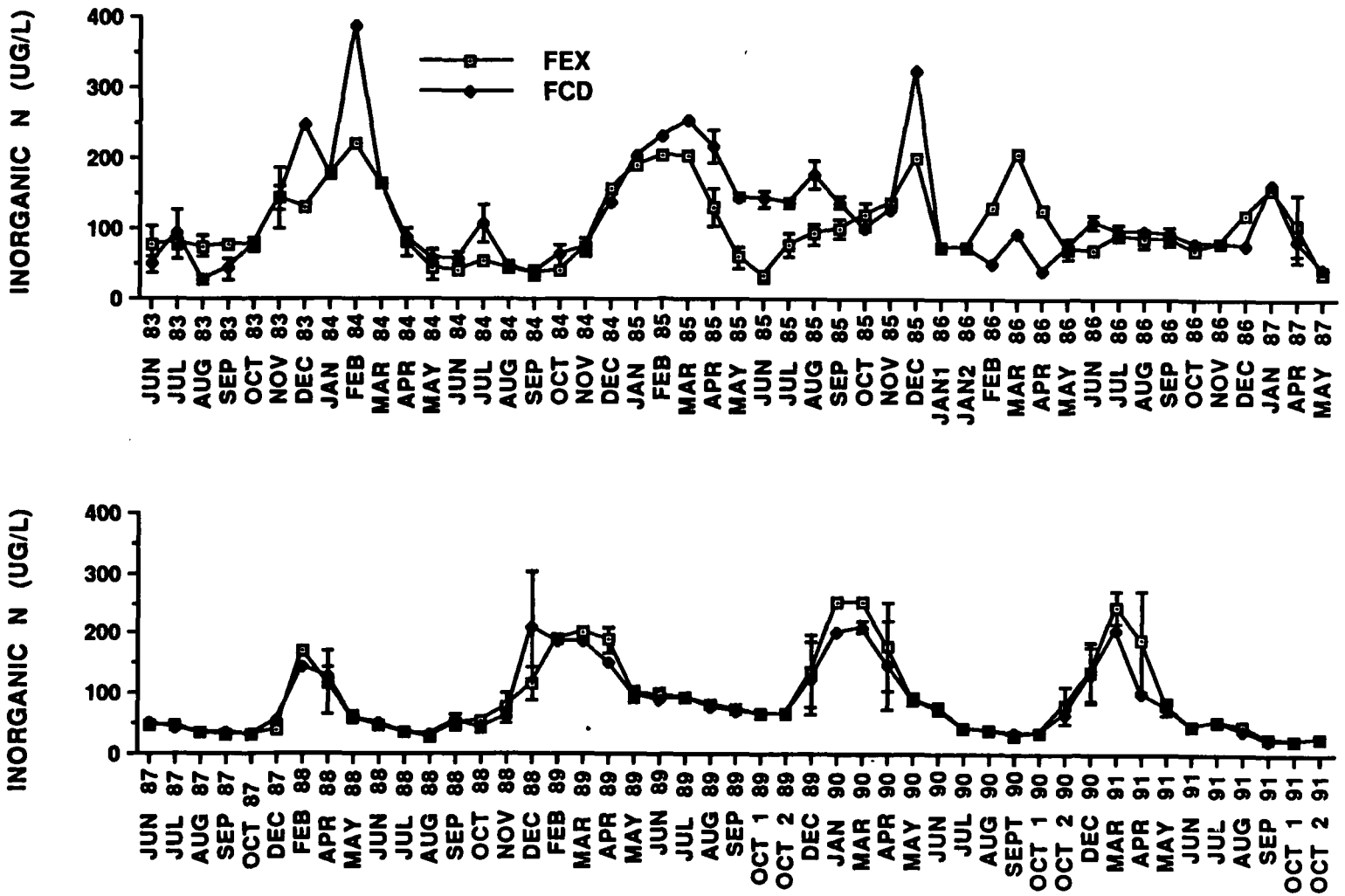

FIGURE 1.14 MEAN INORGANIC NITROGEN CONCENTRATION (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES. 1983-1991.

Table 1.10 Inorganic-N (µg N/L) for the Ford River for 1991. Values are Means ± S. E., N in parentheses.

Date	Inorganic Nitrogen	
	Experimental (FEX)	Control (FCD)
1/19/91	216.60 ± 0.00 (1)	205.10 ± 0.00 (1)
3/3/91	244.90 ± 28.30 (2)	205.10 ± 0.00 (1)
4/22/91	189.90 ± 83.30 (2)	101.20 ± 0.00 (1)
5/20/91	80.39 ± 13.56 (9)	78.20 ± 12.87 (9)
6/17/91	47.98 ± 3.68 (8)	46.13 ± 4.37 (8)
7/15/91	56.17 ± 3.23 (8)	55.46 ± 3.53 (8)
8/12/91	46.48 ± 5.64 (8)	40.39 ± 3.49 (8)
9/9/91	26.40 ± 2.04 (8)	24.93 ± 1.72 (8)
10/7/91	24.44 ± 2.36 (9)	21.81 ± 2.02 (9)
10/28/91	25.57 ± 4.70 (7)	27.29 ± 6.65 (7)

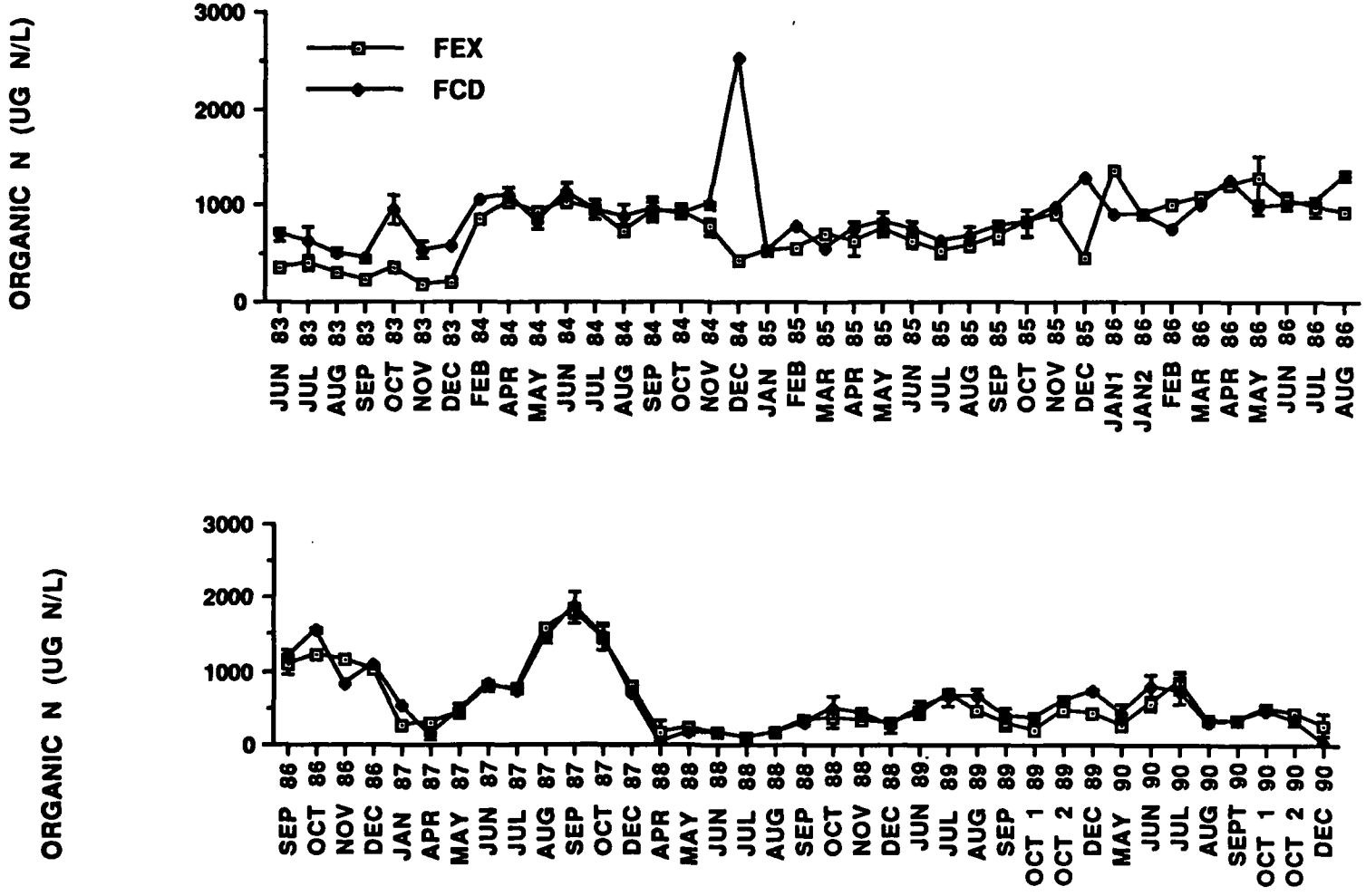

FIGURE 1.15 MEAN ORGANIC NITROGEN CONCENTRATION (±S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES. 1983-1990.

The differences between sites prior to 1987 resulted in overall differences when all data were compared for 1983-1990 (Table 1.7). 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). Measurement of organic nitrogen was discontinued following 1990.

Silicate-Si was quite similar between FEX and FCD in 1993 (Tables 1.8, 1.11, Fig. 1.16). There was no significant differences in silica between the sites for either 1993 or the 1983-1993 periods (Table 1.8). Concentrations at FEX were significantly correlated with concentrations at FCD in 1993 (Table 1.8) and for 1983-1993. (Table 1.7). Overall, concentrations have remained relatively steady in the range of 6 to 10 mg Si/L throughout most of each year studied, except during periods of dilution that have occurred during high flows in April or May most years and during other periods of high discharge (Fig. 1.16, 1.5, 1.6).

Chloride at FEX was significantly different from chloride at FCD for the 1983-91 period (Table 1.7, 1.11, Fig. 1.17). Values for the two sites were significantly correlated for the 1983-91 period (Table 1.7). Concentrations of Cl have been slightly higher at the upstream site (FEX) for most years of the study than they have been at the downstream site (FCD) (Fig 1.17). This gradient may indicate some slight residual effects of chloride inputs from road salting near Channing, MI with dilution of these inputs in a downstream direction. However, concentrations even at the upstream (FEX) site 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). Chloride determination was discontinued in 1991.

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. In 1993 physical parameters were monitored from mid-May through August.

Solar radiation (PAR) was highly variable using the 30 minute interval data (Fig. 1.18). 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

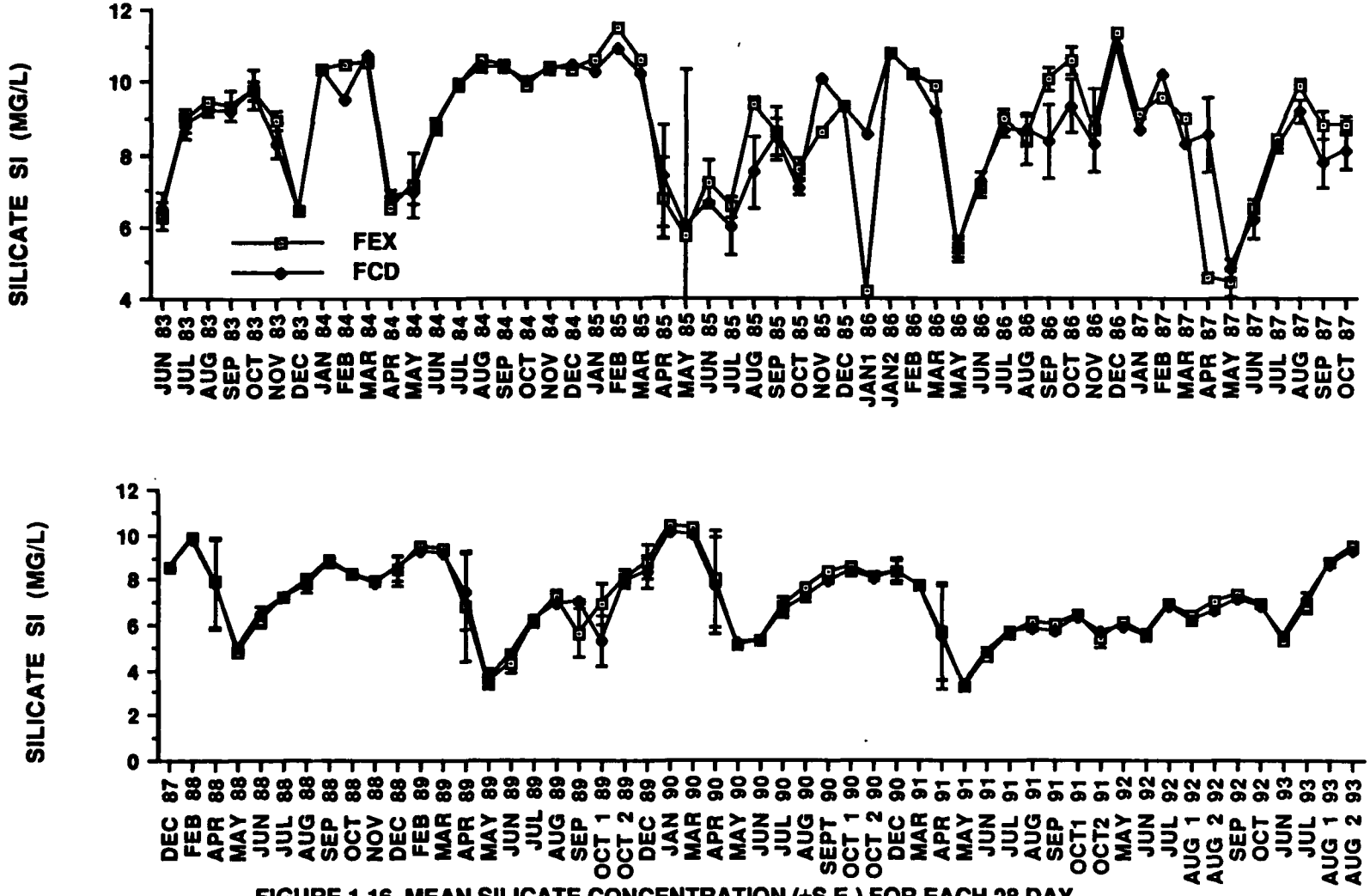

FIGURE 1.16 MEAN SILICATE CONCENTRATION (±S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1993.

Table 1.11 Dissolved Silica (mg Si/L) for the Ford River for 1993. Values are Means ± S.E.,N in Parentheses.

DATE	Silica	
	Experimental (FEX)	Control (FCD)
6/7/93	5.25 ± 0.08 (9)	5.53 ± 0.05 (9)
7/6/93	6.77 ± 0.26 (9)	7.11 ± 0.29 (9)
6/2/93	8.78 ± 0.21 (9)	8.69 ± 0.17 (9)
8/27/93	9.44 ± 0.20 (10)	9.28 ± 0.16 (10)

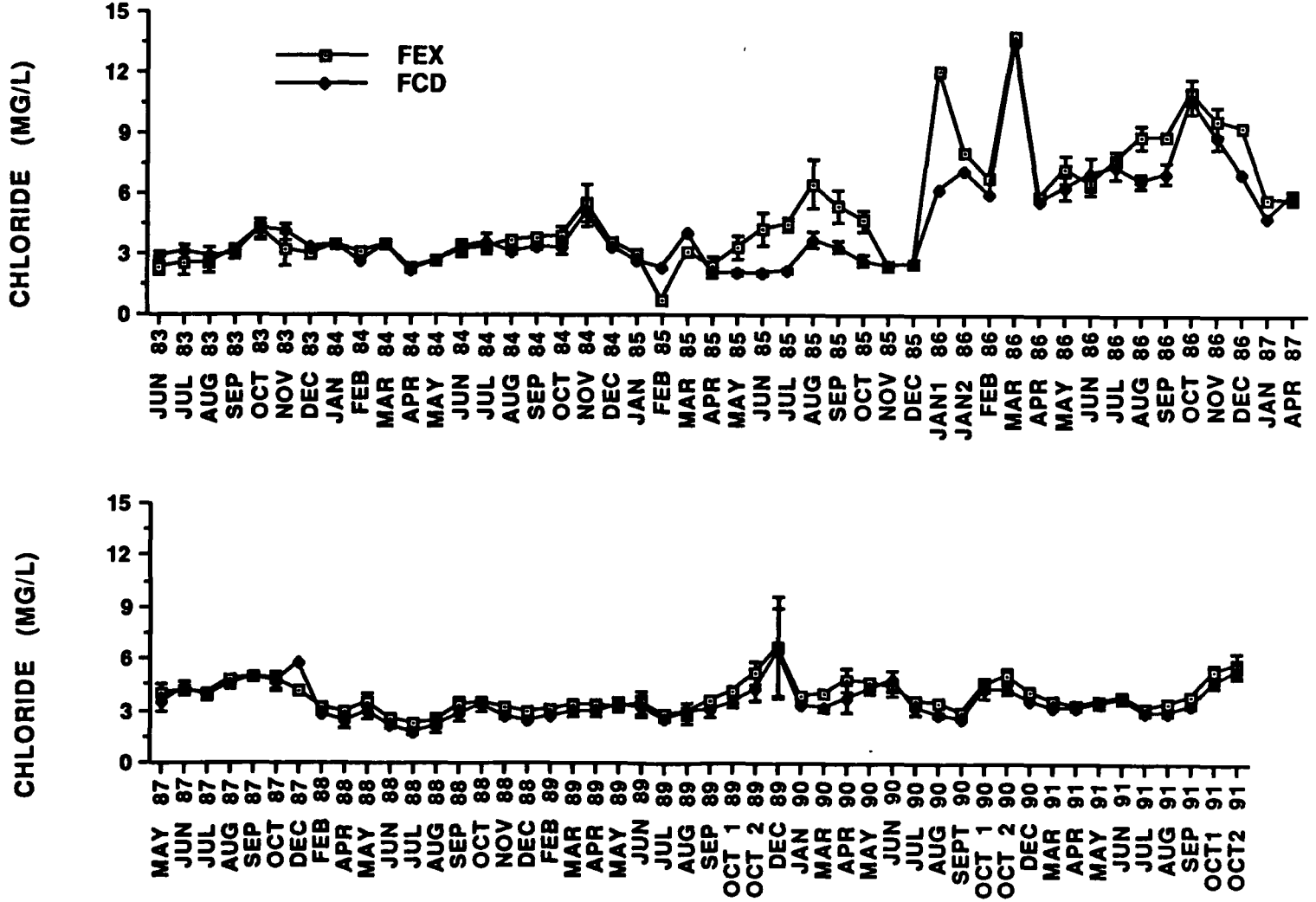

FIGURE 1.17 MEAN CHLORIDE CONCENTRATION (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1991.

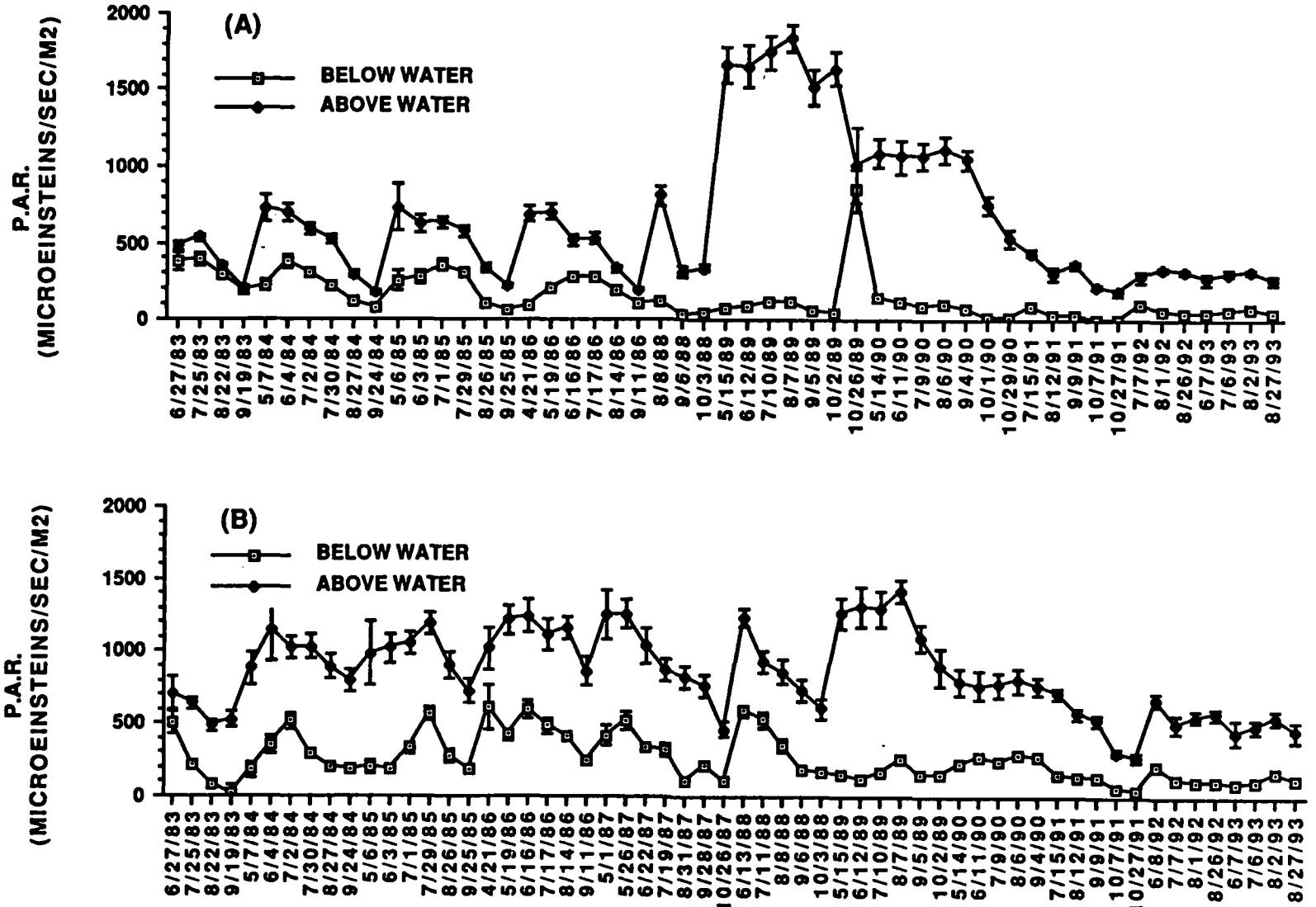

FIGURE 1.18 PHOTOSYNTHETICALLY ACTIVE RADIATION (P.A.R.))(±S.E.) BETWEEN 10:00 AND 14:00 FOR 1983-1993.(A) FCD SITE, (B) FEX SITE

period from 1000 to 1400 hours daily (Fig. 1.18). Prior to 1990, we have a good record of PAR value at FEX, but a gap in above water PAR data at FCD does exist. 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 for both sites in correlations of above water solar PAR with biological parameters such as algal productivity. Since data are collected in an open area, the only difference between sites should be related to differential cloudiness. These differences are not likely to be very large. This approach results in data for each 28 day period for open, unshaded areas of the river. While the diatom sites at both FEX and FCD are selected to be as open as possible, this approach overestimates actual PAR received. Underwater PAR is also monitored near the ambient monitoring station rather than directly at the level of the diatom collectors. In both instances, above and below water PAR can only serve as indices of actual PAR received at the river surface above the diatom collectors and underwater at the the collectors rather than as actual measurements of PAR exposure received. No actual exposure data exists due to cable limitations (the cables that link the solar probes to the data pods are not long enough to obtain actual measurements). We have used FEX data in most years as an index of PAR exposure at both sites. In 1990, the FEX above water solar probe failed, and we used a conversion factor of 0.723 to convert FCD data to an estimate of what FEX data would have been (this conversion factor was developed in 1989 using data collected at the same time at both sites). The data for 1993 indicates an overall decrease of PAR at both sites compared to previous years (Figure 1.18, 1.19).

Air and water temperature have been monitored since 1983 and are available as needed. The water temperatures for 1992-1993 were comparable to those in previous years, (Fig. 1.20, 1.21). Winter sampling was discontinued following the completion of the 1991 field season. The average temperature data for the 28 day exposure periods for the benthic algal sampling are summarized in Fig. 1.21. These data illustrate that average summer temperatures have been less than 20o C for every summer except 1983 and 1988 with 1988 attaining the highest average temperatures since the start of the study.

Stream discharge data have already been presented for the 28 day benthic algal exposure periods (Fig. 1.5) and for mean daily values for 1993 (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 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

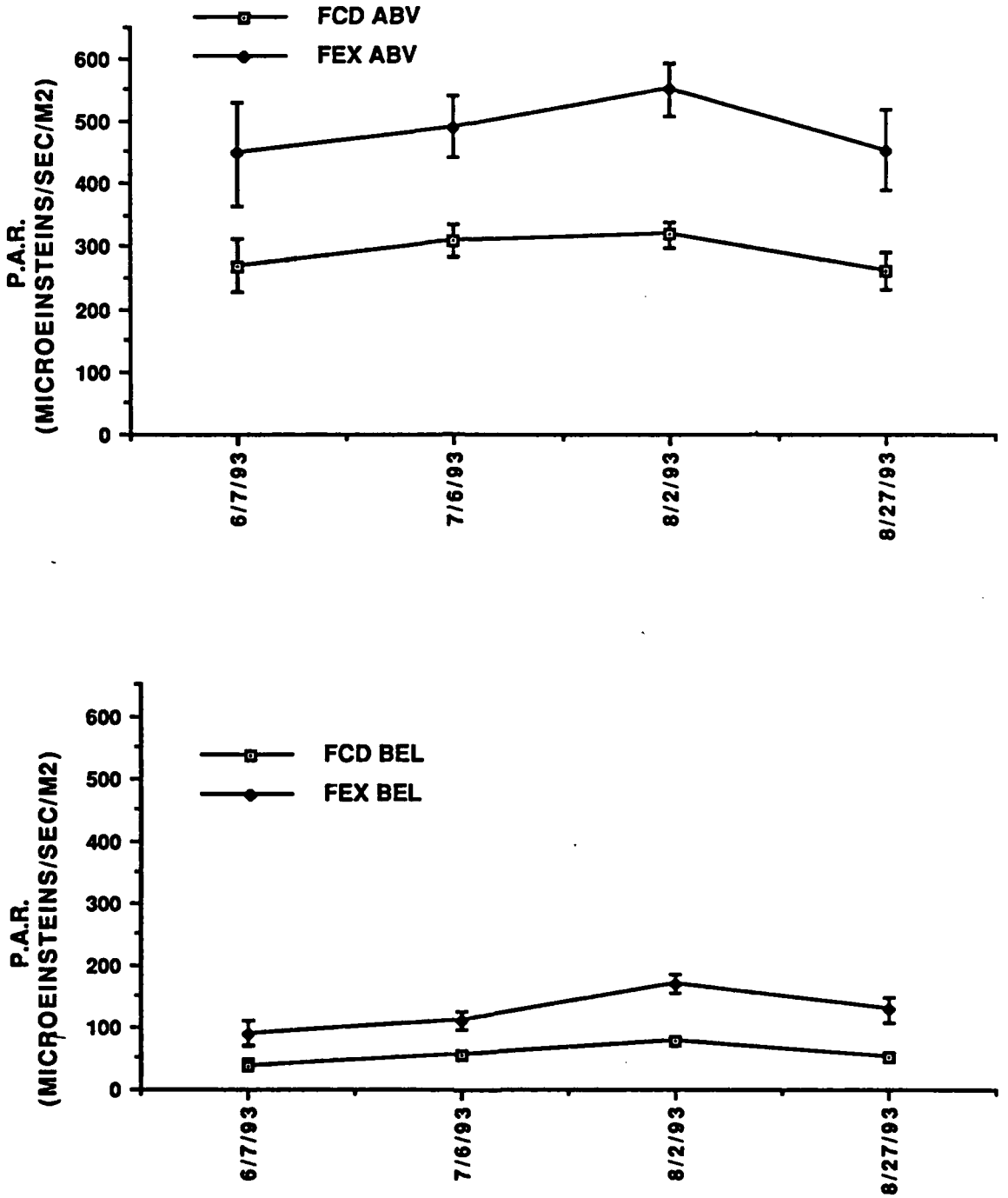

FIGURE 1.19 MEAN SOLAR RADIATION (±S.E.) BETWEEN 10:00 AND 14:00 FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1992-93.

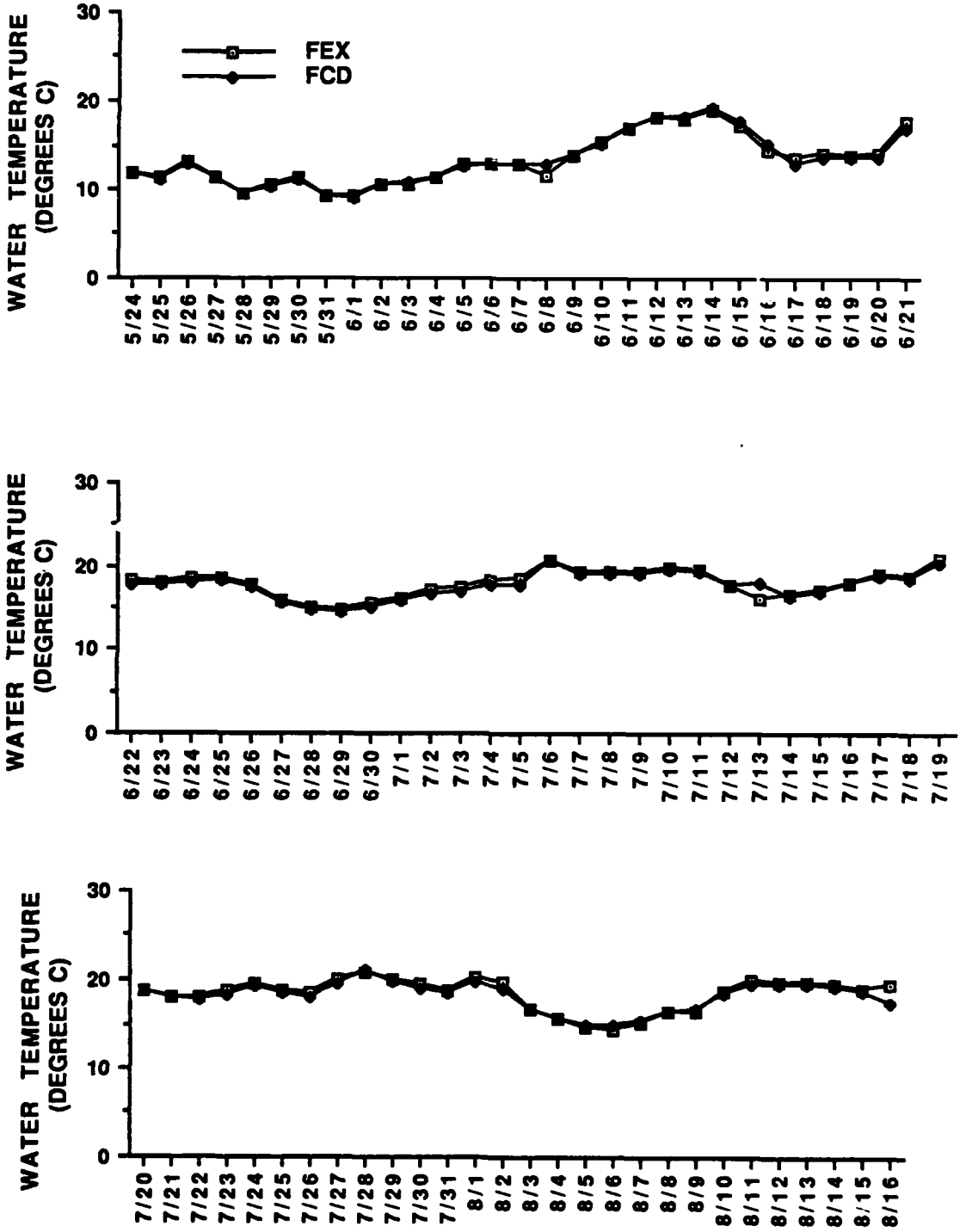

FIGURE 1.20 DAILY WATER TERMPERATURE MEANS FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES FOR 1993.

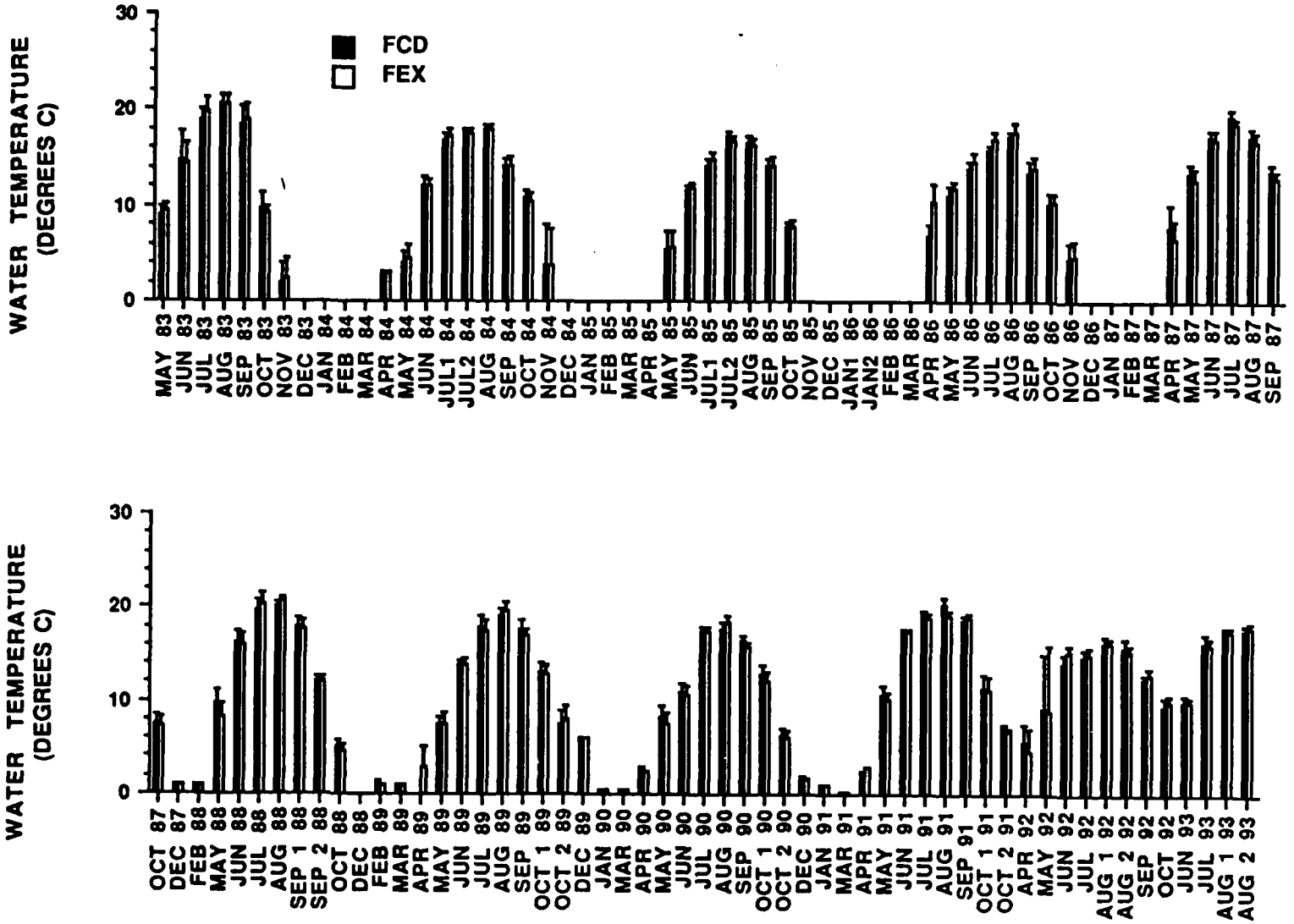

FIGURE 1.21 MEAN WATER TEMPERATURE(±S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1993.

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.

Stream velocities were measured at all four periphyton sites from September, 1992 to August, 1993 (Figure 1.22). These data aided in the placement of periphyton samplers, so that all slides were exposed to similar flow regimes. Except for several high discharge dates during the year, water velocities were within an average of five cm/sec of one another at all four sites.

We have used data from the National Weather Service's nearest stations at Crystal Falls and/or Iron Mountain, MI to calculate the time that has lapsed between the time of removal from the river of each set of 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/Iron Mountain data may not be precise for the Ford River, we have collected supplemental rainfall data for each site for the last several summers (Fig. 1.23) and will include these data in future regressions and correlations.

Exposure to ELF electromagnetic radiation is presented as total exposure for each periphyton sample (usually a 28 day period) for earth electric field exposure (Figs. 1.24, 1.25) and magnetic flux exposure (Figs. 1.26, 1.27). This time period is reasonable for periphyton since new slides are colonized by algae for this time. However, other exposure data may be more appropriate for longer lived insects and fish.

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 a slight increase in a downstream direction. This trend of slight increase from the upstream site to the downstream site for hardness, alkalinity, tubidity, and in some years for nitrate, and ammonium may be related to an expected accumulation of dissolved load in a downstream direction or to local land use

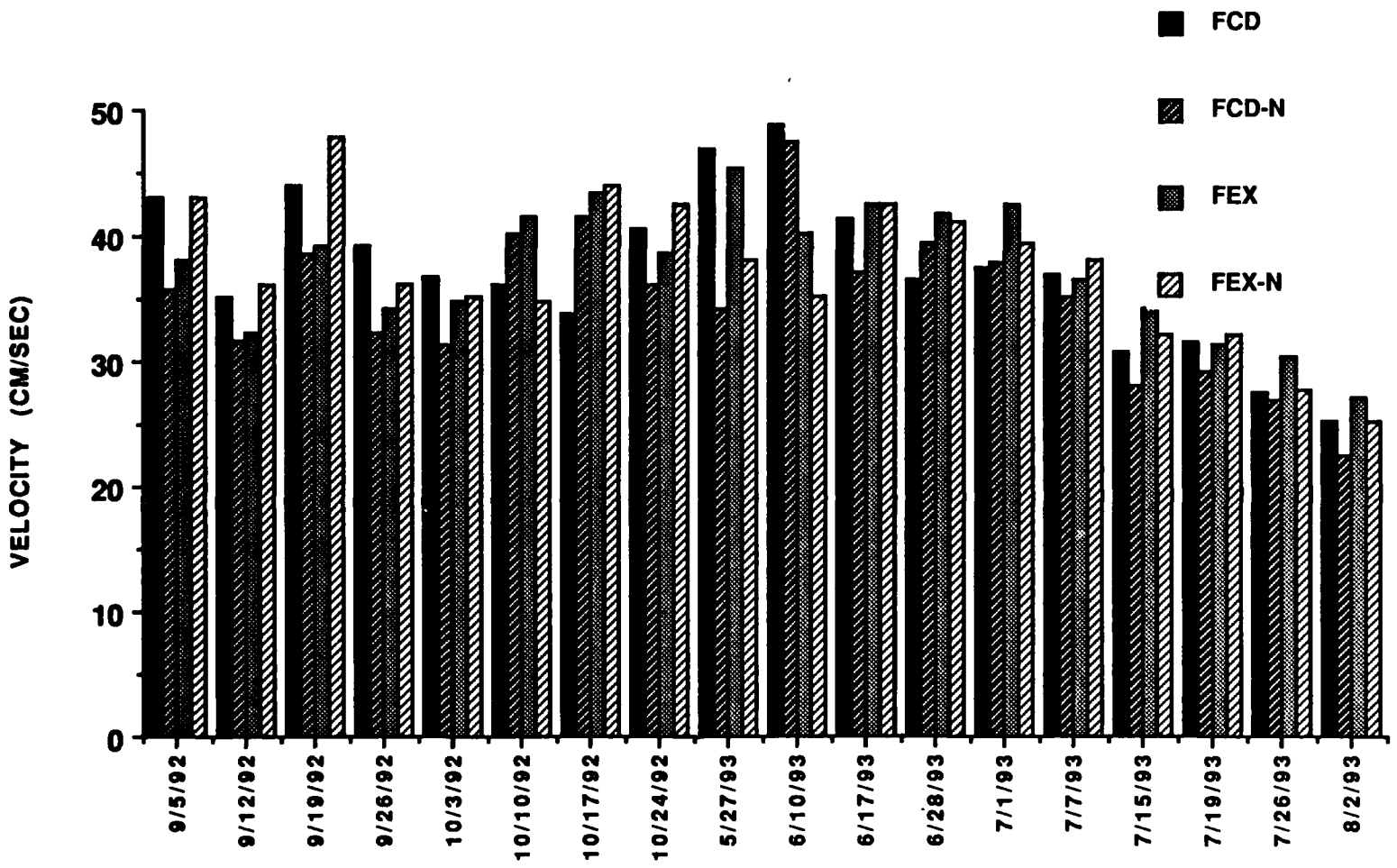

FIGURE 1.22 WATER VELOCITIES AT PERIPHYTON SAMPLERS FOR 1992-1993.

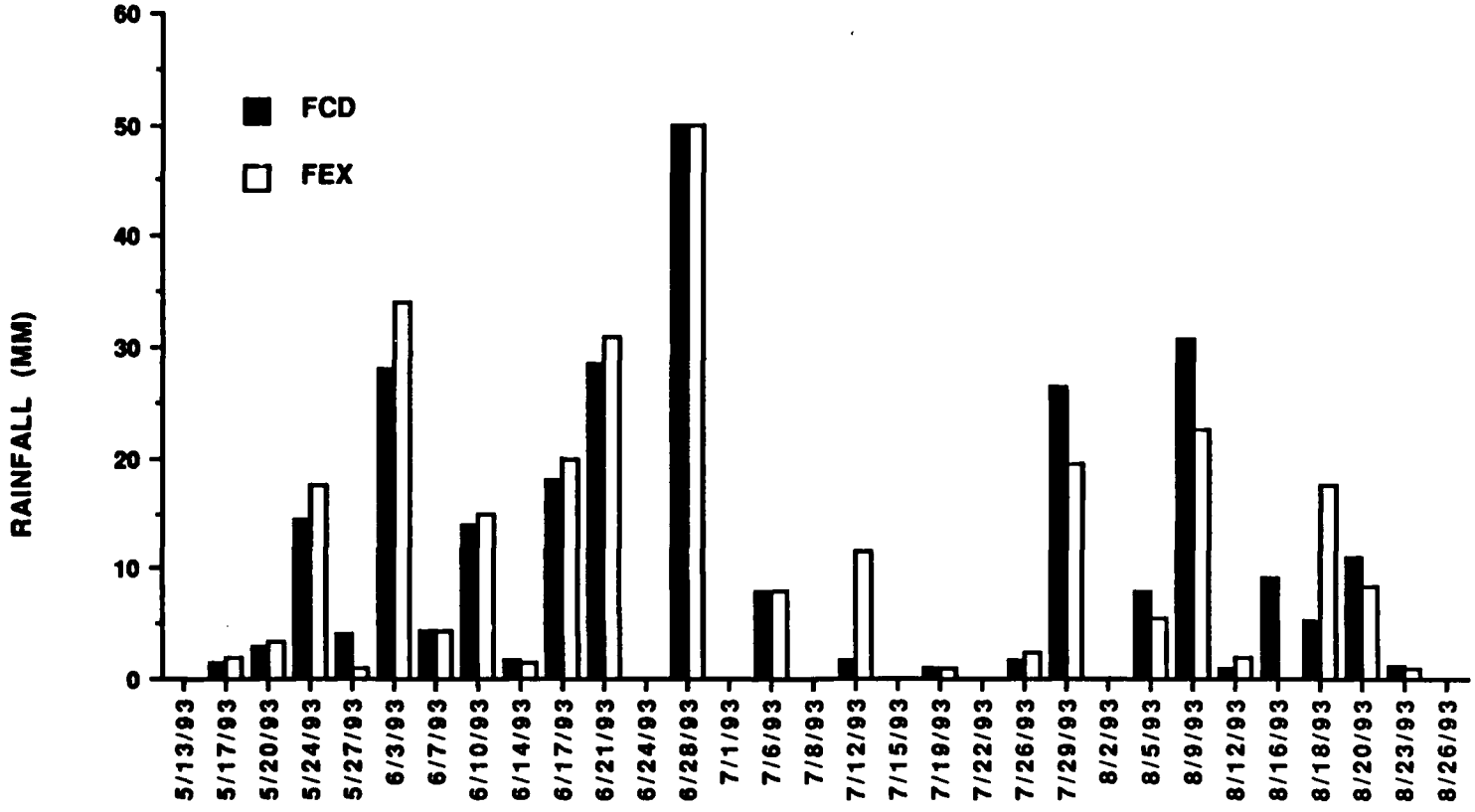

FIGURE 1.23 DAILY RAINFALL AMOUNTS FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES FOR 1993.

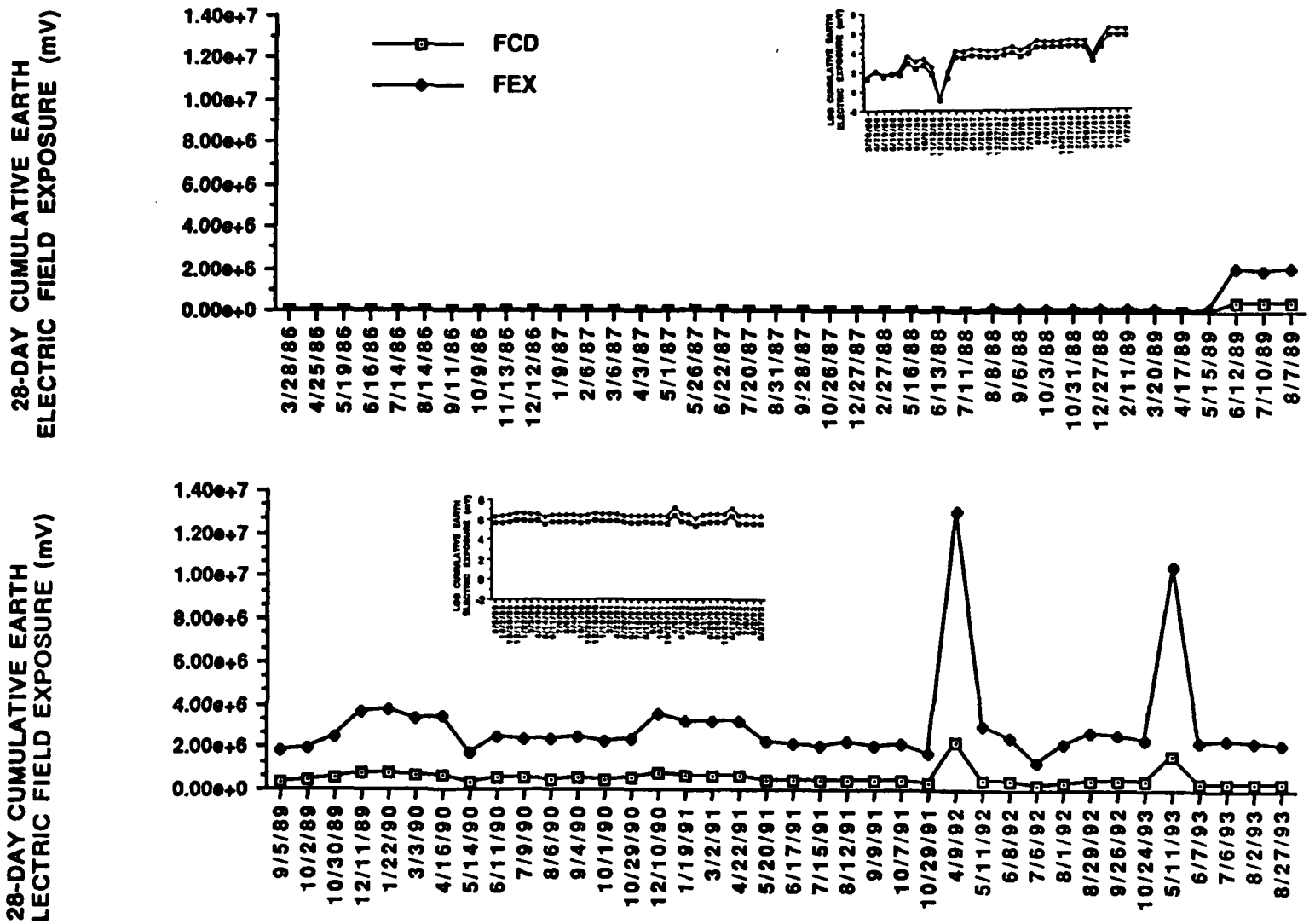

FIGURE 1.24 TOTAL EXPOSURE OF PERIPHYTON TO EARTH ELECTRIC FIELDS FOR EACH SAMPLE COLLECTED FROM THE (FEX) AND CONTROL (FCD) SITES, 1986-1993. THE INSET SHOWS THE LOG TRANSFORMATION OF THE EXPOSURE DATA. THE 4-9-92 AND 5-11-93 DATA POINTS WERE CALCULATED FOR SLIDES LEFT IN THE RIVER ALL WINTER RATHER THAN THE NORMAL 28 DAY INTERVAL.

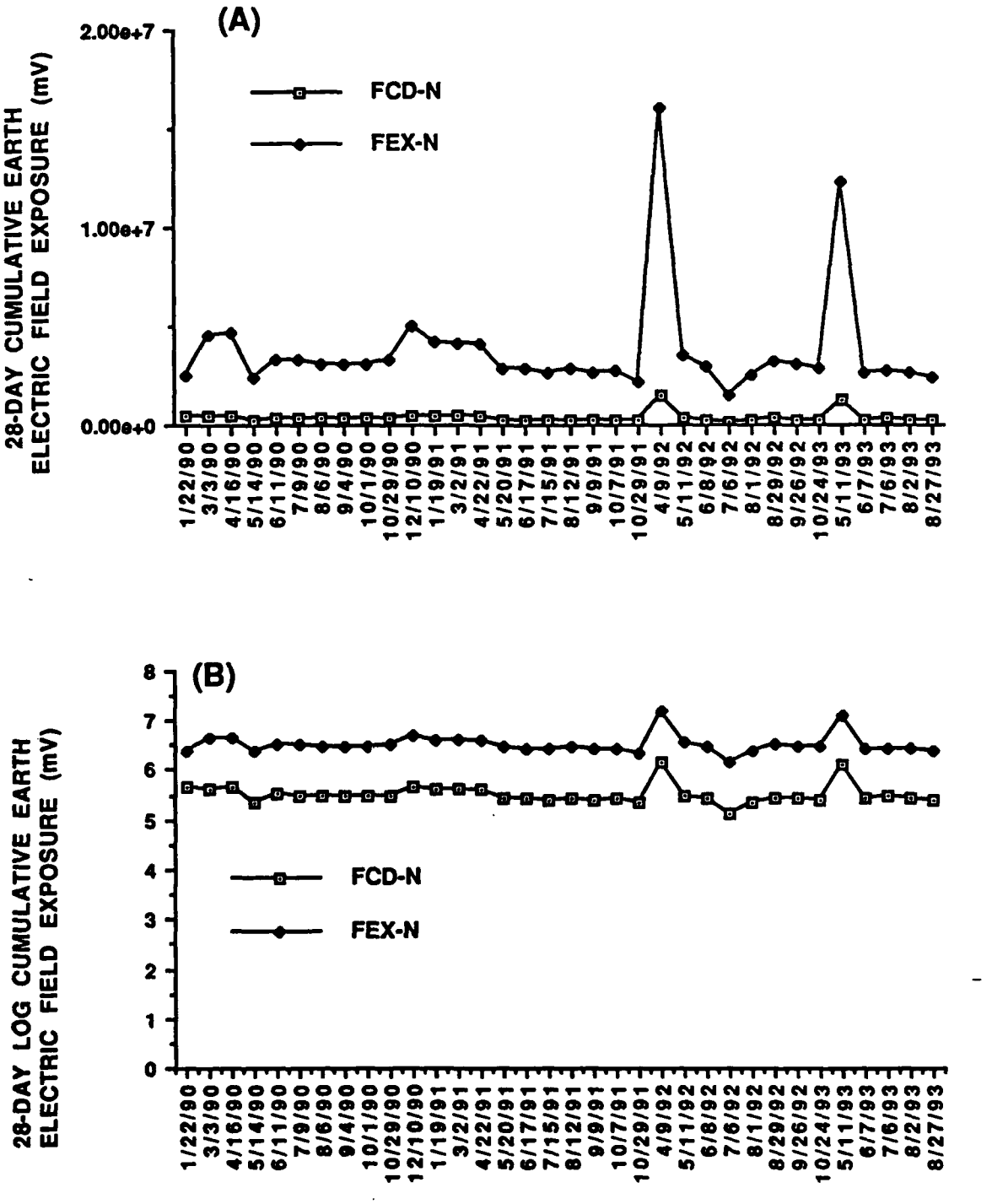

FIGURE 1.25 TOTAL EXPOSURE OF PERIPHYTON TO EARTH ELECTRIC FIELDS FOR EACH SAMPLE COLLECTED FROM THE FEX-N AND FCD-N SITES, 1990-1993; (A) UNTRANSFORMED EXPOSURE DATA, (B) LOG TRANSFORMED EXPOSURE DATA. THE 4-9-92 AND 5-11-93 DATA POINTS WERE CALCULATED FOR SLIDES LEFT IN THE RIVER ALL WINTER RATHER THAN THE NORMAL 28 DAY INTERVAL.

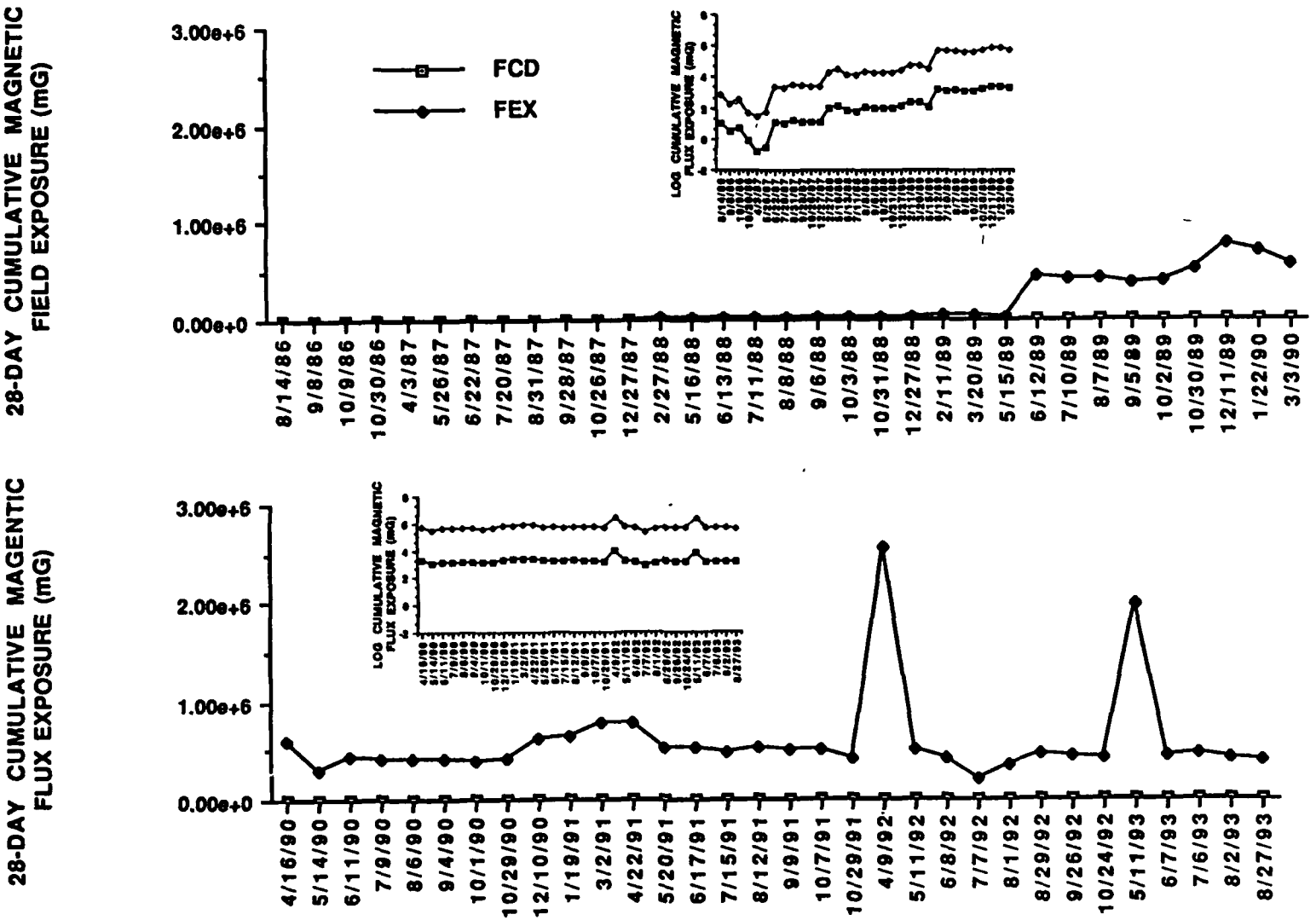

FIGURE 1.26 TOTAL EXPOSURE OF PERIPHYTON TO MAGNETIC FLUX FOR EACH SAMPLE COLLECTED FROM THE EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1986-1993. THE INSET SHOWS THE LOG TRANSFORMATION OF THE EXPOSURE DATA. THE 4-9-92 AND 5-11-93 DATA POINTS WERE CALCULATED FOR SLIDES LEFT IN THE RIVER ALL WINTER RATHER THAN THE NORMAL 28 DAY INTERVAL.

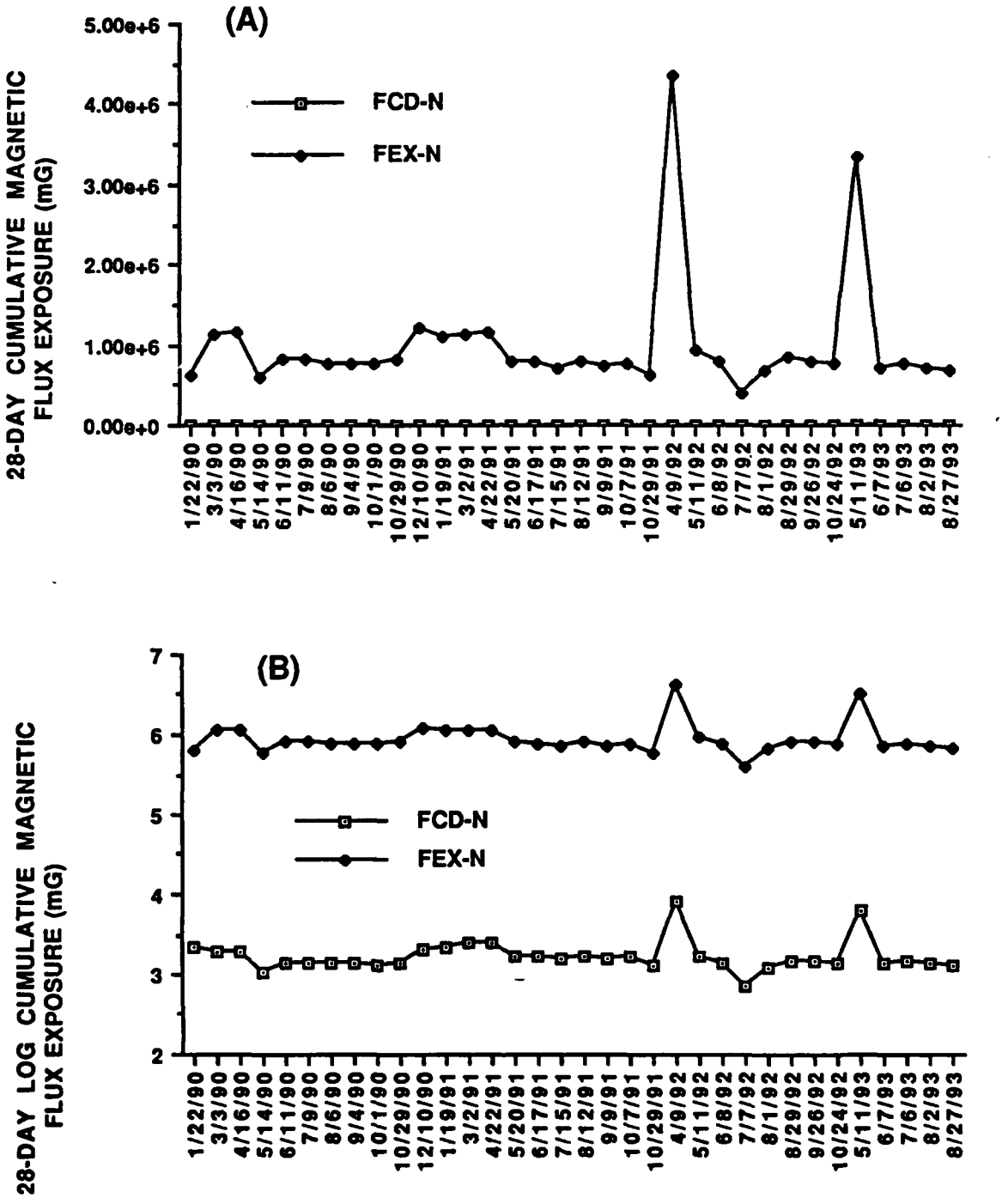

FIGURE 1.27 TOTAL EXPOSURE OF PERIPHYTON TO MAGNETIC FLUX FOR EACH SAMPLE COLLECTED FROM THE FEX-N AND FCD-N SITES, 1990-1993; (A) UNTRANSFORMED EXPOSURE DATA, (B) LOG TRANSFORMED EXPOSURE DATA. THE 4-9-92 AND 5-11-93 DATA POINTS WERE CALCULATED FOR SLIDES LEFT IN THE RIVER ALL WINTER RATHER THAN THE NORMAL 28 DAY INTERVAL.

differences between sites. Whatever the cause, the differences were small and probably would not lead to significant inter-site differences in productivit . We initiated 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.

Chloride 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 prior to 1991. The differences that did occur were slight and should have little impact on site productivity.

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Element 2 - Periphyton Studies.

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, 1989-90, and 1990-91 to provide an additional winter data set. This additional data set proved necessary because of our past approach of analyzing the data on both an annual and summer/winter basis. Winter sampling was discontinued completely following October 1991 due to financial and logistical constraints.

The chlorophyll a to phaeophytin a ratio was eliminated after the 1988-89 reporting year. It was reported in the past as an indicator of the physiological health of the algal community. The high variabilities encountered in this index made its usefulness in detection of ELF effects questionable.

Two new monitoring sites for this element were added 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 mean ELF exposure rate (based on annual measurements from 1989 to 1993) at FEX under full antenna power is 61 mV/m resulting in an exposure that is only 5.5 times greater than the exposure rate of 11.0 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 5C1-3 and 5T2-7 respectively) were added on May 15, 1990. The exposures of 7.4 mV/m at FCD-N and 76 mV/m at FEX-N result in a 10.3 fold difference in exposure between the two sites (FEX-N/FCD-N = 10.3). 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). Note that our FEX-N site is within 5 m of FEX-LINE, the new site used for insect studies. The insect FCD site has also been moved to within 10-15 m of our own FCD-N site.

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 5.5 fold increase in ELF exposure and to a high of an 10.3 fold increase in ELF exposure within 10 m of the antenna crossing. We have presented all data collected (Oct. 1991 to present) at each of the new sites and have analyzed the new data using paired t-tests. The additional person hours required to monitor all four sites were available because of the elimination of the study of periphyton-grazer interactions in Element 3.

We have completed our sampling program for the eleven year study. Our final algal samples were taken in August, 1993.

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 1985, 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 diatom 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 algal 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 a reduction in 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.

Studies that use comparisons between a single control and reference site have a potential problem with pseudoreplication (Stewart-Oaten et al. 1986, Carpenter et al. 1989). In 1986 and 1987, we investigated a new statistical procedure designed by Stewart-Oaten et al (1986) to overcome the potential problem of pseudoreplication. We investigated 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. Since 1989, we have continued the BACI analysis by adding additional data to the previous comparisons and have expanded the analysis to include: accrual rates, photosynthesis/respiration studies and abundances of individual algal species. This analysis has proved to be quite informative and is continued for 1993. In 1990, we introduced Randomized Intervention Analysis (RIA) (Carpenter et al. 1989) as an additional means of analyzing biological and diatom abundance data. We compared these two procedures based on data collected through 1990 (Eggert et al. 1992) and published the results of this comparison (Burton et al. 1992). Randomized Intervention Analysis is particularly useful when a particular data set does not meet one or more of the assumptions of the BACI analysis. Both the BACI and RIA analyses are techniques that can demonstrate that a change in before manipulation and after manipulation responses of

parameters between sites has taken place, but they cannot unequivocally attribute the change to the applied manipulation (Cooper and Barmuta 1993, Eggert et al. 1992). Both procedures also require multiple years of before and after data. Even so, differences that are detected may be due to differential responses to something other than the mamipulation being studied (Cooper and Barmuta 1993) such as weather (Eggert et al. 1992).

Our rationale has been to provide multiple data sets taken independently to be used in determinations of structural and functional indices. By incorporating several methodologies, we hope 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, 1989 and 1990) 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 mm^2 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 200-500 frustules were counted (200-350 valves were counted prior to 1988; counts were increased to 500 in 1988 to decrease variance in counts). Estimates of diatom densities were then calculated from these quantitative samples via the equation:

$$\text{Cells } m^2 = \frac{(\text{Valves Counted})(\text{Area Coverslip})(\text{Volume Concentrate})}{2\,(\text{Area Transect})(\text{Volume Subsample})(\text{Area Sampled})}$$

Diatom species composition was recorded for each slide counted for determination of species richness, Shannon 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.

Analyses for chlorophyll a followed the fluorometric determination described in Methods 1003C and 1002G in Standard Methods (APHA 1985). 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 1985).

Organic matter biomass determinations were conducted following procedures 1003D for productivity estimates in Standard Methods (APHA 1985). While using the gain in ash-

free dry weight per unit area as a measure of net bacterial and algal production (APHA 1985), 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 (Oemke and Burton 1986) 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 even though we have some concern with pseudoreplication (Hurlbert 1984) and have gone to BACI and RIA analyses because of these concerns. Paired t-test comparisons of all parameters for the "before" antenna operation period from June 1983 to May 1986 and the "after" operation at full power period from June 1989 through August 1993 will be presented in this report. We have not included the transitional antenna testing period in this report. 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. This analysis may also suffer from lack of true replication (Hurlbert 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 differences 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. According to Stewart-Oaten et al (1986), the independence of error assumption required by the BACI analysis may be considered to be "plausible if large, local, long-lasting random effects are unlikely". While our initial analysis of the data, as well as our sampling regime of 28-day independent measurements indicated that the assumption had been appropriately met, any possible serial correlations were checked for using the Durbin-Watson (1951) test. The second criterion 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 examined seasonal variations of chlorophyll a and AFDW-biomass standing crop and production, cell volume, biovolume, cell density, species diversity, evenness, and diatom abundance. BACI analysis was performed on data sets of ice-free months (April-October) and on data sets of months in which Cocconeis placentula was the dominant species. We have a very complete data set for the ice-free periods from the beginning of the study to present. Our winter data set is not as complete since winter sampling was done from 1983 through 1991 but was discontinued thereafter. By emphasizing the ice-free periods rather than the complete year-round data set we are avoiding comparing "before" and "after" data sets not matched well seasonally (Smith et al 1993). By analyzing months in which Cocconeis placentula is dominant we are assured of comparing a similar summer diatom community between years. Cocconeis placentula is the species that best represents the summer diatom community due to its summer abundance. The months used in this comparison are July-September, 1983, 1984, and 1985, versus July-October 2. 1989, August-October 1, 1990, June-October 7, 1991, and July-August 1992 and 1993. All time intervals prior to May, 1986 represent the "before" period. The "transitional" 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. Our "after"

period consisted of all data collected from June 1989 to present. This date was altered from the October 1989 date used in past reports in order to include several months in which the antennae was operated very close to full power. Note that this after period corresponds to a stepwise increase in exposure to electric (Fig. 1.24) and magnetic fields (Fig. 1.26) between the 28 day sampling period that ended in May and the 28 day period that ended in June 1989. Using the BACI design we ran comparisons on all the biological data for the ice-free periods and the periods when Cocconeis placentula was dominant; i.e. sampling dates in 1983, 1984, 1985, and 1986 as the "before" period, and dates in 1989, 1990, 1991, 1992 and 1993 as the "after" period (For biovolume, cell volume, cell density, and diatom relative abundance, BACI analyses are complete through August 1992. BACI analysis will be performed through August 1993 for these parameters in the final report).

Beginning in 1990, we 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 was calculated from both the "before" and "after" data sets. The absolute value of the difference between these means represented the test statistic. Random permutations of the time series of inter-site differences provided an estimate of the distribution of the test statistic. In effect, we 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, determined whether a significant change had 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. The protocol used with BACI of considering data only from ice-free periods and from periods in which Cocconeis placentula was dominant, was also followed for RIA.

By using a randomly created error distribution, the RIA design eliminated 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, reduces 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. This was not

a problem with the majority of the data sets analyzed with RIA, except for the comparisons of the Cocconeis placentula dominant periods, in which the sample size was approximately 25.

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 and is applicable for most studies of this type.

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. In response to reviewer's comments in 1990, we have also added a power analysis of each of our biological parameters. A power curve was developed using the mean and standard errors associated with each summer and winter 1983-1990 data set at the control site. A power function provides information regarding the probability of correctly rejecting the null hypothesis of no significant difference at $p < 0.05$ level between the control and experimental sites for a set of assumed values of a biological parameter (Pfaffenberger and Patterson 1981). In order to standardize each power curve so comparisons could be made between parameters, power was calculated for specific percent changes in means for each biological parameter. Power was then plotted against the percent change in mean for each parameter. Ideally, the power of a function will rise very rapidly from zero as the percent change in observed mean departs from the true mean for a given biological parameter. Both the minimum detectable difference and power analysis will allow us to identify the parameters most likely to detect any changes in the inter-site relationship over time.

In previous years we have used analysis of covariance (ANCOVA) with the ELF exposure data, presented in element 1, as the covariate to directly assess the effects of ELF exposure on the biological parameters. ANCOVA, as calculated in this study, provided a means of standardizing the values of each parameter at the two sites for the inter-site differences in ELF exposure, and permitted us to compare the standardized values between sites. This allowed 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

detected a significant difference between the sites. In previous years, we used 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 did not differ from the results of the paired t-test on the same data set, we concluded 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.

Upon further investigation of this procedure however, there is some doubt as to whether ELF exposure represents a valid covariate. Steel and Torrie (1960) states that ANCOVA was intended for use when the independent variable, or covariate, measures environmental effects not accounted for in the experimental design and is not influenced by treatments. In this study. ELF exposure is our treatment, thus possibly making ELF exposure an inappropriate covariate. Steel and Torrie (1960) then went on to say that if the covariate is influenced by the treatments, adjustments made by the ANCOVA calculations would remove part of the treatment effect. They urged that care be taken in the interpretation of the data. Based on reviewers' comments we have determined that our usage of ANCOVA with ELF exposure as a covariate is inappropriate, and have eliminated those analyses from this report.

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, 30% in 89-90, 45% in 90-91, and 26% in 91-92. AFDW-biomass had C.V.'s that averaged 40% in 84-85, 64% in 85-86, 45% in 86-87, 48% in 87-88, 36% in 88-89 and 89-90, 45% in 90-91, and 30% in 91-92. 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, 18% in 89-90, 11% in 90-91, and 11% in 1992 (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 this report include low flow, Cocconeis placentula dominated time periods and enable us to better 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, 2% in 89-90, 4% in 90-91, and 4% in 91-92. For species evenness C.V.'s averaged 7% in 85-86, 6% in 86-87, 4% in 87-88, 5% in 88-89, 2% in 89-90, 3.5% in 90-91, and 4% in 91-92. 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 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 (also see Oemke and Burton 1986). 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 1985; 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 between 1987-1990, 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 for the above parameters from 1983-1993, 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. During 1988-89, 1989-90, and 1990-91 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 September, 1992 through August, 1993 followed annual patterns of summer peaks and winter lows (Fig. 2.1, Table 2.1). In general, values at the new FEX and FCD sites paralleled those of FEX and FCD, respectively (Table 2.1). Annual patterns have indicated that chlorophyll a peaks during the summer months of July or August, although in 1989, 1990, and 1991 the highest chlorophyll a standing crops occurred in May, perhaps because of relatively sunny and warm weather during those years in May. In 1993, the highest chlorophyll a standing crop at all four sites occurred in August (Table 2.1). Chlorophyll a levels have varied from year to year, but there appears to be no consistent pattern of highs occurring before or after the antenna went operational at the contol site (Fig. 2.1). For example, the highest values averaged over the entire summer period include a before summer of 1983, a transitional summer of 1988, and an after summer of 1989 (Fig. 2.1). The period from 1984 through

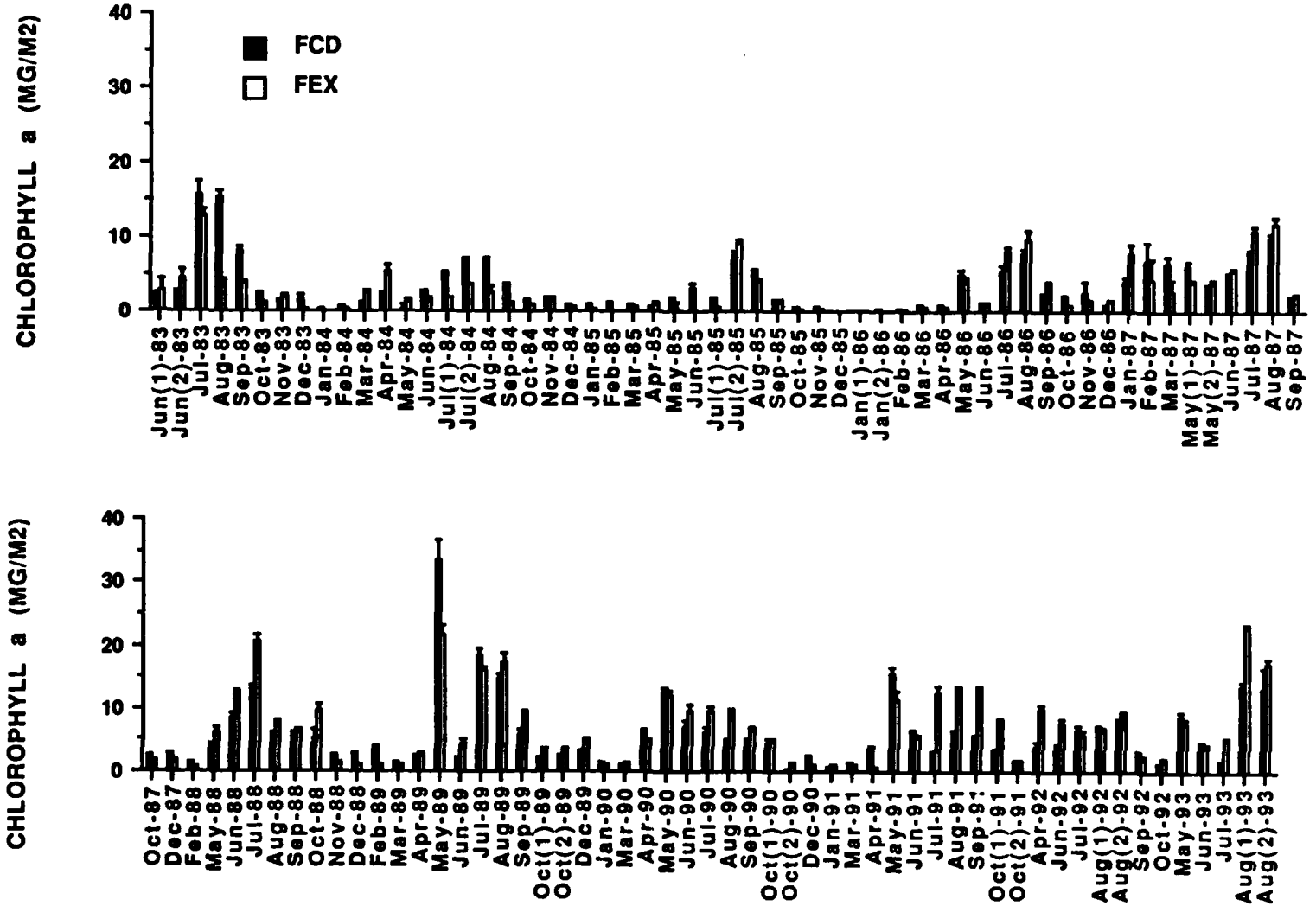


FIGURE 2.1 CHLOROPHYLL a STANDING CROP FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES ON THE FORD RIVER, 1982-1993.

Table 2.1 Chlorophyll *a* (mg/m^2) for Experimental (FEX and FEX-N) and Control (FCD and FCD-N) sites for 1992-1993. Values are Means ± S.E, N in parentheses.

Date	Experimental		Control	
	FEX	FEX-N	FCD	FCD-N
9/26/92	2.17 ± 0.28 (10)	1.53 ± 0.11 (9)	2.90 ± 0.27 (10)	1.96 ± 0.19 (9)
10/24/92	1.92 ± 0.17 (10)	1.78 ± 0.22 (10)	1.18 ± 0.21 (10)	3.38 ± 0.32 (10)
5/11/93	7.58 ± 0.96 (11)	6.21 ± 1.72 (4)	8.64 ± 0.95 (10)	9.04 ± 0.82 (10)
6/7/93	3.87 ± 0.40 (10)	4.88 ± 0.73 (10)	4.41 ± 0.48 (9)	4.18 ± 0.48 (10)
7/6/93	5.29 ± 0.23 (10)	3.64 ± 0.35 (10)	1.67 ± 0.10 (10)	1.83 ± 0.18 (10)
8/2/93	23.05 ± 0.41 (10)	19.33 ± 1.04 (10)	13.47 ± 0.91 (10)	12.58 ± 0.35 (10)
8/27/93	17.16 ± 0.65 (10)	16.89 ± 0.30 (10)	13.36 ± 0.31 (10)	14.70 ± 0.36 (10)

1986 was characterized by low summer values compared to 1983 and the period from 1987 to present (Fig. 2.1). The period of 1984-86 also was characterized by some of the higher 28 day discharge averages that we have recorded (Fig. 1.5). Most measures of algal standing crop (density, chlorophyll a, AFDW-organic matter accrual), as well as species composition appear to have increased at both the control and antenna sites for the 1987-93 period as compared to the 1984-86 period. 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 in chlorophyll a standing crop 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, 1990, 1991 and 1993 (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.

Results of paired t-tests and correlations of biological parameters between the control (FCD) and antenna (FEX) sites show that chlorophyll a at the two sites was significantly different for the before (Table 2.2) and after (Table 2.3) periods. However, the pattern of differences was quite distinct between the two periods, especially for the June to October period (Table 2.4). During the before period (1983-1985), chlorophyll a levels were consistently higher at the control (FCD) site than they were at the antenna site (FEX) (Table 2.4). This pattern reversed in 1986 at the start of the transition period (period of testing the antenna at levels below the 150 amp operating power) (Table 2.4). The reversed pattern of FEX having higher chlorophyll a standing crops than FCD continued through most years of the after period (1989, 1990, 1991, and 1993), but was less apparent in 1992. Chlorophyll a standing crops in July and August of 1993 were higher at FEX, consistant with the general pattern since 1986 (Table 2.4).

Paired t-tests were also used to test for differences in chlorophyll a standing crop between the original antenna site (FEX) which is located 30 m upstream of the antenna and the new antenna site (FEX-N) which is located 10 m downstream of the antenna (Table 2.5). Chlorophyll a

Table 2.2 Paired t-test and Correlations between the Control (FCD) and Experimental (FEX) sites for Biological Parameters for 1983-1986.

Parameter	df	Paired t-value	Significance (NS = p > 0.05)	Correlation Coefficient	Significance (NS = p > 0.05)
Chlorophyll a	39	2.399	p<0.05	0.783	p<0.01
AFDW	38	0.575	NS	0.687	p<0.01
Chlorophyll a daily accrual	39	2.096	p<0.05	0.851	p<0.01
AFDW daily accrual	41	-0.327	NS	0.562	p<0.05
Species Diversity	38	-0.308	NS	0.757	p<0.01
Species Evenness	38	-1.638	NS	0.752	p<0.01
Cell density	38	1.682	NS	0.652	p<0.01
Cell volume	38	2.159	p<0.05	0.708	p<0.01
Biovolume	38	1.247	NS	0.316	NS
P/R	10	-1.41	NS	0.435	NS

Table 2.3 Paired t-tests and Correlations between the Control (FCD) and Experimental (FEX) sites for biological parameters for June 1989-Aug 1993.

Parameter	df	Paired t-value	Significance	Correlation coefficient	Significance
Cnlorophyll *a*	39	-3.320	p<0.01	0.809	P<0.01
AFDW	37	-2.764	P<0.01	0.794	P<0.01
Chlorophyll *a* daily accrual	36	-3.726	p<0.01	0.694	P<0.01
AFDW daily accrual	36	-3.686	p<0.01	0.526	P<0.01
Species Diversity	39	3.064	p<0.01	0.919	P<0.01
Species Evenness	39	2.123	P<0.05	0.894	P<0.01
Cell density	39	-1.543	NS	0.723	P<0.01
Cell volume	39	0.590	NS	0.637	P<0.01
Biovolume	39	-1.047	NS	0.622	P<0.01
P/R	42	-2.402	p<0.05	0.655	p<0.01

Table 2.4 Comparison between the Control(FCD) and Experimental(FEX) sites for Chlorophyll a.
"+" = FCD value higher than FEX value.
"-" = FEX value higher than FCD value.
"0" = FCD and FEX values within 0.4 mg/m2.

Date	July	August	September	October
1983	+	+	+	+
1984	+	+	+	+
1985	0	+	0	0
1986	-	-	-	+
1987	-	-	0	+
1988	-	-	0	-
1989	+	-	-	-
1990	-	-	-	-
1991	-	-	-	-
1992	+	-	+	-
1993	-	-		

Table 2.5 Paired t-test and Correlations between the Experimental (FEX) and the New Experimental (FEX-N) sites for Biological parameters for June 1990-Aug 1993.

Parameter	df	Paired t-value	Significance	Correlation coefficient	Significance
Chlorophyll *a*	26	2.100	$p<0.05$	0.950	$p<0.01$
AFDW	25	0.943	NS	0.915	$P<0.01$
Chlorophyll *a* daily accrual	26	1.167	NS	0.945	$p<0.01$
AFDW daily accrual	25	2.284	$P<0.05$	0.757	$p<0.01$
Species Diversity	28	0.134	NS	0.930	$P<0.01$
Species Evenness	28	-0.212	NS	0.921	$P<0.01$
Cell density	28	-1.103	NS	0.463	$P<0.05$
Cell volume	28	-0.981	NS	0.893	$P<0.01$
Biovolume	28	-0.895	NS	0.819	$P<0.01$

standing crop was greater at FEX than at FEX-N, and the two sites were significantly correlated (Table 2.5). Comparisons between the old and new (FCD versus FCD-N) control sites failed to detect significant differences between the sites (Table 2.6). Chlorophyll *a* standing crops were significantly different between the new antenna site (FEX-N) and the new control site (FCD-N) (Table 2.7), as was the case for comparisons between the original (FEX) antenna and control (FCD) sites for the after period (Table 2.3).

We have computed the minimum detectable differences for each biological parameter through 1992 (Table 2.8). 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 to detect a difference between FEX and FCD for the winter data set highlights the variability found in our winter data for chlorophyll *a*. A power analysis conducted on the biological parameters indicated that the ability to detect a change in chlorophyll *a* is moderate to poor (Figure 2.2A). For example, at a power of 0.4, one would be able to detect less than a 25% change in summer chlorophyll *a* levels. The winter data set is even less powerful, and winter comparisons are not emphasized in this report.

Results of both the BACI and RIA comparisons on the log(x+1) transformed chlorophyll *a* standing crop data for the ice-free periods indicated that a significant difference ($p<0.01$) occurred when "before" (6/83-4/86) and "after" (6/89-8/93) means were compared (Table 2.9). Comparisons of the *Cocconeis placentula* dominant months (Table 2.10) resulted in a significant difference ($p<0.01$) between "before" and "after" months, based on both BACI and RIA. Analysis of the chlorophyll *a* data for the ice-free and *Cocconeis placentula* periods, revealed significant autocorrelations according to the Durbin-Watson test of the independence assumption. Thus, randomized intervention analysis (RIA) was used to confirm the results of the BACI comparisons. Even with RIA analysis, serial autocorrelation can result in underestimation of the true P value, so it is advisable to require $P < 0.01$ for rejection of the null hypothesis (Carpenter *et al* 1989). Using this criterion, we can say with some confidence that the intersite relationship for chlorophyll *a* standing crop was different between "before" and "after" periods. While neither BACI or RIA give any indication as to how these differences may have arisen, examination of patterns in actual values (Table 2.4, Fig. 2.1) show that chlorophyll *a* values at FEX were significantly (t-tests, Table 2.2) lower than chlorophyll *a* values at FCD during the "before" period (1983-86) but higher (Table 2.3) at the antenna site (FEX) than at the

Table 2.6 Paired t-test and Correlations between the Control (FCD) and the New Control (FCD-N) sites for Biological parameters for June 1990-Aug 1993.

Parameter	df	Paired t-value	Significance	Correlation coefficient	Significance
Chlorophyll a	27	0.478	NS	0.908	$p < 0.01$
AFDW	27	0.681	NS	0.804	$P < 0.01$
Chlorophyll a daily accrual	26	-0.054	NS	0.688	$p < 0.01$
AFDW daily accrual	26	0.380	NS	0.800	$p < 0.01$
Species Diversity	27	2.063	$P < 0.05$	0.946	$P < 0.01$
Species Evenness	27	2.570	$P < 0.05$	0.941	$P < 0.01$
Cell density	27	0.087	NS	0.773	$P < 0.01$
Cell volume	27	1.162	NS	0.775	$p < 0.01$
Biovolume	27	0.404	NS	0.606	$p < 0.01$

Table 2.7 Paired t-test and Correlations between the New Experimental (FEX-N) and New Control (FCD-N) sites for Biological parameters for June 1990-Aug 1993.

Parameter	df	Paired t-value	Significance	Correlation coefficient	Significance
Chlorophyll a	27	-3.283	P < 0.01	0.894	p < 0.01
AFDW	25	-3.335	P < 0.01	0.930	P < 0.01
Chlorophyll a daily accrual	26	-2.615	P < 0.05	0.749	p < 0.01
AFDW daily accrual	26	-2.725	P < 0.05	0.731	p < 0.01
Species Diversity	27	0.847	NS	0.809	P < 0.01
Species Evenness	27	-0.375	NS	0.860	P < 0.01
Cell density	27	-0.905	NS	0.270	NS
Cell volume	27	-0.450	NS	0.789	p < 0.01
Biovolume	27	-1.339	NS	0.285	NS

Table 2.8 Minimum detectable differences for major biological parameters using paired T-tests. Values were computed for 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

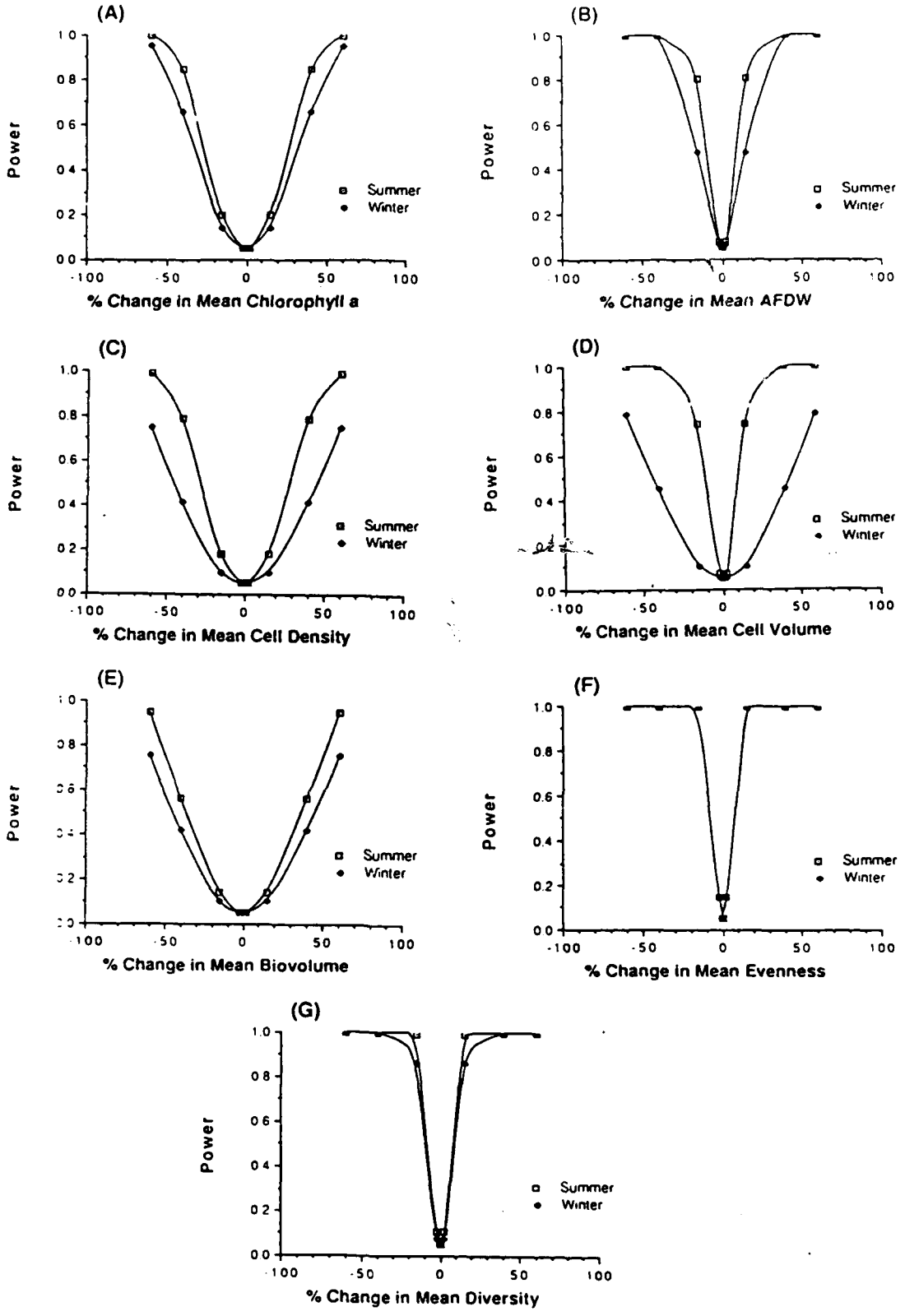


Figure 2.2 Power curves for biological parameters calculated from summer and winter data sets at FCD from 1983-1990; (A) Chlorophyll a standing crop, (B) AFDW-Biomass standing crop, (C) Cell Density, (D) Cell Volume, (E) Biovolume, (F) Species Evenness, (G) Species Diversity.

Table 2.9 Summary of BACI and RIA Comparisons for Biological Parameters between Control (FCD) and Experimental (FEX) sites for 1983-1993. The comparisons were made using months in which the Ford River was free of ice cover (April - October). Biovolume, cell volume, and density comparisons were made through 1992.

Parameter	N	BACI Signif. ($p<0.05$)	RIA Signif. ($p<0.05$)
AFDW	54	NS	$p<0.01$
AFDW Accrual	56	NS	$p<0.05$
Chlorophyll *a*	56	$P<0.01$	$p<0.01$
Chlorophyll *a* Accrual	55	$p<0.01$	$p<0.01$
Biovolume	49	$p<0.05$	NS
Cell Volume	49	NS	NS
Density	49	$p<0.01$	$P<0.05$
Diversity	56	NS	NS
Evenness	56	NS	NS
P/R Values	48	NS	NS

Table 2.10 Summary of BACI and RIA Comparisons for Biological Parameters between Control (FCD) and Experimental (FEX) sites for 1983-1993. The comparisons were made using months in which Cocconeis placentula was dominant. Those time periods being: July-Sept. 1983, 1984, and 1985; versus, July-Oct.(1) 1989, Aug-Oct.(1) 1990, June-Oct.(1) 1991, and July-Aug.(2) 1992 and 1993. Biovolume, cell volume, and density comparisons were made through 1992.

Parameter	N	BACI Signif. ($p<0.05$)	RIA Signif. ($p<0.05$)
AFDW	28	$p<0.01$	$p<0.05$
AFDW Accrual	27	$p<0.05$	NS
Chlorophyll a	28	$P<0.01$	$p<0.01$
Chlorophyll a Accrual	26	$p<0.01$	$p<0.05$
Biovolume	26	NS	NS
Cell Volume	26	NS	NS
Density	25	$p<0.05$	$p<0.01$
Diversity	28	NS	NS
Evenness	28	NS	NS

control site (FCD) after the antenna became operational in 1989. This reversal in pattern with the antenna site having higher chlorophyll *a* values compared to the control site occurred just at the time when antenna testing first began at very low amperage in 1986 (Table 2.4). Thus, periphyton in the Ford River are either very sensitive to ELF electromagnetic fields and chlorophyll production is stimulated by antenna operation or the change coincides with some site specific weather related phenomenon. Sensitivity to ELF fields seems to be the most plausible explanation.

Daily chlorophyll *a* accrual rates followed the same pattern as did standing crop with mid-summer peaks and winter lows (Fig. 2.3, Table 2.11). Daily rates peaked in August at both FEX and FCD. Paired t-tests between the antenna site (FEX) and the control site (FCD) showed that there were significant differences between sites for the period before (Table 2.2) and after (Table 2.3) antenna operation began for chlorophyll *a* accrual rate just as there had been for chlorophyll *a* standing crop. Like the pattern for chlorophyll *a* standing crop, chlorophyll *a* accrual rate tended to be higher at FCD than it was at FEX before antenna operation while the reverse was true after antenna operation began, especially when June-October periods of 1983-85 are compared to the after periods of 1989-93 (Fig. 2.3). There was also a significant difference in chlorophyll *a* accrual rate between the new control (FCD-N) and antenna sites (FEX-N) (Table 2.7). Chlorophyll *a* accrual rate between the old and new antenna sites (FEX versus FEX-N) have not been significantly different since the new site was included in 1990 (Table 2.5). Likewise, the old (FCD) and new (FCD-N) control sites have had similar chlorophyll *a* accrual rates (Table 2.6). The minimum detectable difference for chlorophyll *a* accrual (Table 2.8) of 32.1% is similar to that for chlorophyll *a* standing crop.

BACI analysis of the log (x+1) transformed chlorophyll *a* accrual rates indicate that there is a difference in the between site relationship "before" impact (6/83-4/86) and the relationship "after" impact (6/89-8/93) for the ice-free periods and periods in which *Cocconeis placentula* was dominant (Table 2.9 and 2.10). The chlorophyll *a* accrual data for the ice-free period showed evidence of serial correlation according to the Durbin-Watson test results. Therefore, RIA was used to confirm the difference detected in the BACI ice-free period comparison (Table 2.9). Since the RIA analysis on the ice-free data set produced a $p<.01$, one can still be confident that a real difference existed in chlorophyll *a* accrual rates between "before" and "after" periods, according to Carpenter *et als* (1989) criterion. The data for chlorophyll *a* accrual were collected after 14 days

Table 2.11 Daily accrual rates of chlorophyll a ($mg/m^2/d$) for Experimental (FEX and FEX-N) and Control (FCD and FCD-N) sites for 1992-1993. Values are Means ± S.E, N in parentheses.

Date	Experimental		Control	
	FEX	FEX-N	FCD	FCD-N
9/12/92	0.07 ± 0.01 (10)	0.05 ± 0.00 (10)	0.05 ± 0.00 (10)	0.06 ± 0.00 (9)
10/10/92	0.05 ± 0.01 (10)	0.05 ± 0.00 (10)	0.07 ± 0.02 (10)	0.08 ± 0.00 (10)
5/24/93	0.22 ± 0.02 (10)	0.22 ± 0.03 (10)	0.08 ± 0.01 (10)	0.09 ± 0.01 (10)
6/24/93	0.04 ± 0.00 (9)	0.02 ± 0.00 (10)	0.03 ± 0.00 (10)	0.06 ± 0.01 (10)
7/19/93	0.33 ± 0.02 (10)	0.32 ± 0.02 (10)	0.12 ± 0.00 (10)	0.08 ± 0.00 (10)
8/16/93	0.55 ± 0.02 (10)	0.54 ± 0.02 (10)	0.31 ± 0.01 (9)	0.29 ± 0.02 (10)

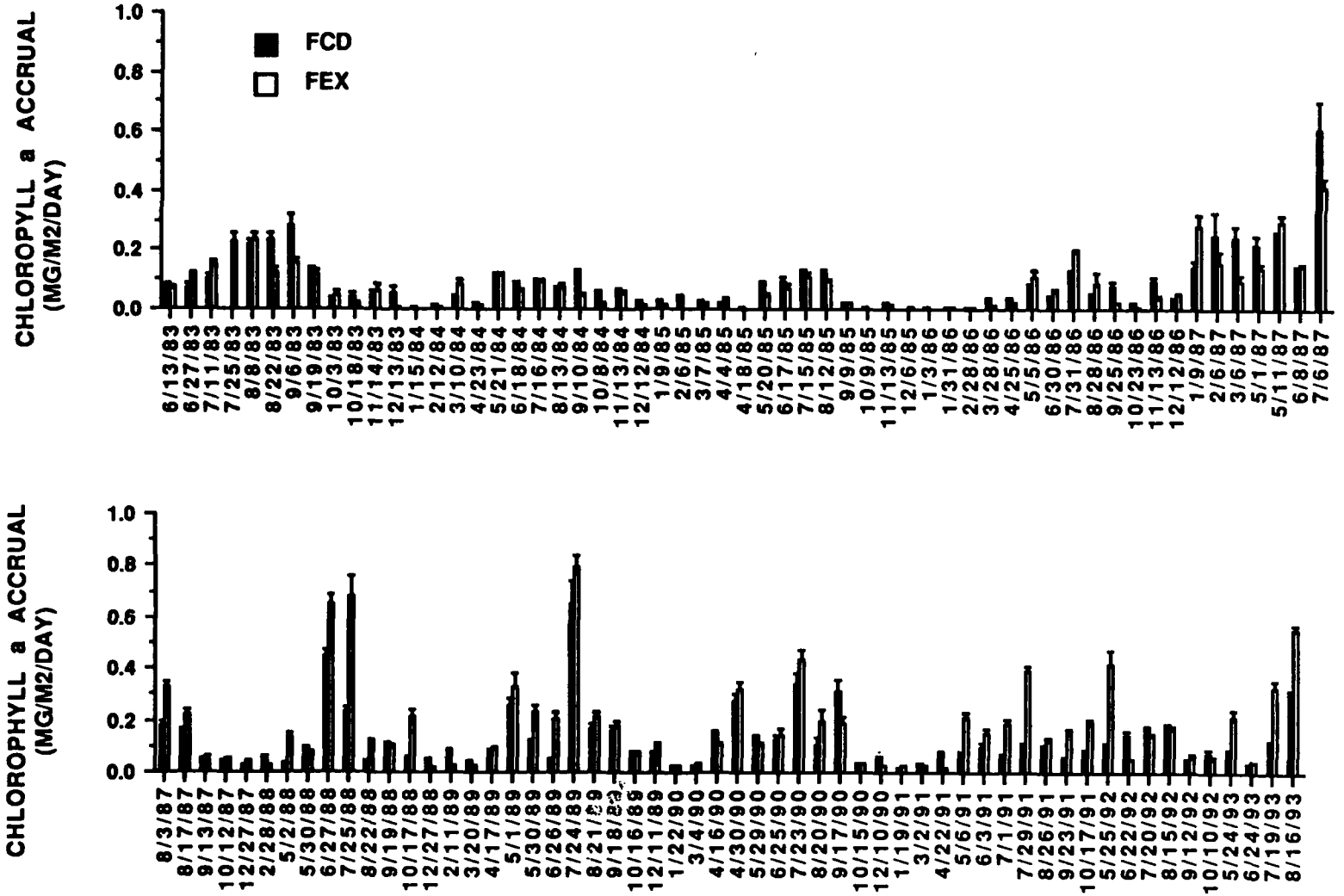


FIGURE 2.3 ACCRUAL RATES OF CHLOROPHYLL a FOR EXPERIMENTAL (FEX) AND CONTROL (FCD)SITES ON THE FORD RIVER, 1983-1993.

of exposure from different slides than those used for chlorophyll a standing crop determination, which were collected after 28 days of exposure. BACI results and especially RIA results from these two separately collected measurements of chlorophyll a showed that the inter-site relationship before the antenna was turned on was significantly different from the relationship after the antenna was operational. This change could be due to an ELF effect.

C. Patterns of Organic Matter Accumulation

Organic matter measured as accumulation of ash free dry weight (AFDW) on glass slides was more similar between FEX and FCD in 1992-1993 than chlorophyll a (Figs. 2.1, 2.4, Tables 2.1, 2.12). The annual pattern for organic matter standing crop was similar to that of previous years (Figure 2.4). Generally, FEX-N and FCD-N paralleled organic matter standing crop levels at FEX and FCD from September, 1992 to August, 1993.

Paired t-tests between FEX and FCD AFDW organic matter for the before antenna period showed no significant differences between sites (Table 2.2). However, AFDW organic matter differences between the control and antenna sites were significant for the after full operation period (June 1989-August 1993, Table 2.3) with the antenna site (FEX) tending to have a higher organic matter biomass than did the control (FCD) (Fig. 2.4). There was also a significant difference between the two new sites (FCD-N versus FEX-N) for the after full operation time period from June 1990- August 1993 (Table 2.7). There were no significant differences between the two experimental sites (FEX versus FEX-N) and the two control sites (FCD versus FCD-N) for this same time period (Tables 2.5 and 2.6). BACI analyses conducted on log (x+1) transformed AFDW-organic matter biomass data indicated a difference in the between site relationship "before" impact (6/83-4/86) compared with the relationship "after" impact (6/89-8/93) for the periods in which Cocconeis placentula was dominant (Table 2.10). RIA comfirmed these results (Table 2.10). Using BACI analysis, no significant difference was found in the between-site relationship of organic matter biomass for ice-free periods ($P = 0.07$) (Table 2.9). The results of RIA analysis for the ice-free periods indicated a significant difference in the between-site relationship, thus not agreeing with the BACI results (Table 2.9). It is not clear why BACI and RIA gave conflicting results for the ice-free periods. Overall, the organic matter biomass results are similar to those for chlorophyll a in that FEX had generally higher measured values than did FCD but are less convincing than the chlorophyll a data.

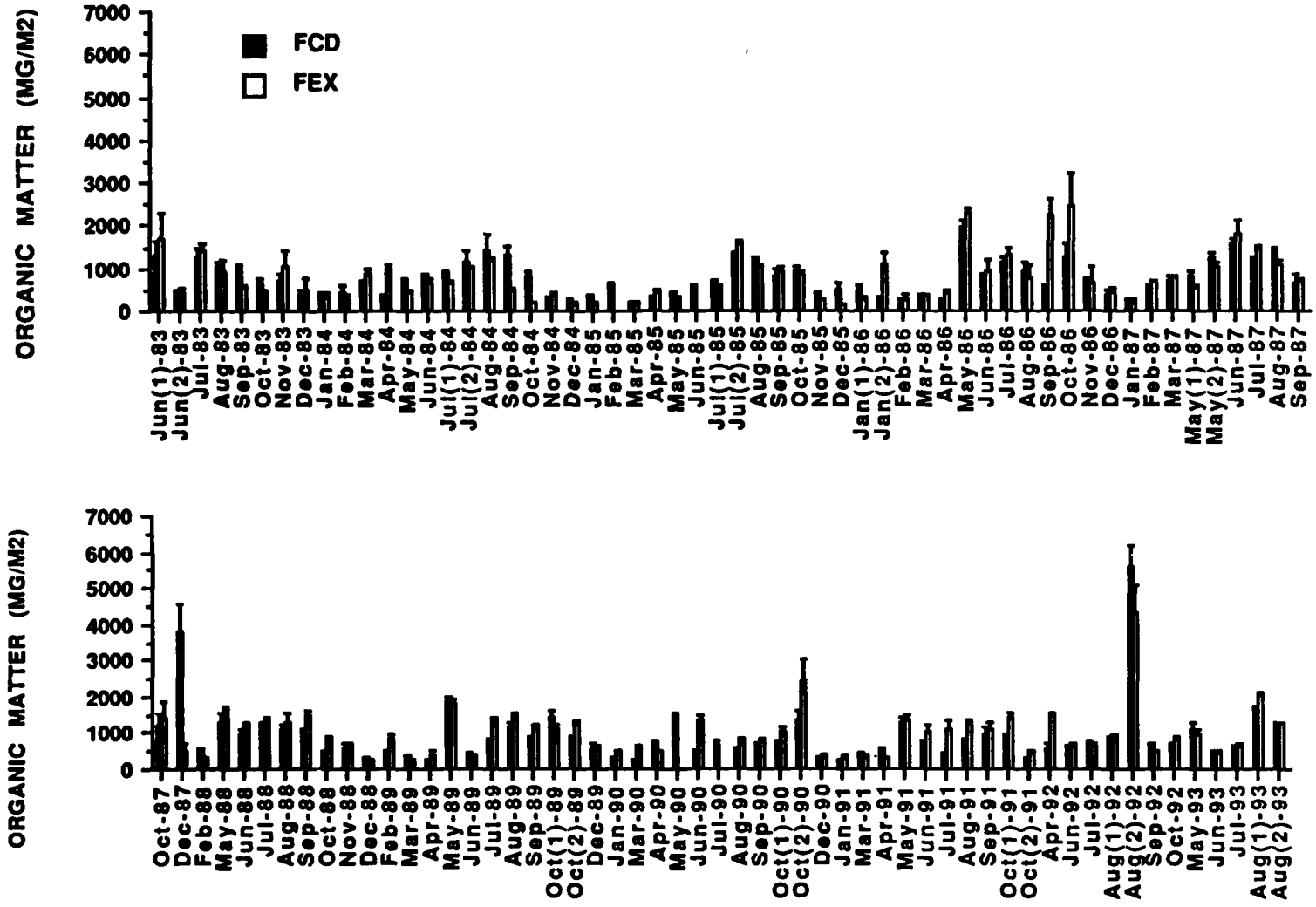


FIGURE 2.4 ORGANIC MATTER STANDING CROP FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES ON THE FORD RIVER, 1983-1993.

Table 2.12 Ash Free Dry Weight Biomass (mg/m^2) for Experimental (FEX and FEX-N) and Control (FCD and FCD-N) sites for 1992-1993. Values are Means ± S.E., N in parentheses.

Date	Experimental		Control	
	FEX	FEX-N	FCD	FCD-N
9/26/92	493 ± 45 (10)	603 ± 29 (10)	653 ± 48 (10)	736 ± 39 (10)
10/24/92	821 ± 101 (10)	816 ± 81 (10)	653 ± 61 (10)	968 ± 32 (10)
5/11/93	987 ± 135 (10)	----	1099 ± 156 (10)	1291 ± 115 (10)
6/7/93	456 ± 61 (5)	648 ± 75 (10)	474 ± 44 (9)	536 ± 115 (10)
7/6/93	667 ± 8 (5)	669 ± 16 (10)	605 ± 29 (10)	469 ± 17 (10)
8/2/93	2069 ± 22 (10)	1837 ± 69 (10)	1712 ± 32 (10)	1731 ± 38 (10)
8/27/93	1261 ± 37 (10)	1073 ± 140 (9)	1259 ± 50 (10)	1328 ± 241 (8)

Organic matter accrual rates (Figure 2.5 and Table 2.13) followed a pattern of winter lows and summer highs similar to the pattern followed by organic matter standing crop. Paired t-tests between the control (FCD) and experimental (FEX) sites for the "before" period show no significant difference in AFDW accrual rate (Table 2.2), however there is a significant difference between the two sites for the "after" antenna operation time period (Table 2.3). There was a significant difference between the two new sites (FEX-N versus FCD-N) (Table 2.7). The minimum detectable difference for organic matter accrual was 27.1% (Table 2.8), similar to the value for organic matter standing crop. BACI analysis on untransformed AFDW-organic matter accrual during the ice-free periods (Table 2.9) indicated that there were no significant differences ($p<0.05$) in the between site relationship "before" testing began on the ELF antenna compared with the "after" period. Results of RIA tests on organic matter accrual for the same periods indicated a significant difference between the "before" and "after" data sets (Table 2.9). Comparisons between the Cocconeis placentula dominant months indicated a significant difference according to BACI but no significant difference according to RIA analysis (Table 2.10). The BACI results are probably more trustworthy in this case. The Cocconeis dominant periods were usually restricted to two or three months out of the year, hence the total number of pooled observations was low ($N < 30$). Randomized Intervention Analysis suffers from limited statistical power when sample size is much below 40 (Carpenter et al 1989).

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. 2.6). Typically, the lowest values occurred in January or 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/m^2. The peak values for diatom cell density occurred at less predictable intervals (Fig. 2.6). The highest monthly densities of cells were reported in August 1983, June 1984, June 1985, May 1986, May 1987, May 1988 and 1989, May - July of 1990, May 1991, August 1992, and May - June 1993 (Fig. 2.6). Thus, the highest cell densities measured were found to occur anytime within a four month spring-summer period. The duration of continued high cell

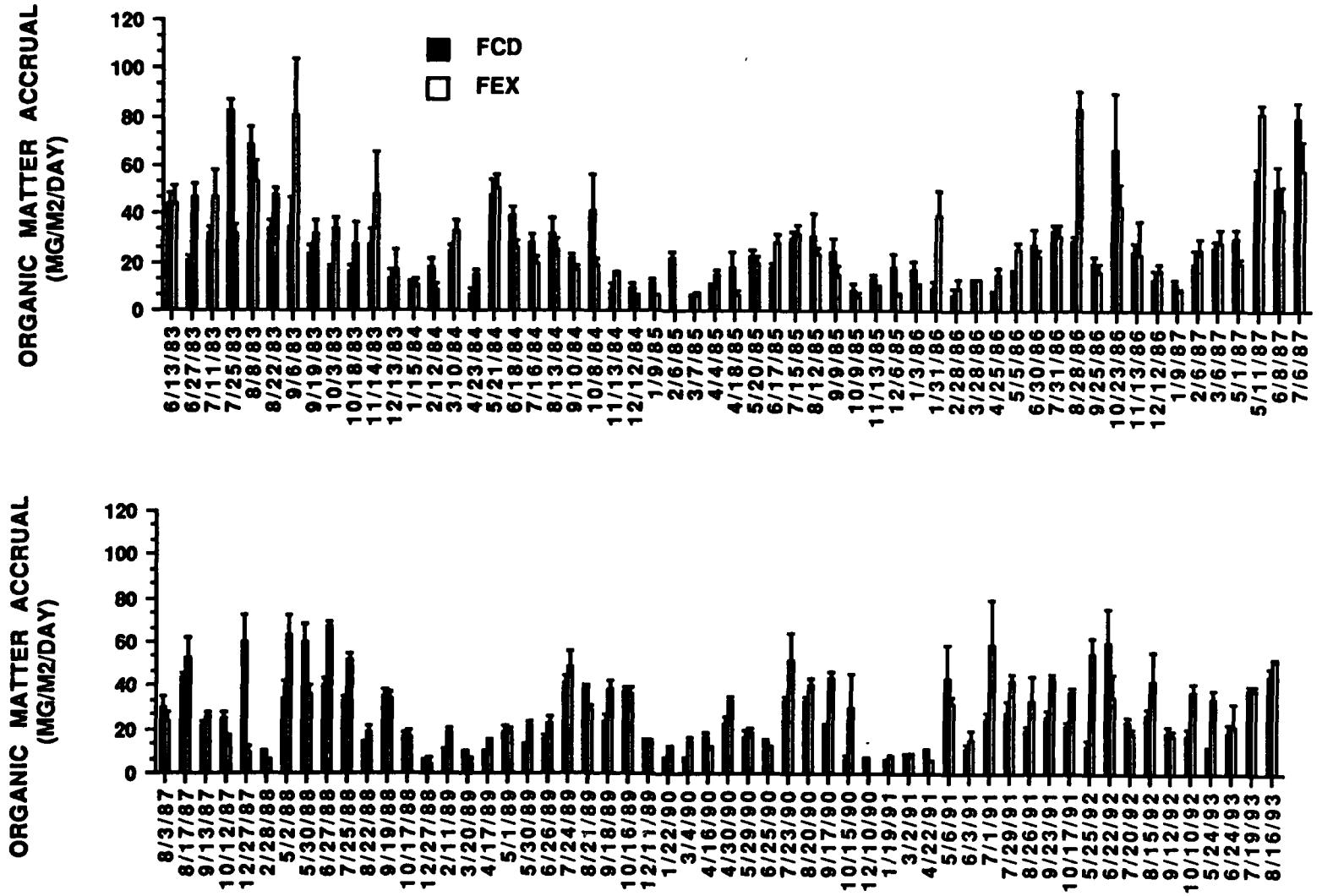


FIGURE 2.5 ACCRUAL RATES OF ORGANIC BIOMASS FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES ON THE FORD RIVER, 1983-1993.

Table 2.13 Daily accrual rates of AFDW-Biomass ($mg/m^2/d$) for Experimental (FEX and FEX-N) and Control (FCD and FCD-N) sites for 1992-1993. Values are Means ± S.E., N in parentheses.

Date	Experimental		Control	
	FEX	FEX-N	FCD	FCD-N
9/12/92	23 ± 4 (10)	37 ± 12 (10)	11 ± 3 (10)	23 ± 4 (10)
10/10/92	37 ± 4 (10)	29 ± 3 (10)	18 ± 3 (10)	22 ± 2 (10)
5/24/93	34 ± 5 (10)	36 ± 3 (10)	11 ± 2 (8)	15 ± 2 (10)
6/24/93	22 ± 10 (10)	13 ± 2 (10)	19 ± 4 (9)	12 ± 2 (8)
7/19/93	38 ± 2 (10)	39 ± 2 (10)	39 ± 2 (10)	21 ± 2 (10)
8/16/93	52 ± 1 (10)	60 ± 2 (10)	45 ± 4 (10)	37 ± 3 (8)

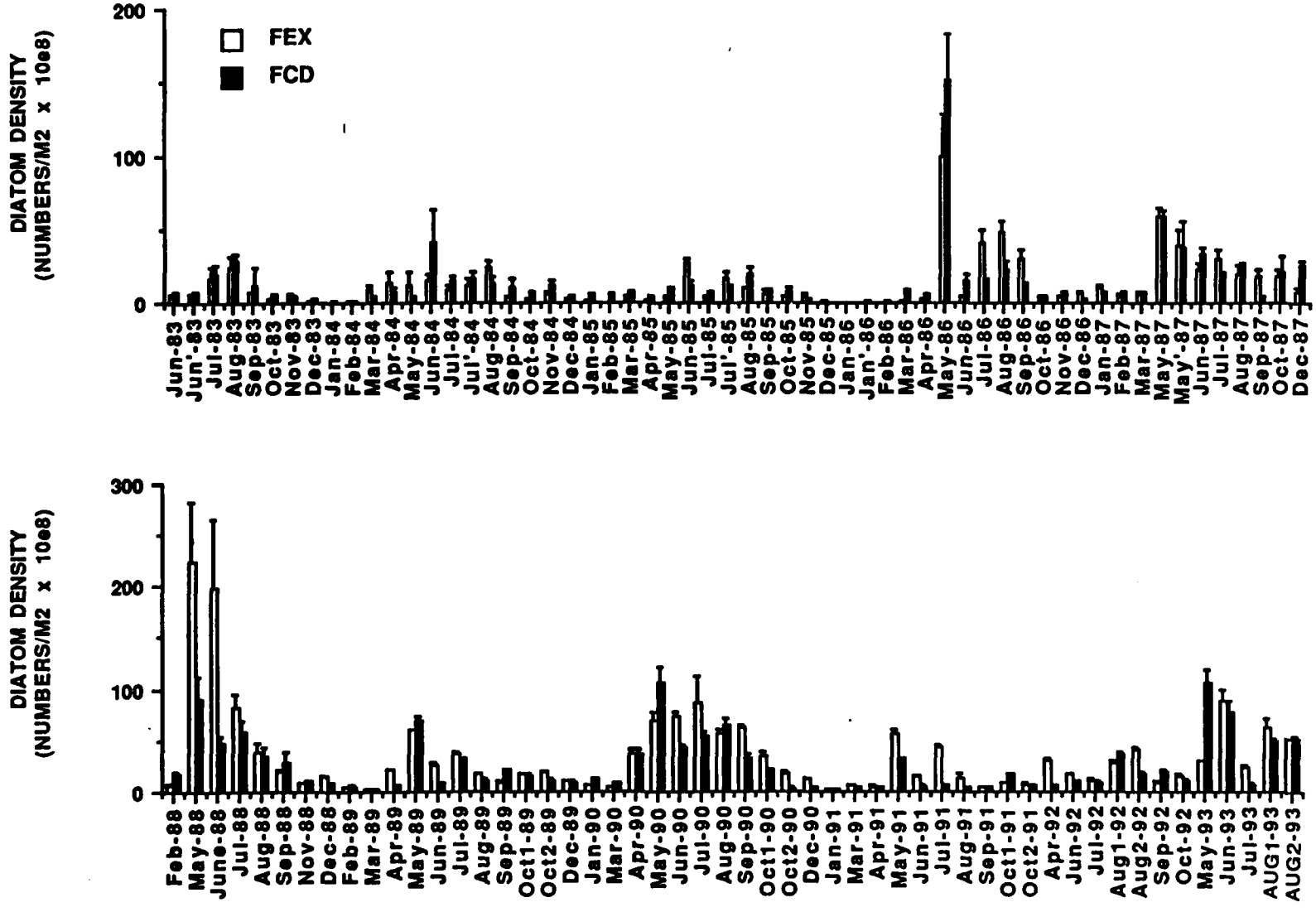


FIGURE 2.6 DIATOM CELL DENSITIES FOR THE FORD RIVER, 1983-1993

densities also varied by year (Fig. 2.6); 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 1993, cell densities remained relatively high from the late spring through the summer, with the exception of July, where they decreased substantially (Table 2.14, Fig. 2.6). A large storm event which produced 5 cm of rain in late June (Fig 1.23) and caused discharges to exceed 5 m^3/s (Fig 1.6) may have been responsible for the low cell densities in July (the July 28 day colonization period ended on 7/6/93). Data from FEX-N and FCD-N sites from September, 1992 to August, 1993 followed the patterns apparent at FEX and FCD in most cases (Table 2.14).

Paired t-tests demonstrated that cell densities were not different between the antenna site (FEX) and the control site (FCD) for the time period after the antenna was operational (June, 1989-August, 1993) (Table 2.3), and demonstrated no significant difference between the two sites prior to antenna operation (Table 2.2). The May, 1993 date was particularly influential in the t-test on the "after" data (Fig 2.6). Removing this date from the analysis resulted in a significant difference between FEX and FCD for cell density ($p<0.01$). Results of paired t-tests which include the new sites and data from June, 1990 to August, 1993 showed no significant differences in cell densities for FEX vs FEX-N, FCD vs FCD-N and FCD-N vs FEX-N (Tables 2.5, 2.6, and 2.7). The FEX vs. FEX-N and FCD vs FCD-N comparisons both indicated significant correlations between sites. FCD-N and FEX-N were not significantly correlated. BACI and RIA results on the ice-free log (x+1) transformed cell density data indicated a significant difference between "before" (6/83-4/86) and "after" (6/89-8/92) periods (Table 2.9). BACI and RIA results were also significant for the Cocconeis dominant log (x+1) transformed data (Table 2.10). Cell density is highly variable (Figure 2.6), resulting in a rather large (approximately 50%) minimum detectable difference (Table 2.8). Power analysis of cell density indicate that the data are only moderately powerful, similar to the chlorophyll a power analysis, and the winter data set is even less powerful (Figure 2.2C).

E. Patterns in Individual Cell Volume and Total Biovolume

Individual cell volumes for the 9.5 year period (Fig. 2.7, Table 2.15) were characterized by a trend towards larger 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

Table 2.14 Cell Density (cells/m^2 x 10^8) for Experimental (FEX and FEX-N) and Control (FCD and FCD-N) sites for 1992-1993. Values are Means ± S.E, N in parentheses.

Date	Experimental		Control	
	FEX	FEX-N	FCD	FCD-N
9/26/92	9.35 ± 0.49 (3)	7.62 ± 0.31 (3)	19.09 ± 3.49 (3)	11.52 ± 3.32 (3)
10/24/92	15.47 ± 2.45 (3)	12.25 ± 1.91 (3)	11.69 ± 1.36 (3)	28.85 ± 0.73 (3)
5/11/93	30.94 ± 0.34 (3)	26.81 ± 2.78 (3)	106.10 ± 11.67 (3)	179.50 ± 13.35 (3)
6/8/93	88.61 ± 9.89 (3)	46.38 ± 0.46 (3)	77.48 ± 9.94 (3)	33.31 ± 0.91 (3)
7/6/93	23.70 ± 2.68 (3)	11.19 ± 0.55 (3)	7.52 ± 0.32 (3)	8.35 ± 0.80 (3)
8/2/93	61.93 ± 10.34 (3)	66.15 ± 9.55 (3)	49.88 ± 1.90 (3)	48.28 ± 3.03 (3)
8/27/93	51.98 ± 0.67 (3)	59.63 ± 1.51 (3)	51.44 ± 2.52 (3)	25.30 ± 0.74 (3)

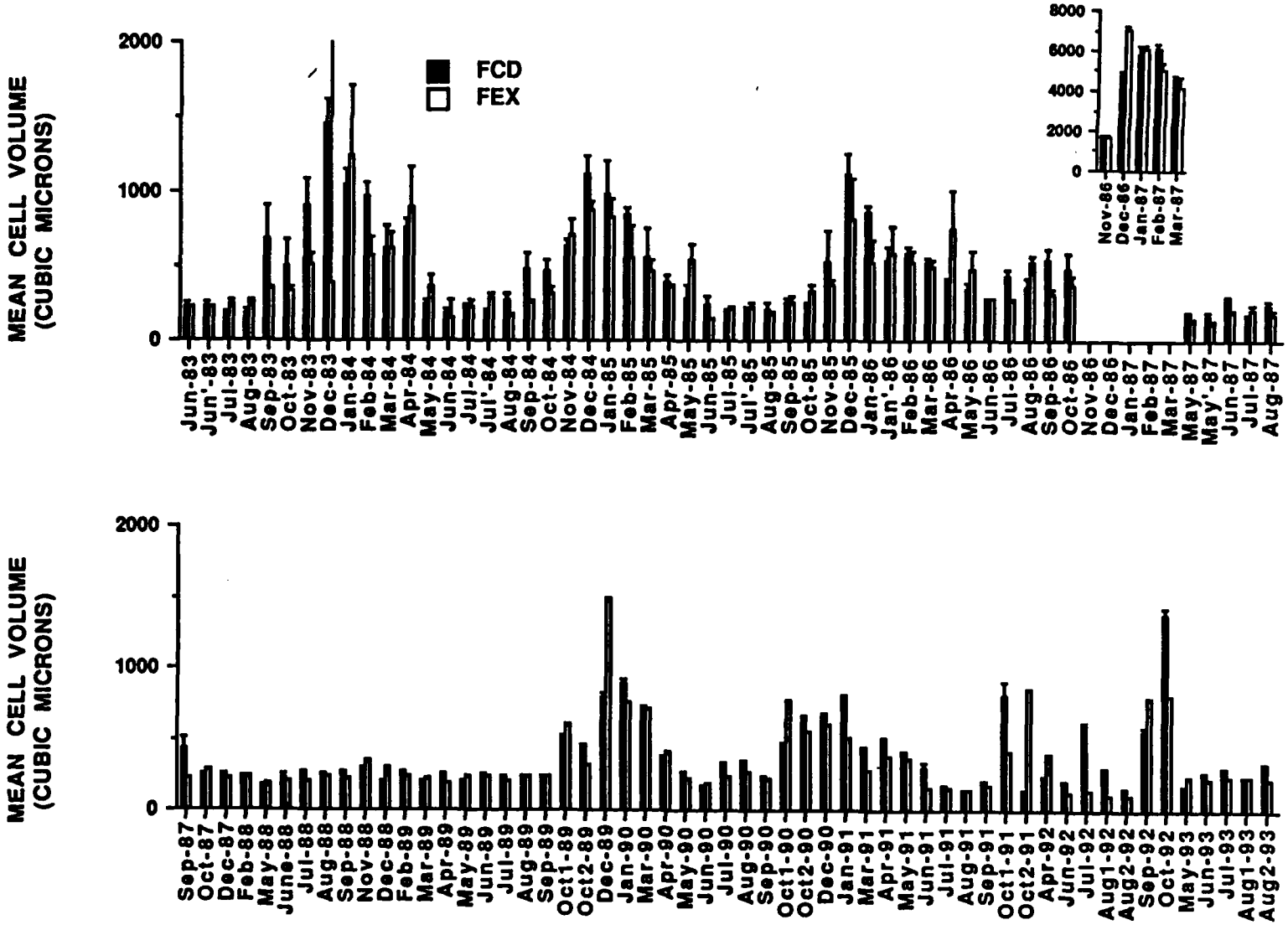


FIGURE 2.7 INDIVIDUAL CELL SIZES FOR THE FORD RIVER.

Table 2.15 Average Individual Diatom Cell Volume (cubic micrometers) for Experimental (FEX and FEX-N) and Control (FCD and FCD-N) sites for 1992-1993. Values are Means ± S.E, N in parentheses.

Date	Experimental		Control	
	FEX	FEX-N	FCD	FCD-N
9/26/92	794.5 ± 11.9 (3)	595.0 ± 43.7 (3)	558.2 ± 33.2 (3)	973.9 ± 33.7 (3)
10/24/92	806.8 ± 21.4 (3)	1078.1 ± 42.0 (3)	1373.1 ± 50.7 (3)	1045.8 ± 86.7 (3)
5/11/93	230.8 ± 11.1 (3)	208.1 ± 6.8 (3)	165.6 ± 9.7 (3)	215.3 ± 16.3 (3)
6/8/93	216.1 ± 17.5 (3)	303.3 ± 16.3 (3)	259.2 ± 12.2 (3)	179.7 ± 27.3 (3)
7/6/93	245.3 ± 14.8 (3)	283.3 ± 13.0 (3)	279.6 ± 17.6 (3)	240.7 ± 10.8 (3)
8/2/93	236.6 ± 7.6 (3)	233.3 ± 6.7 (3)	238.0 ± 5.1 (3)	228.3 ± 6.9 (3)
8/27/93	221.6 ± 3.0 (3)	276.8 ± 20.6 (3)	317.2 ± 18.5 (3)	242.0 ± 8.0 (3)

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. The cell volume for the winter of 1989-90 returned to the levels seen before 1986-87. For the period beginning September 1992 and ending August 1993 cell volumes were similar to past years for the most part. September and October 1992 showed particularly high cell volumes, due to the presence of large diatom species such as Cymbella minuta and Synedra ulna (Fig. 2.15 and Fig. 2.17).

Paired t-tests between the cell volume at the control site (FCD) and experimental site (FEX) were significantly different for the period before antenna operation (Table 2.2), but not for the time period after antenna operation (Table 2.3). There were no significant differences between any of the new sites (Tables 2.5, 2.6, and 2.7). BACI and RIA comparisons of untransformed cell volume data indicated that "before" data were not different from "after" data when either ice-free or Cocconeis dominant periods were considered (Tables 2.9, 2.10). Although cell volume is fairly variable between years (Fig. 2.7), it remains fairly consistent between sites resulting in a relatively low (approximately 25%) minimum detectable difference (Table 2.8). A power curve of the summer mean cell volume data indicates a relatively high ability to detect small changes in cell volume (Figure 2.2D). By comparison, the winter data are much less powerful.

Total biovolume is calculated from individual cell volumes and density of each of the diatom species present and is a crude estimate of diatom biomass. Total diatom biovolume for 1993 was highest in June at both FEX and FCD (Fig. 2.8, Table 2.16). Both density (Fig. 2.6) and biovolume (Fig. 2.8) 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. Total biovolume at all sites varied somewhat during the 1992 summer. The relatively low biovolume at both sites in July 1993 (Fig. 2.8) is a direct reflection of the low cell densities that month (Fig. 2.6). The large biovolume peak observed during the 1986-87 winter has not been repeated consistently due to the reduced abundance 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. 2.8).

Paired t-tests showed no significant differences in diatom biovolume between the control (FCD) and experimental

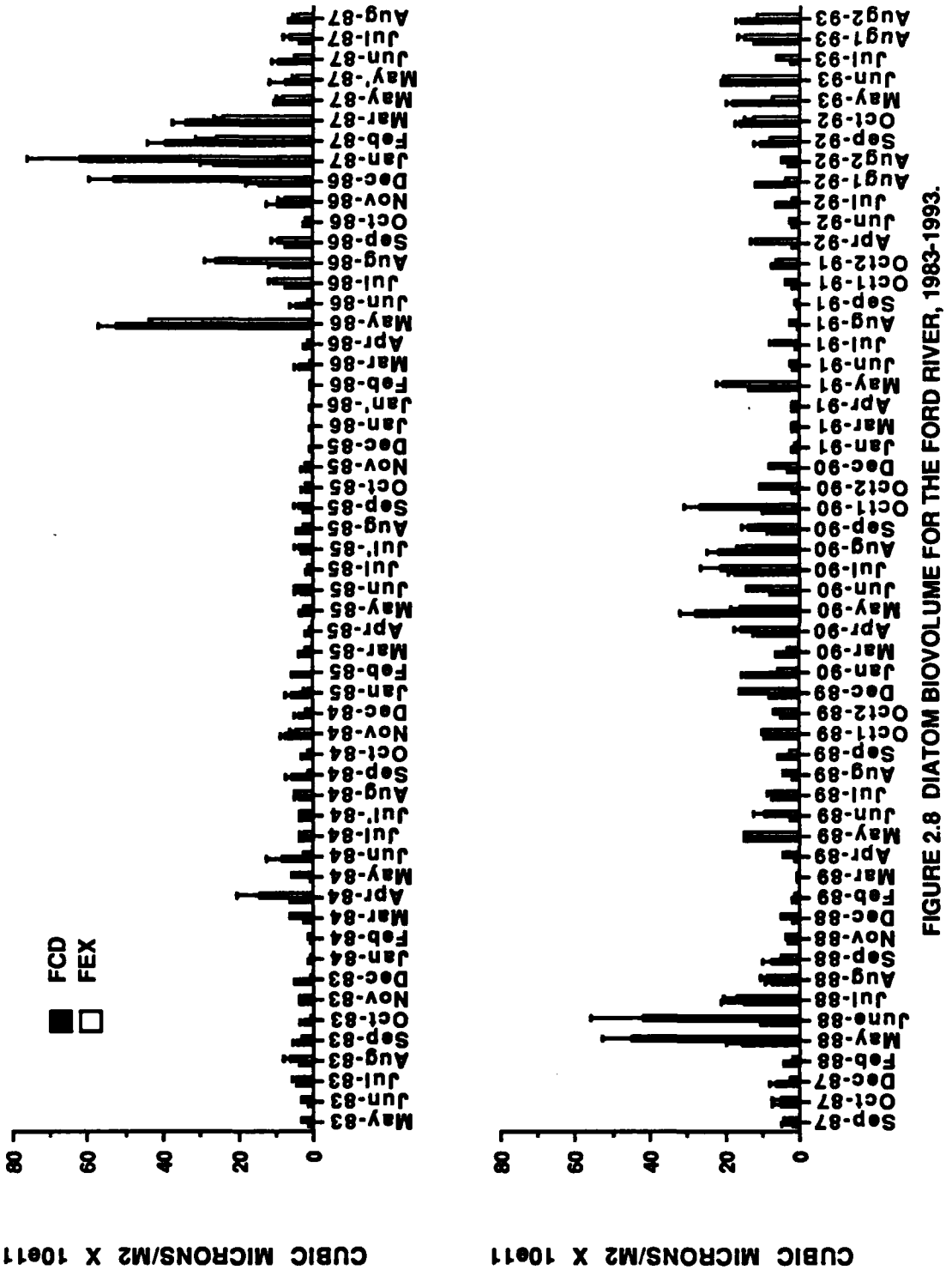


FIGURE 2.8 DIATOM BIOVOLUME FOR THE FORD RIVER, 1983-1993.

Table 2.16 Total Diatom Biovolume (cubic micrometers/m^2 x 10^{11}) for Experimental (FEX and FEX-N) and Control (FCD and FCD-N) sites for 1992-1993. Values are Means ± S.E, N in parentheses.

Date	Experimental		Control	
	FEX	FEX-N	FCD	FCD-N
9/26/92	7.44 ± 0.49 (3)	4.56 ± 0.50 (3)	10.60 ± 1.93 (3)	11.25 ± 3.39 (3)
10/24/92	12.52 ± 2.08 (3)	13.27 ± 2.37 (3)	15.91 ± 1.31 (3)	30.30 ± 3.25 (3)
5/11/93	7.14 ± 0.25 (3)	5.62 ± 0.76 (3)	17.88 ± 1.59 (3)	38.23 ± 0.76 (3)
6/8/93	18.84 ± 1.18 (3)	14.09 ± 0.87 (3)	20.08 ± 0.92 (3)	6.02 ± 1.06 (3)
7/6/93	5.74 ± 0.33 (3)	3.16 ± 0.15 (3)	2.10 ± 0.10 (3)	2.00 ± 0.19 (3)
8/2/93	14.53 ± 2.03 (3)	15.57 ± 2.75 (3)	11.87 ± 0.51 (3)	11.03 ± 0.80 (3)
8/27/93	11.51 ± 0.31 (3)	16.44 ± 0.82 (3)	16.30 ± 1.08 (3)	6.13 ± 0.34 (3)

(FEX) sites for either the before or after antenna operation time periods (Tables 2.2 and 2.3). There were no significant differences between either the control sites (FCD versus FCD-N), the experimental sites (FEX versus FEX-N), or the new sites (FCD-N versus FEX-N) (Table 2.5, 2.6, 2.7). BACI and RIA comparisons of log (x+1) transformed biovolume data gave conflicting results for the ice-free periods (Table 2.9). BACI analyses suggested that there was a significant difference in the between site relationship "before" and "after" the antenna became operational; however, RIA analyses failed to confirm this difference. There was no difference between the before and after periods for the Cocconeis dominated months (Table 2.10). The high variability in between site differences (Fig. 2.8) accounted for the high minimum detectable difference in biovolume (Table 2.8). Power curves indicated that biovolume was the least powerful of the biological parameters for both the summer and winter data sets (Figure 2.2E).

F. Patterns of Species Diversity and Species Evenness

The pattern in Shannon diversity (H') and the evenness index (J') over the period from 1983 to 1993 (Figs. 2.9 and 2.10, Tables 2.17 and 2.18) 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 lowest values in the summer months. The pattern of summer lows compared to earlier high winter values continued for the 1992-93 period.

The pattern of winter highs and summer lows for diversity and evenness corresponded with predictable patterns in species abundance. With the exception of 1989, only Achnanthes minutissima and Cocconeis placentula ever achieved dominance greater than 10 % of the individuals in the community during the ice-free season from 1983 to 1993 (Table 2.19). Typically, Achnanthes was the most dominant species present in May and June (Fig. 2.11), but decreased in abundance and was replaced by Cocconeis as the most dominant species in July and August (Fig. 2.12). In 1993, Cocconeis abundances followed a similar pattern, reaching its highest levels (65-75% during the summer period) since the start of the study (Fig. 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

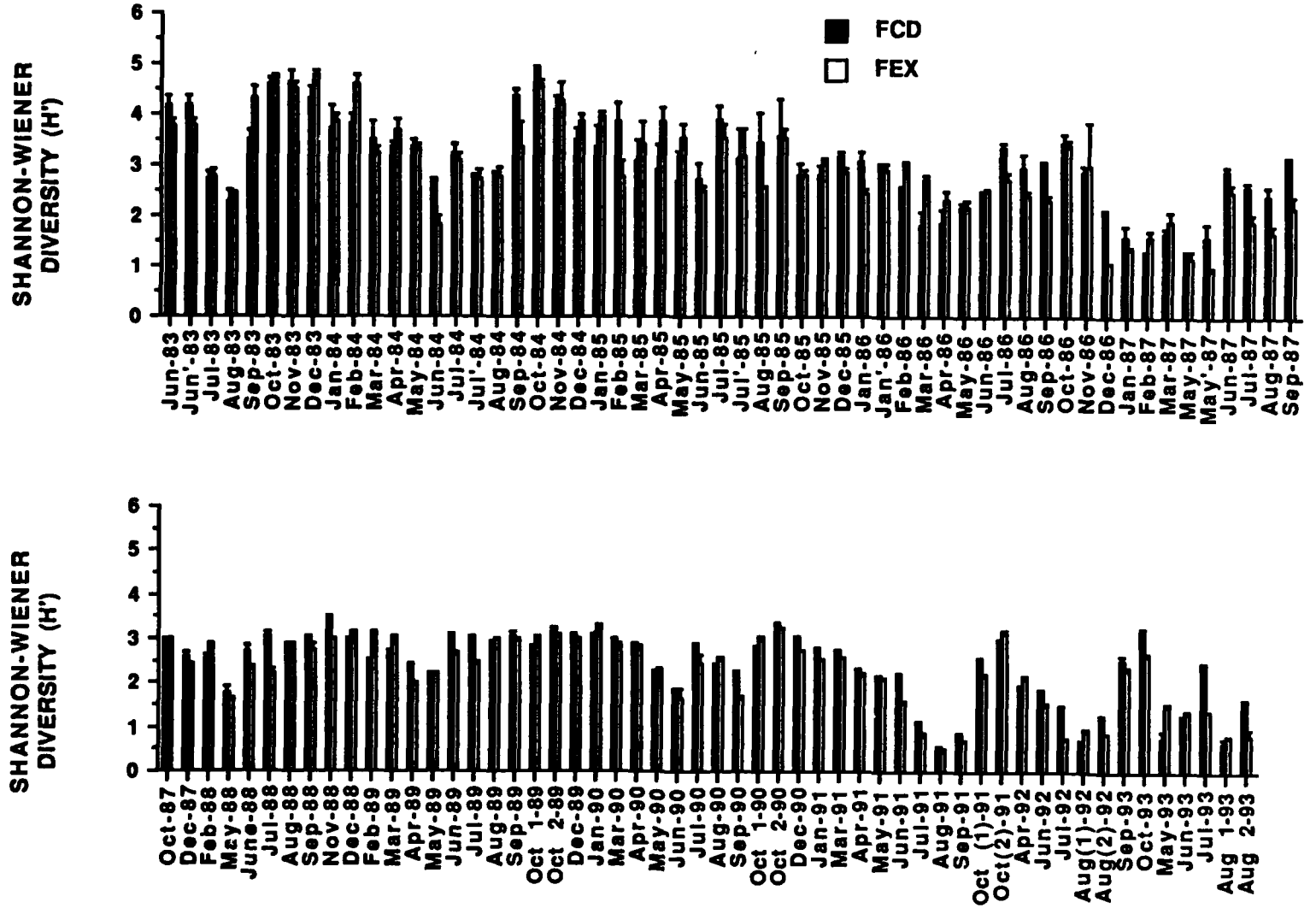


FIGURE 2.9 DIATOM SPECIES DIVERSITY FOR THE FORD RIVER, 1983-1993.

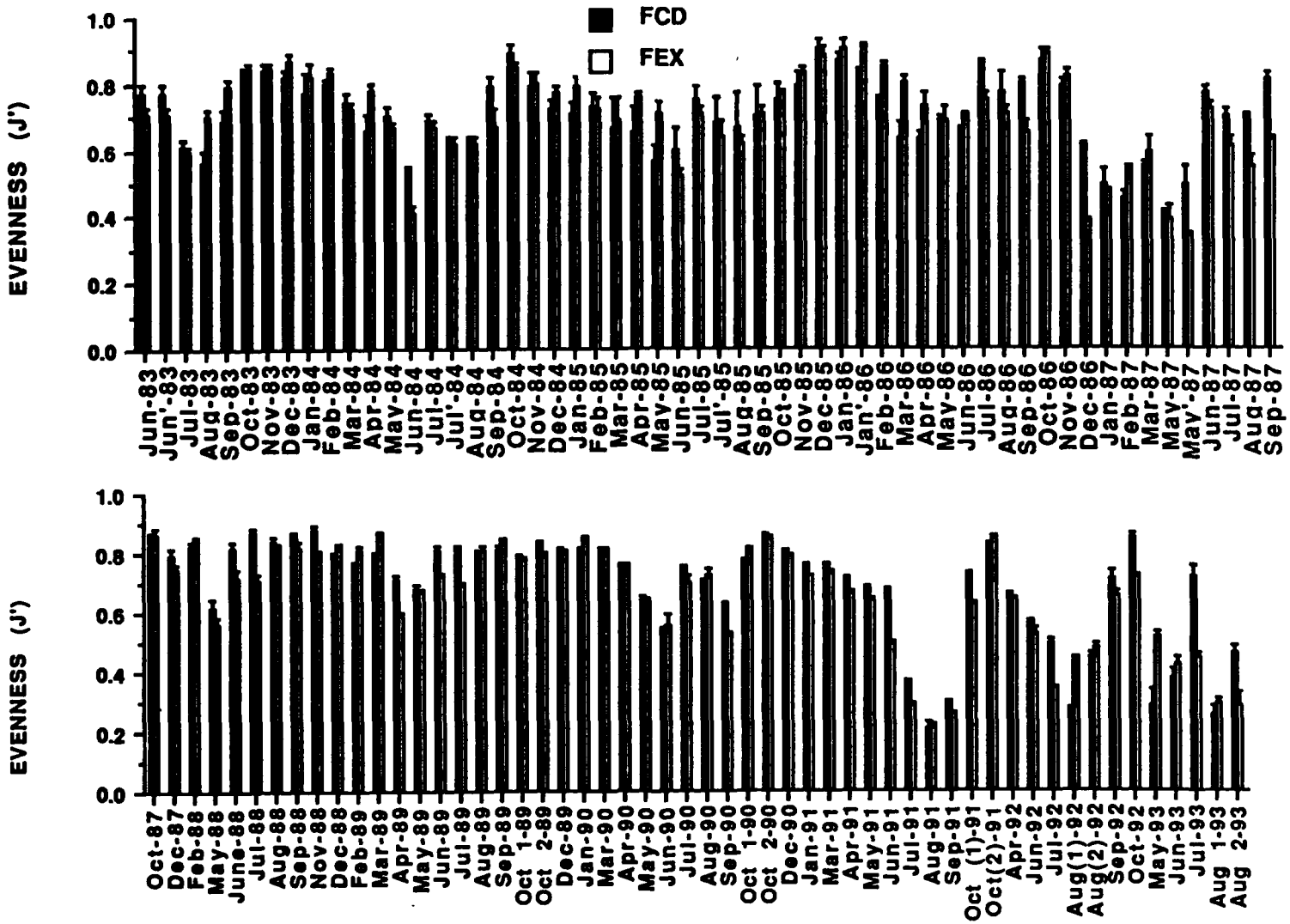


FIGURE 2.10 DIATOM SPECIES EVENNESS FOR THE FORD RIVER, 1983-1993.

Table 2.17 Species Diversity (H') for Experimental (FEX and FEX-N) and Control (FCD and FCD-N) sites for 1992-1993. Values are Means ± S.E, N in parentheses.

Date	Experimental		Control	
	FEX	FEX-N	FCD	FCD-N
9/26/92	2.340 ± 0.028 (3)	2.067 ± 0.060 (3)	2.510 ± 0.126 (3)	2.627 ± 0.032 (3)
10/24/92	2.632 ± 0.056 (3)	2.691 ± 0.078 (3)	3.200 ± 0.126 (3)	3.187 ± 0.031 (3)
5/11/93	1.508 ± 0.029 (3)	1.402 ± 0.087 (3)	0.781 ± 0.172 (3)	0.977 ± 0.031 (3)
6/8/93	1.324 ± 0.082 (3)	1.541 ± 0.122 (3)	1.216 ± 0.083 (3)	0.775 ± 0.223 (3)
7/6/93	1.280 ± 0.040 (3)	1.671 ± 0.096 (3)	2.435 ± 0.060 (3)	1.714 ± 0.025 (3)
8/2/93	0.818 ± 0.030 (3)	0.793 ± 0.015 (3)	0.658 ± 0.106 (3)	0.490 ± 0.026 (3)
8/27/93	0.835 ± 0.171 (3)	1.626 ± 0.048 (3)	1.603 ± 0.048 (3)	1.209 ± 0.081 (3)

Table 2.18 Species Evenness (J') for Experimental (FEX and FEX-N) and Control (FCD and FCD-N) sites for 1992-1993. Values are Means ± S.E, N in parentheses.

Date	Experimental		Control	
	FEX	FEX-N	FCD	FCD-N
9/26/92	0.657 ± 0.009 (3)	0.609 ± 0.015 (3)	0.708 ± 0.027 (3)	0.756 ± 0.010 (3)
10/24/92	0.712 ± 0.010 (3)	0.713 ± 0.027 (3)	0.849 ± 0.012 (3)	0.826 ± 0.006 (3)
5/11/93	0.515 ± 0.013 (3)	0.429 ± 0.020 (3)	0.288 ± 0.047 (3)	0.348 ± 0.007 (3)
6/8/93	0.424 ± 0.024 (3)	0.517 ± 0.028 (3)	0.374 ± 0.036 (3)	0.274 ± 0.066 (3)
7/6/93	0.449 ± 0.013 (3)	0.547 ± 0.014 (3)	0.715 ± 0.039 (3)	0.524 ± 0.014 (3)
8/2/93	0.289 ± 0.017 (3)	0.267 ± 0.007 (3)	0.254 ± 0.029 (3)	0.202 ± 0.009 (3)
8/27/93	0.282 ± 0.051 (3)	0.463 ± 0.042 (3)	0.464 ± 0.018 (3)	0.387 ± 0.018 (3)

Table 2.19 Dominant Summer Diatom Species at Experimental (FEX) and Control (FCD) Sites, 1983-1993. Values for each species indicate percent dominance by numbers.

Site		Achnanthes minutissima	Cocconeis placentula	Diatoma tenue	Fragilaria vaucheriae	Gomphonema intricatum	Gomphonema olivaceum	Meridion circulare	Navicula cryptocephala	Synedra ulna
FEX										
	83	15	34							
	84	40	27							
	85	32	31							
	86	31	20							
	87	30	19							
	88	24	25							
	89	19	15		10					
	90	35	12							
	91	21	60							
	92	30	52							
	93	24	56							
FCD										
	83	14	39							
	84	34	21							
	85	32	24							
	86	22	9							
	87	24	20							
	88	22	14							
	89	16	15		12					
	90	29	15							
	91	19	55							
	92	27	52							4
	93	28	46							

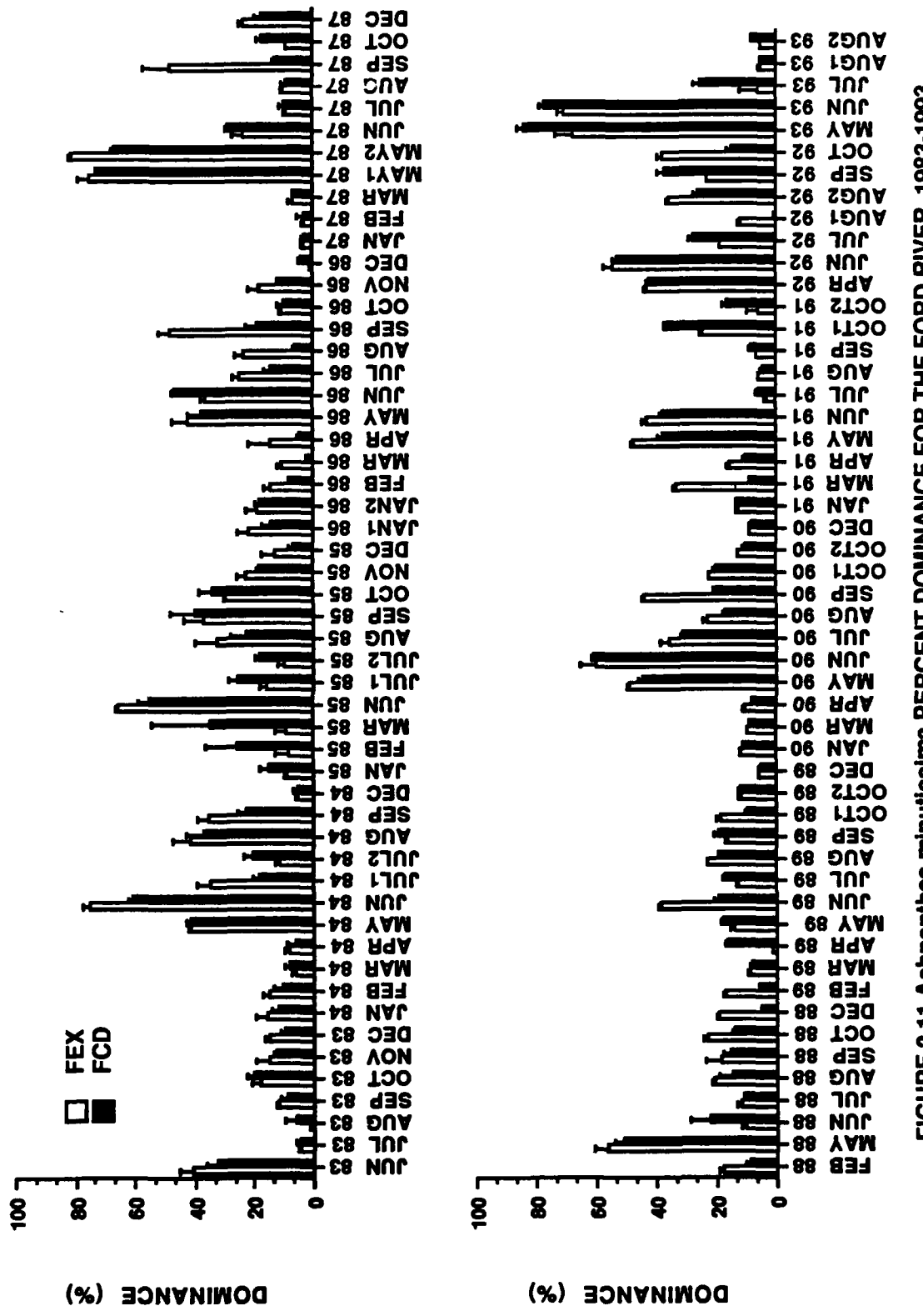


FIGURE 2.11 Achnanthes minutissima PERCENT DOMINANCE FOR THE FORD RIVER, 1983-1993.

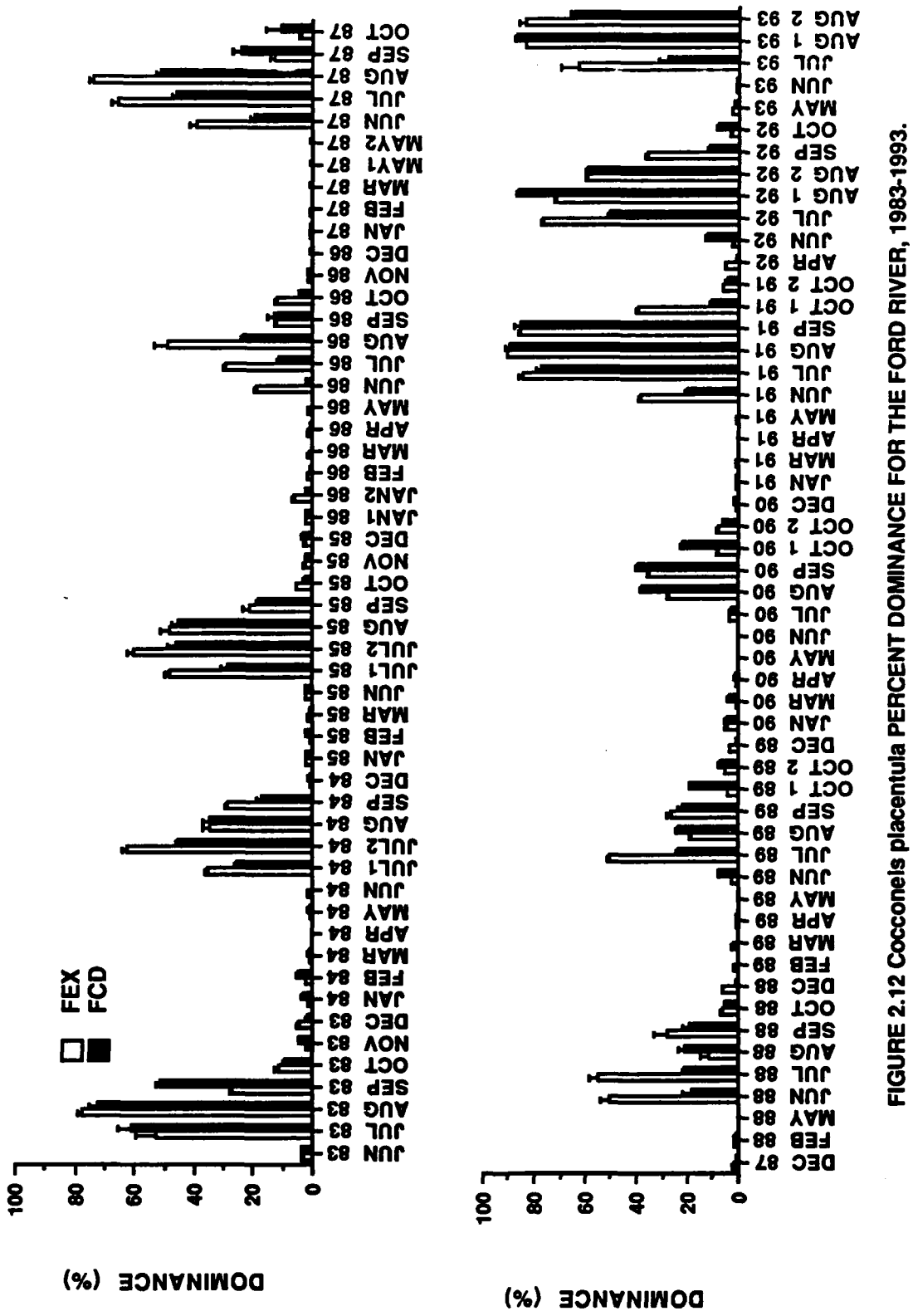


FIGURE 2.12 Cocconeis placentula PERCENT DOMINANCE FOR THE FORD RIVER, 1983-1993.

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. We have almost completed the calculations necessary for this and expect to report dominance based on biovolume in the final report.

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. From the summer 1991 through August 1993, Fragilaria relative abundance has been quite low with respect to the eight year period preceding (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 2.20). The winter of 1990-1991 followed this dominance pattern, with the reappearance of Gomphonema as a dominant species (Table 2.20, Fig. 2.14). Synedra ulna, which became a dominant species during the unusually warm winter of 1986-87 when it reached abundance levels of 51%, was not a dominant member of the winter community during 1990 (Table 2.20, Fig. 2.15). The variable winter species abundance pattern observed during 1990 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, Cymbella minuta, Fragilaria construens and Synedra ulna have also responded in a predictable manner throughout the eight year period (Figs. 2.16, 2.17, 2.18, 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 Cymbella minuta (Fig. 2.17). There are three winter abundant species: Achnanthes lanceolota, Fragilaria construens and Synedra ulna (Figs. 2.16, 2.18, 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. 2.9, 2.10).

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 2.21). Differences between the control and impact sites were calculated using the arcsin square root of

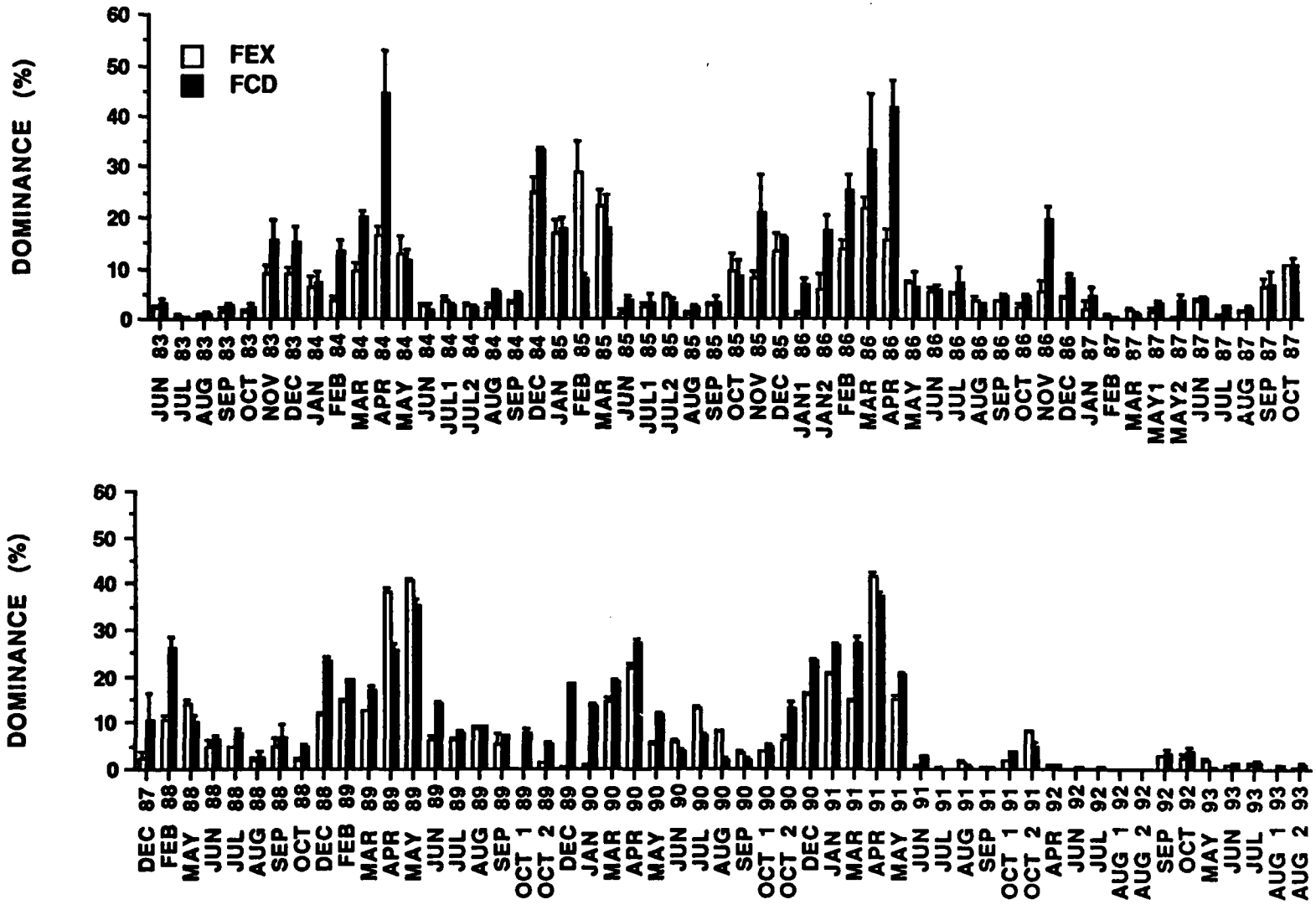
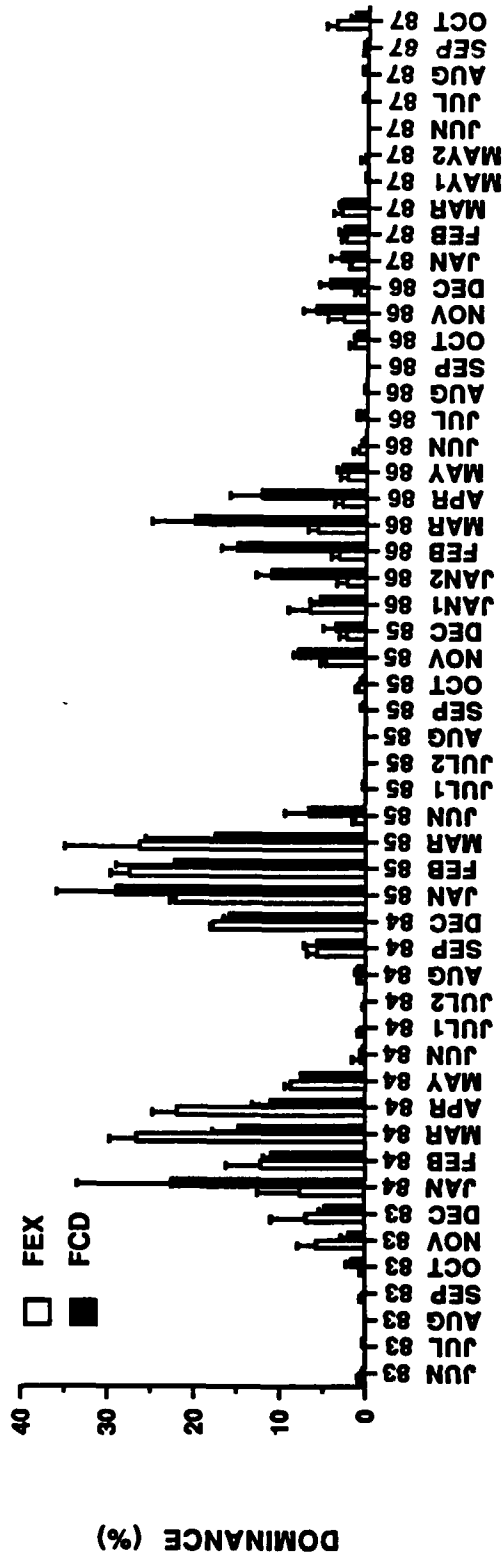


FIGURE 2.13 Fragilaria vaucheriae PERCENT DOMINANCE FOR THE FORD RIVER, 1983-1993.

Table 2.20 Dominant Winter Diatom Species at Experimental (FEX) and Control(FCD) Sites, 1983-1990. Values for each species indicate percent dominance by numbers.

Site and Year	Achnanthes minutissima	Cocconeis placentula	Diatoma tenue	Fragilaria vaucheriae	Gomphonema intricatum	Gomphonema olivaceum	Meridion circulare	Navicula cryptocephala	Synedra ulna
FEX									
83	13			9		14	10		
84	8			23		23			
85	16			11		4	8		
86			10						53
87	21			6	12	8		12	
88	12			19		3			
89	9			9					13
90	18			23		13			
FCD									
83	10			19		11	13		
84	21			12		21			
85	10			23		11	11		
86			8						50
87	13			16	6	14		6	
88	9			21		15			
89	8			19					10
90	10			27		5			



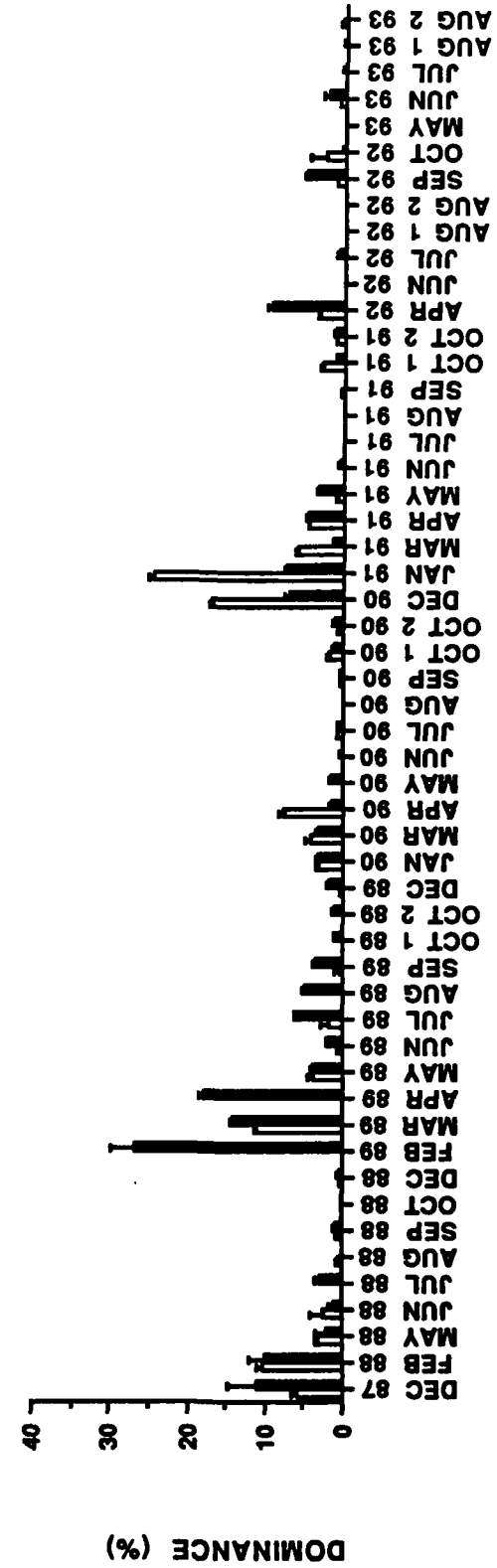


FIGURE 2.14 Gomphonema olivaceum PERCENT DOMINANCE FOR THE FORD RIVER, 1983-1993.

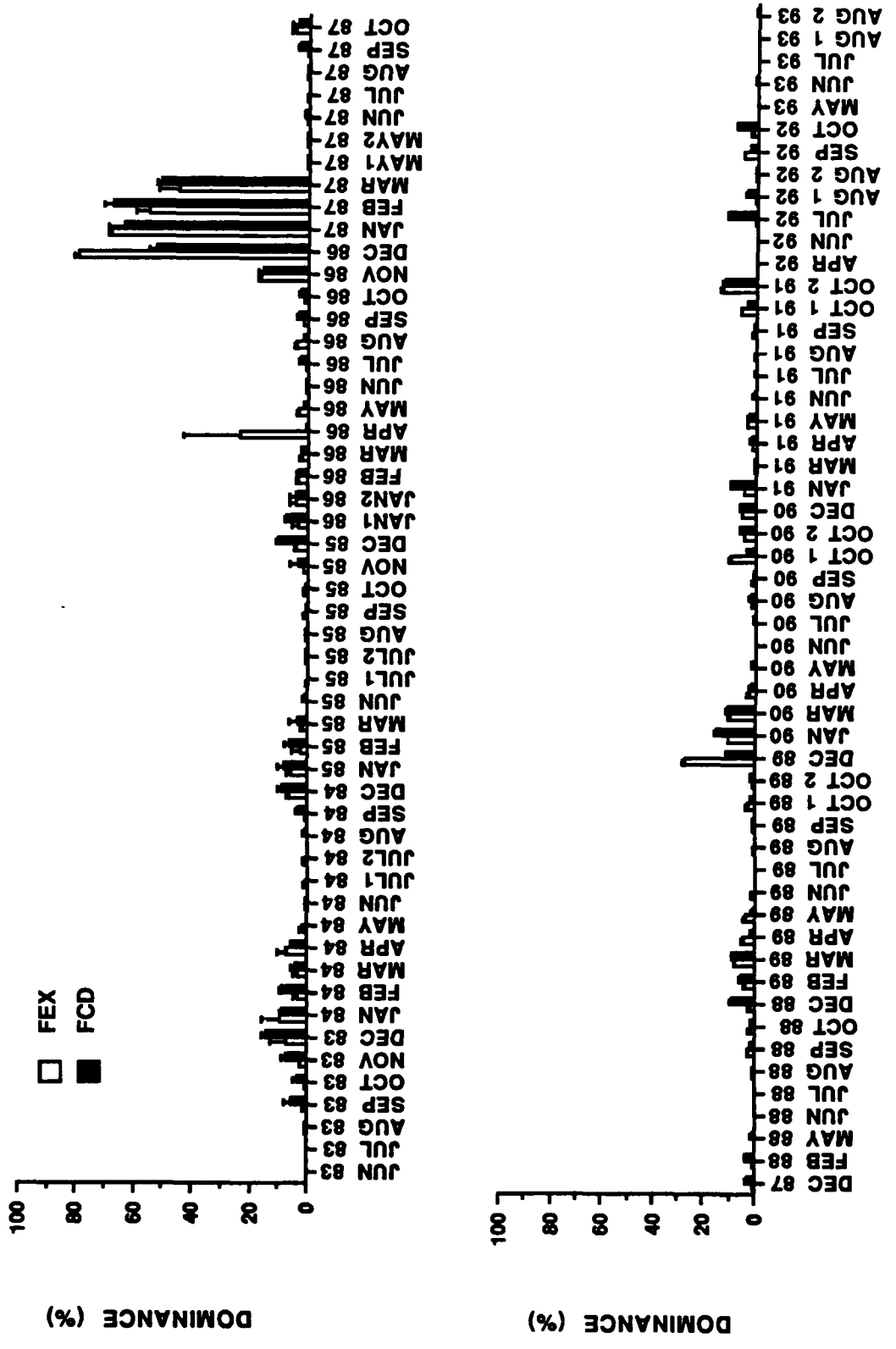
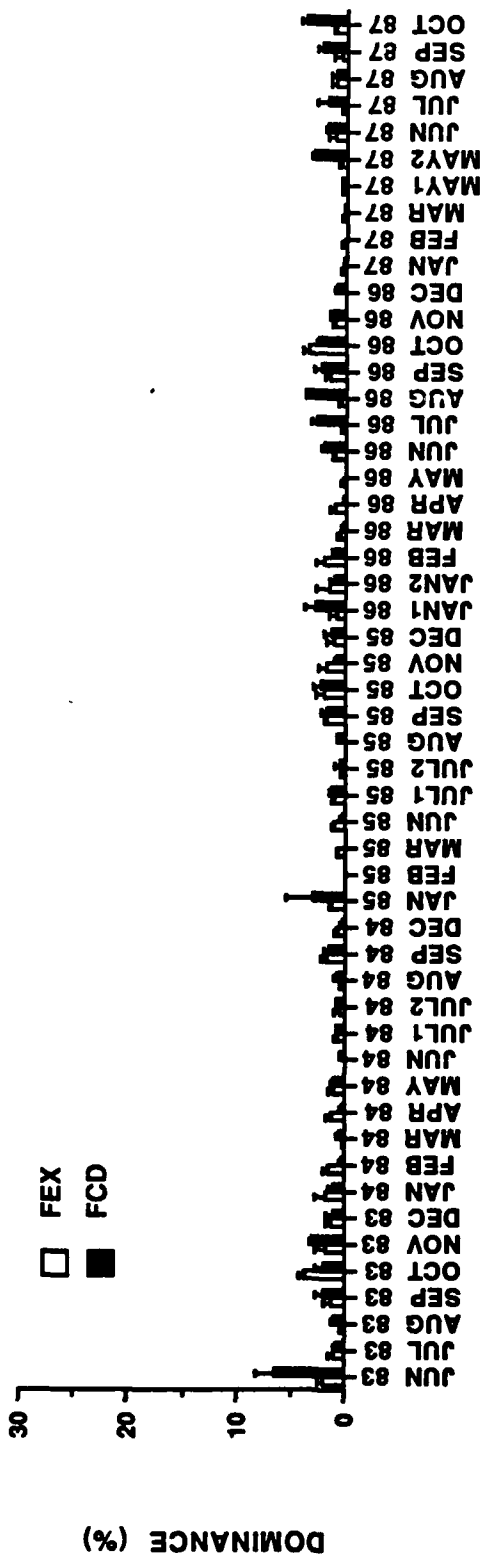


FIGURE 2.15 Synedra ulna PERCENT DOMINANCE FOR THE FORD RIVER, 1983-1993.



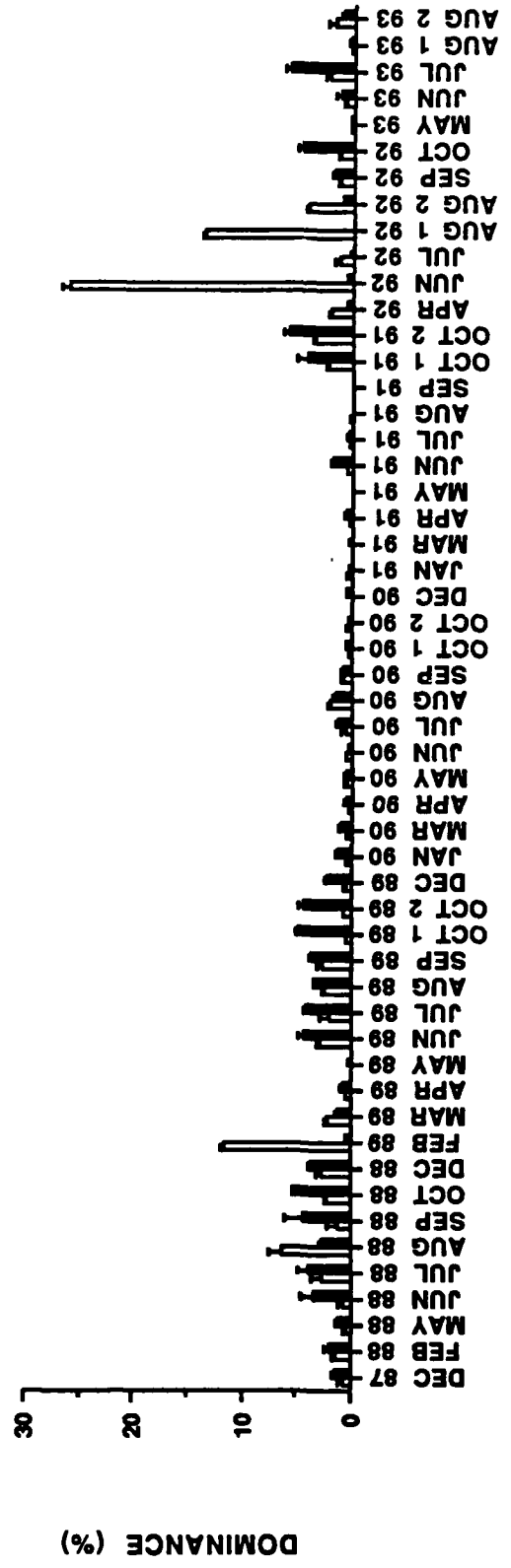


FIGURE 2.16 Achnanthes lanceolata PERCENT DOMINANCE FOR THE FORD RIVER, 1983-1993.

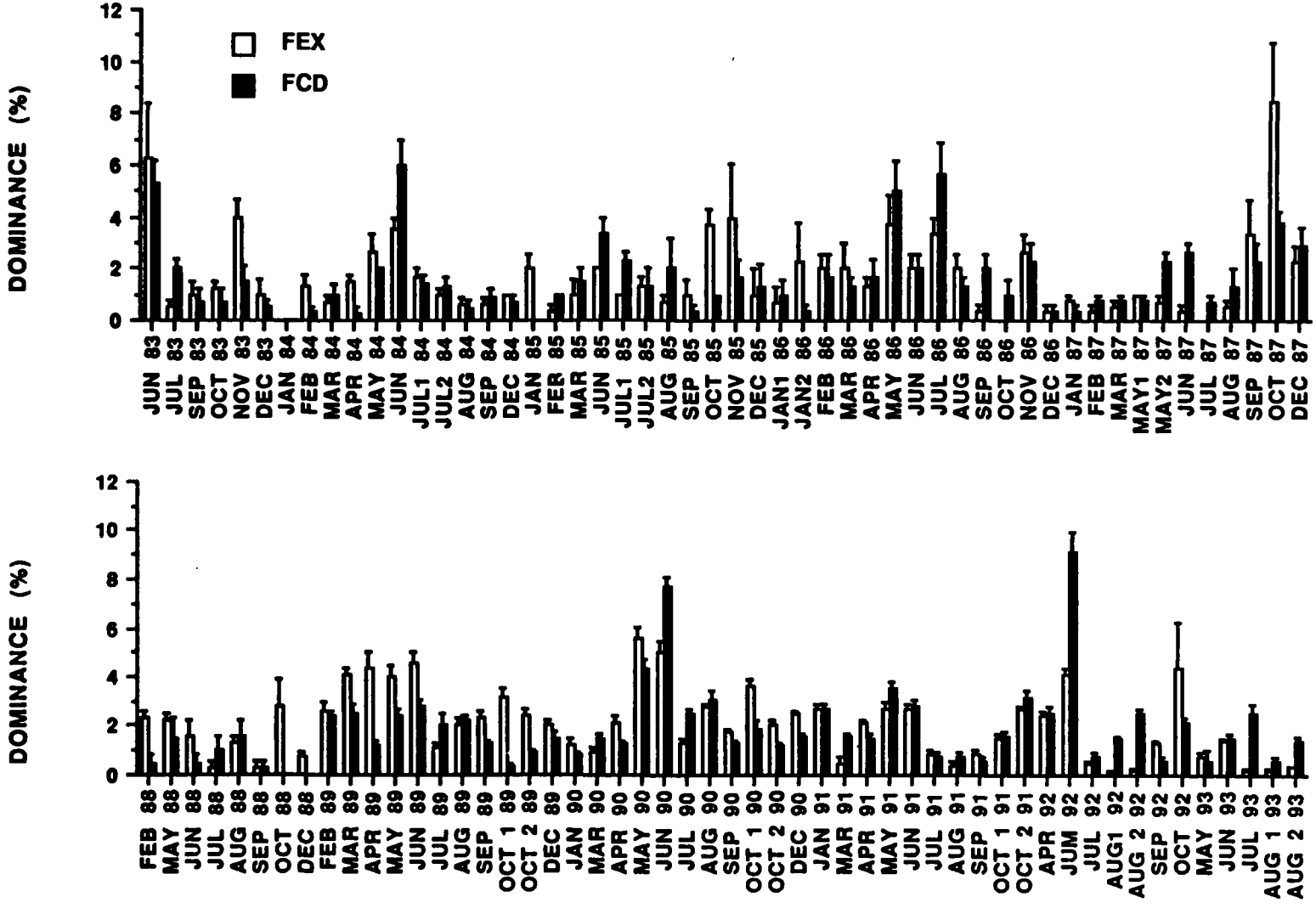


FIGURE 2.17 Cymbella minuta PERCENT DOMINANCE FOR THE FORD RIVER, 1983-1993.

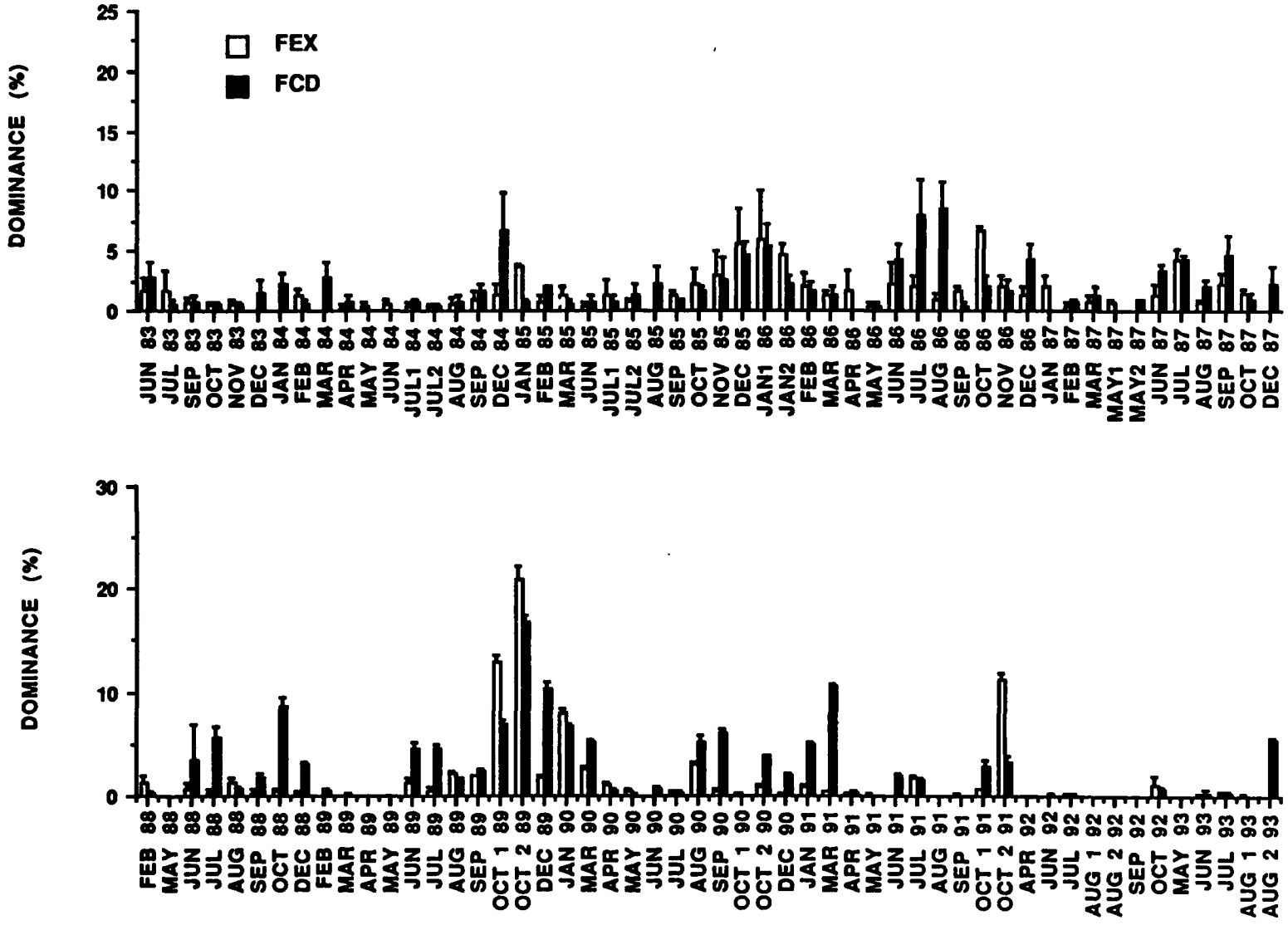


FIGURE 2.18 Fragilaria construens PERCENT DOMINANCE FOR THE FORD RIVER, 1983-1993.

Table 2.21 Summary of Diatom Abundance BACI and RIA Comparisons between Control (FCD) and Experimental (FEX) Sites for 1983-1992.

Parameter	Comparison	BACI Signif. ($p < 0.05$)	RIA Signif. ($p < 0.05$)
Summer			
Achnanthes minutissima	Summer 83-85 vs. 90-92	NS	
Cocconeis placentula	Summer 83-85 vs. 90-92	NS	
Cymbella minuta	Summer 83-85 vs. 90-92	NS	
Winter			
Achnanthes minutissima	Winter 83-86 vs. 89-90	NS	NS
Fragilaria vaucheriae	Winter 83-86 vs. 89-90	NS	NS
Gomphonema olivaceum	Winter 83-86 vs. 89-90	NS	NS
Synedra ulna	Winter 83-86 vs. 89-90	NS	NS

the mean transformation suggested by Steel and Torrie (1960) for proportional data. There have been no significant changes in the inter-site relationships between the before and after antenna operational periods for any of the dominant summer (Achnanthes, Cocconeis) or winter species (Achnanthes, Fragilaria, Gomphonema) when the entire seasonal 1983-1985 "before" data were compared to the 1989-1992 "after" data (Table 2.22). Seasonal pooled BACI comparisons of mean differences for the typically non-dominant species Cymbella minuta and Synedra ulna were also not significant (Table 2.22).

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 1989-92 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 2.22). With the addition of several more years of data, the analysis of these species may prove to be sensitive indicators of potential ELF effects.

Paired t-tests between the control (FCD) and experimental site (FEX) showed no significant difference for either diversity or evenness for the time period before antenna operation (Table 2.2). There were significant differences in diversity and evenness between the two sites after antenna operation began (Table 2.3). The new control site (FCD-N) and FCD differed significantly in both diversity and evenness (Table 2.6). The new antenna site (FEX-N) conversely, did not differ significantly from FEX for the two parameters (Table 2.5). Significant correlation coefficients between both antenna sites and both control sites were found for diversity and evenness. When the site of highest exposure (FEX-N) was compared to the site of lowest exposure (FCD-N) for the June, 1990-August,1993 period, neither diversity nor evenness were found to differ significantly (Table 2.7).

Both evenness and diversity exhibit low minimum detectable differences, 5.1% and 7.4%, respectively (Table 2.8). Additionally, power analyses completed for each parameter indicated that both diversity and evenness represent our most sensitive parameters for detecting potential ELF effects (Fig. 2.2F, 2.2G).

Table 2.22 Results of Monthly BACI Comparisons of Dominant Diatom Species, 1983-1992. Degrees of freedom in parentheses.

Species	Comparison	BACI Significance (NS = p > 0.05)
Achnanthes minutissima	May & Jun 83-85 vs. May & Jun 89-92 (8)	NS
Cocconeis placentula	July - Sept. 83-85 vs. July-Aug.89; Aug.-Oct.90; June-Oct.91; July-Aug.92 (27)	NS
Fragilaria vaucheriae	Feb.- May 83-86 vs. Feb.- May 89-90 (14)	NS
Gomphonema olivaceum	Feb & Mar 83-86 vs. Feb & Mar 89-90 (6)	NS

Results of BACI and RIA comparisons for untransformed diversity data and log (x+1) transformed evenness data indicated that no significant changes occurred in the inter-site relationship for the "before" (6/83-4/86) and "after" (10/89-8/93) ice-free and Cocconeis dominant data sets (Tables 2.15).

G. 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. 1978). 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. 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 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. From 1985 to 1989 the studies were done at the FEX and FCD periphyton sites. When FEX-N and FCD-N were instigated in 1990, the production and respiration studies were permanently moved to these sites to take advantage of their 10 fold difference in ELF exposure.

The assumptions made for the purposes of production calculations considered algal periphyton to occupy only on 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 2.23) from dissolved oxygen, chlorophyll a, and rock surface area measurements.

Table 2.23 Hourly Production and Respiration Rates for Rock Substrates of the Ford River.

Date	NET PRIMARY PRODUCTION			RESPIRATION*			GROSS PRIMARY PRODUCTION**	
	mgO_2/m^2	mg Chl a/m^2	$\frac{mgO_2}{mg\ Chl\ a}$	mgO_2/m^2	mg Chl a/m^2	$\frac{mgO_2}{mg\ Chl\ a}$	mgO_2/m^2	$\frac{mgO_2}{mg\ Chl\ a}$
FORD CONTROL SITE (FCD)								
6/11/93	127.22 ± 7.41	48.44 ± 2.75	2.64 ± 0.30	35.07 ± 4.15	36.45 ± 3.74	0.99 ± 0.17	162.28	3.64
7/7/93	141.70 ± 7.99	40.06 ± 5.73	3.68 ± 0.51	33.70 ± 2.62	28.87 ± 2.61	1.20 ± 0.18	175.40	4.87
7/30/93	71.88 ± 3.66	29.77 ± 1.79	2.43 ± 0.18	64.63 ± 3.08	29.59 ± 0.60	2.18 ± 0.08	136.51	4.61
8/11/93	120.85 ± 12.59	35.69 ± 0.77	3.37 ± 0.28	29.25 ± 6.62	31.51 ± 10.30	1.00 ± 0.14	150.10	4.37
Ave ± S.E.	115.41 ± 15.15	38.49 ± 3.93	3.03 ± 0.30	40.66 ± 8.09	31.61 ± 1.71	1.34 ± 0.28	156.07 ± 8.32	4.37 ± 0.26
FORD EXPERIMENTAL SITE (FEX)								
6/11/93	106.39 ± 7.20	32.26 ± 7.00	3.52 ± 0.55	20.89 ± 5.10	18.15 ± 0.88	1.17 ± 0.32	127.28	4.69
7/7/93	120.39 ± 3.16	9.78 ± 0.74	12.49 ± 1.19	16.56 ± 1.79	11.74 ± 0.30	1.42 ± 0.19	136.95	13.90
7/30/93	104.96	26.24	3.95 ± 0.04	51.41 ± 4.55	25.40 ± 4.02	2.15 ± 0.47	156.37	6.11
8/11/93	123.28 ± 7.60	24.36 ± 0.27	5.06 ± 0.26	56.38 ± 2.46	20.31 ± 0.75	2.79 ± 0.19	179.66	7.84
Ave ± S.E.	113.76 ± 4.71	23.16 ± 4.77	6.26 ± 2.10	36.31 ± 10.24	18.90 ± 2.83	1.88 ± 0.37	150.07 ± 11.57	8.14 ± 2.03

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

** = Total Metabolism = Respiration = Net Primary Production

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.

Paired t-tests between the control site (FCD) and antenna site (FEX) showed no significant difference in gross primary production for the time period before antenna operation (Table 2.2) and a significant difference for the time period after antenna operation (Table 2.3). Gross and net primary production and respiration, standardized by the amount of Chl a present, were higher at the experimental (FEX) site than at the control (FCD) site for 1993 (Table 2.24). We have analyzed gross primary production rates from 1984 to 1993 with the BACI technique (Table 2.9). There was no significant difference in the between site relationship for the pooled "before" and "after" data.

I. Summary

1. Comparisons between the original and new sites

Two new sites were included in 1990 to increase the exposure to electromagnetic fields so that the antenna site receives 10.3 times more exposure than the control site. There was only a 5 fold difference between the original control and antenna sites. The differences between the old and new control sites were not significant for any parameters except species diversity and evenness (the old site had higher values). The old and new antenna sites were not significantly different for any parameters except chlorophyll a standing crop and AFDW organic biomass accrual rate (the old site had higher values).

2. 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. "Before" (6/83-4/86) and "after" (6/89-8/93),

control (FCD) and impact (FEX) (BACI), and Randomized Intervention Analysis (RIA) indicate that the between site relationship in chlorophyll a has changed since the antenna began operating at full power. The paired t-tests indicate that this change has been a reversal of the pre-operational pattern when the control site was characterized by significantly higher levels of chlorophyll a than was the antenna site. After testing of the antenna began in 1986, this pattern reversed, and there were significantly higher levels of chlorophyll a standing crop and rates of accrual at the antenna site. Thus, ELF electromagnetic radiation may have stimulated chlorophyll production under the antenna.

3. Organic Matter

Organic matter (AFDW-biomass) standing crop and accrual rates showed considerable year-to-year variability similar to chlorophyll a. 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. These parameters showed significant differences between the control site (FCD) and experimental site (FEX) for the time period after antenna operation. BACI analyses and RIA showed that a difference had occurred in AFDW-organic matter standing crop since the testing of the antenna began in 1986 for the periods when Cocconeis placentula was dominant. When the ice-free standing crop data set was analyzed using BACI and RIA the results were more equivocal. BACI and RIA analyses gave conflicting results for organic matter accrual rates for both ice-free and Cocconeis dominant periods. In the case of the Cocconeis dominant data set low sample size make the RIA results difficult to interpret. Taken as a whole, these data are clearly not as robust as the chlorophyll a data but suggest that ELF antenna operation may be stimulating additional accumulation of organic matter biomass on the rock surface biofilm at the antenna site.

4. Diatom Cell Density

Diatom cell density was not statistically different between FEX and FCD sites according to paired t-tests of the time period after antenna operation. The removal of a single potential "outlyer" data point however, resulted in a statistically significant difference ($p<0.01$). BACI analyses and RIA indicated that data collected before antenna operation in 1983-86 were significantly different from data collected after the antenna starting operating at full power in 1989. Data for diatom density suggest the possibility that

operation of the antenna has led to increased standing crop of diatoms in the river, especially during the summer months.

5. Total Biovolume and Individual Cell Volume

Individual cell volume and biovolume comparisons of diatoms between the control (FCD) and experimental (FEX) sites showed no significant differences for the time period after antenna operation. BACI analysis and RIA detected no significant changes in the inter-site relationship for cell volume. For the ice-free period, BACI analysis showed a significant difference between the "before" and "after" biovolume data but this finding was not supported by RIA analysis. Neither BACI or RIA tests were significant when the Cocconeis dominant biovolume data set was considered. 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 cell density. The total diatom biovolume data are highly variable leading to less power to detect changes than is desirable. Nevertheless, trends for biovolume are in the same direction as are those for chlorophyll a, AFDW organic matter, and cell density. Since all of these parameters are related to increased algal biomass and production and have increased at the antenna site after antenna operation began, the conclusion that antenna operation may be stimulating algal growth appears to be warranted.

6. Species Diversity and Evenness

Diatom species diversity and evenness are the least variable parameters that are monitored. Differences of less than 10 % can be statistically detected with these parameters. Diversity and evenness were significantly different between FEX and FCD during the time after antenna operation using paired t-tests, but not for the period prior to antenna operation. Annual trends showed a high diversity and evenness during winter (except winter of 1986-87) and lower values during the summer periods. Neither diversity or evenness for the diatom community has been significantly affected since operation of the ELF antenna began according to the paired BACI and RIA analyses.

7. Changes in abundance of individual diatoms

In 1993, 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 1993 summer period. During the 1991 summer, Cocconeis reached its highest abundances ever

observed since 1983. Three species achieved dominance during the winter of 1989. BACI analyses were presented for four dominant and two non-dominant species of diatoms and showed that no significant differences have occurred before and after antenna operation began for any of these 6 species.

8. Photosynthesis-Respiration Studies

Net primary production, respiration, and gross primary production of the community on rock surfaces did not differ greatly between sites for the time period after antenna operation, however paired t-tests suggest there is a significant difference between FCD and FEX. BACI analysis indicated that there have been no significant differences between FEX and FCD sites for gross primary production rates for "before" and "after" data.

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Element 3 - Effects of Insect Grazer Populations of Periphyton Communities

Changes from workplan - This element was eliminated following the 1989 field season, since effects were determined to be too variable and inconsistent from year to year to be useful in detecting ELF effects. Efforts previously spent on this element were used for the periphyton studies at two additional sites for Element 2.

Element 4: Summary for Richness and Biomass of Stream Insects

Data were grouped according to season for statistical analyses after looking at coefficient of variation values: **Sprir g** (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. Coefficient of variation values were highest during those seasons. Seasonal data were first analyzed, using 2-Way ANOVAS. Data from each site were regressed against years, ELF cumulative exposure, discharge, and water cumulative degree days to determine which physical factors were more important in accounting for the biotic variance. Usually discharge was most correlated in the spring. Discharge and/or cumulative degrees was most important in the summer. There were mixed results with regard to the fall season data.

B.A.C.I. tests and R.I.A. tests were used to look for significant before versus after ELF activation associations. One biotic parameter in the R.I.A. tests showed significant before versus after differences; namely, total insect mass in the summer stable period. Multiple regressions showed that discharge and water temperature were correlated with insect mass, and so those parameters were graphically analyzed to determine whether there were clusters of points for years before E.L.F. activation versus after E.L.F. activation, the hypothesis being that, by chance alone, other physical factors had changed in a manner similar to E.L.F. field intensities and durations. There were no sequential pattern in the graphs. Sequential multiple regressions, using E.L.F. cumulative ground field exposure rather than years were performed to see if E.L.F. exposure was related to summer insect mass changes. Each statistical run incorporated an additional year. Discharge was shown to be more important than E.L.F. exposure or cumulative degree days over the years at FEX. All three variables at FCD contributed to the R^2 values. Evenso, discharge generally was the most important physical factor. These results suggest to us that E.L.F. exposure did not directly affect changes in insect mass at the experimental site. Variation in discharge and water temperature is much greater in the spring and fall seasons, and it was much easier to detect differences attributable to those physical factors in the spring and fall than in the summer. Total insect mass showed no significant before versus after differences in the spring and fall.

R.I.A. tests showed significant differences for number of individuals (without chironomids) in the summer and fall, and significant differences for percent chironomid dominance in the fall. Numbers of individuals is the most

highly variable parameter we have. Only means are used in the B.A.C.I. and R.I.A. analyses so the tests do not take extreme variability into consideration. Both biotic parameters were similar at FEX and FCD after E.L.F. full power, but were higher at FEX before E.L.F. activation. We hypothesize that the substrate at FEX became more sandy over the years, owing to higher beaver activity just upstream of the FEX site. (At FCD, beaver activity did occur, but it occurred below the FCD site).

Discharge and water temperatures were highly correlated with taxon richness, with insect mass, and with periphyton density. The linear relationship was very pronounced in May each year, with the hignest R^2 value being for taxon richness versus water temperature (R^2= 0.85).

ANCOVAS showed no differences between sites with respect to mean dry weight values per individual and physiological time (cumulative degree days for water temperatures) for the collector-gatherer mayfly, Paraleptophlebia mollis. Five other prominent taxa were monitored at the sites. Graphical analyses revealed no obvious differences between the sites for those species.

A summary table gives statistical results for FEX and FCD comparisons for the biotic parameters. (See Tables 4.1B and 4.5B for 2-way ANOVAS comparing FEX, FCD, and FEX.LINE).

Summary of Statistics for Structural and Functional Community Parameters
2-Way ANOVAS and Multiple Regressions: 1986-1993
B.A.C.I. and R.I.A.: Before: April 84 - May, 86 .After = June 89 - Aug., 93

PARAMETER, SEASON	***2-WAY ANOVA: Signif. factors (FEX vs. FCD)***	***MULT.REG.: For Vars. with R^2 > .29***	***BACI TEST S***	***RIA Tests***
DIVERSITY				
Spring	Friedman: none	N/A	N/A	n.s.
Summer	Site, Year,S*Y	FEX: Disch,CDD	n.s.	
Fall	Site, Year	FEX: Disch	n.s.	
EVENNESS				
Spring	Friedman: none	N/A	N/A	n.s.
Summer	Site, Year,S*Y	FEX: Disch,CDD	n.s.	
Fall	Site, Year		n.s	
RICHNESS				
Spring	Site, Year,S*Y	FEX: Disch	n.s.	
Summer	Site, Year	FEX: Disch FCD: Disch	n.s.	
Fall	Site, Year, S*Y		n.s.	

NO. INDIVIDUALS				
Spring	Site, Year, S*Y	FEX: Disch FCD: Disch	n.s.	
Summer	Site, Year, S*Y	FCD: Disch	N/A	***
Fall	Site, Year, S*Y	FEX: Disch, CDD	N/A	***
CHIRO. # DOM.				
Spring	Site, Year, S*Y		**	
Summer	Friedman: Site		n.s	
Fall	Site, Year	FEX: Yr, CDD	N/A	***
TOTAL INSECT MASS				
Spring	Year	FEX: Disch	n.s.	
Summer	Site, Year, S*Y	FEX: Disch FCD: Disch, CDD, ELF fields	N/A	***
Fall	Site, Year, S*Y		n.s.	
CHIRO. MASS DOMINANCE				
Spring	Year		n.s.	
Summer	Site, Year		n.s.	
Fall	Friedman: Site		n.s.	
COLL.GATH. MASS DOM.				
Spring	Site, Year		n.s.	
Summer	Site, Year		n.s.	
Fall	Site, Year		n.s.	
PRED./PREY RATIO				
Spring	Year		n.s.	
Summer	Site, Year, S*Y		n.s.	
Fall	Site, Year		n.s.	

N/A = Not appropriate or failed Tukey's Test

Disch = Discharge
CDD = Cumulative Degree Days
Yr = Year

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 July, 1990. It 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 of six taxa of aquatic insects are altered after E.L.F. activation.

Rationale

There is considerable controversy over whether extremely low fequency (E.L.F.) electromagnetic fields impose potential biological effects on exposed organisms. Studies on predominantly terrestrial organisms exposed to electric fields have reported loss of coordination (Watson, 1988), increased incidence of rearing activity (Rudolph et al., 1985), impedance of navigation (Tenforde, 1989), and alterations of life history patterns (Walters and Carstensen, 1986). Other experimental findings, however, suggest little or no biological effects from exposure (Sheppard and Eisenbud, 1977; Ganskopp et al., 1991; Stout, 1992). Some aquatic organisms (e.g. bacteria, algae, elasmobranch fishes) are known to possess magnetite, a biogenic compound responsible for geomagnetic sensitivity, which allows them to respond behaviorally to weak electromagnetic fields (Frankel and Blakemore, 1989; Kirschvink, 1989). It is possible that aquatic insects may also have the capacity to detect E.L.F. fields and alter their behavior accordingly. To our knowledge, only one study has been conducted that explores potential effects of electromagnetic fields on stream insects (Stout, 1992). We therefore performed experiments where we attempted to document the existence or absence of E.L.F. field-induced effects on a range of structural and functional community parameters associated with a lotic insect community.

The composition of a benthic invertebrate community may be modified by biotic factors, notably predation (Peckarsky and Dodson, 1980; Gilinsky, 1984; Power, 1990). Others have demonstrated, however, that benthic community structure, particularly in streams, is often governed principally by physical

factors, which in turn may influence the intensity of biotic interactions (Stout, 1981, Feminella and Resh 1990). High discharge events and floods can scour the benthic substrata, rendering it temporally barren of aquatic biota and thus creating areas with high potentials for colonization and recruitment of epilithic algae and insects. Current velocity may directly affect the size of substrate particles on the stream bottom, which itself is an important determinant of insect distributions (Rabeni and Minshall, 1977; Stout, 1981). In streams in the northern United States, discharge levels and water temperatures often change discretely by season. To have predictive power on the potential effects of physical variables on stream dwelling invertebrates, therefore, it is advantageous to monitor the system of study over a period of several years. Such long-term monitoring also makes clear the separation between natural variability and effects attributable to alterations in physical parameters (McElravy et al., 1989).

The present study encompasses 10 years (April, 1984-August, 1993) of monitoring E.L.F. cumulative ground field exposures, discharge rates, and maximum-minimum daily water temperatures. We wished to determine the independent variables most responsible for variation in structural community parameters; namely, insect diversity, richness, evenness, numbers of individuals, and percent dominance of chironomids at two experimental sites, FEX and FEX.LINE, and at one reference site, FCD, for the Ford River in the upper peninsula of Michigan. We also monitored several functional community parameters: total insect mass, percent dominance of collector-gatherer insect mass and of chironomid mass as well as predator/prey mass ratios. Finally, we followed changes in numbers and sizes of six insect taxa to see whether their growth rates and recruitment levels were affected by E.L.F. cumulative exposures and/or changes in physical factors within seasons over the years.

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.

Structural Community Indices: Benthic insect samples can include a large number of non-biting midges (Chironomidae), and our samples are no exception. Each sample can contain up to 3,000 individuals. Because identifications to genus, let alone to species, are very time consuming, efforts at adjusting to possible differences in numbers of taxa among the two experimental (FEX and FEX.LINE) sites and the reference (FCD) site were made. Structural community indices were computed both with and without chironomids at the sites, and separate analyses were performed on the three

data sets to determine whether the unavoidable bias for this taxonomic family unit differentially affected the indices at the three sites for previous Annual Reports (See 1991 Annual Report). Because chironomids were usually more abundant relative to other taxa at the more sandy site, FCD, we excluded chironomids from taxon diversity, evenness, and numbers of individuals indices for this Report. Seasonal trends in chironomid numerical dominance at the three sites were analyzed to quantify our rationale for deleting that family from indices that would be biased when taxa within the family could not be identified to lower taxonomic units.

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 standing stock 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 most sensitive insect functional feeding group may be those collector-gatherers and grazers that consume periphyton. In addition, an index that reflects the potential insect prey for the insect predators was monitored, using relative mass values of predators to their prey. This index may be sensitive to physical differences and changes among sites or to any impacts of E.L.F. on predator/prey dynamics.

Changes in numerical recruitment and estimates of growth rates (insect mass per unit individual) were monitored for five species of collector-gatherers or scraper-grazers as well as for the family Chironomidae, which includes all functional feeding groupings. If a major resource, namely the primary producers in the stream, were affected by E.L.F. operations, then growth rates and recruitment of these periphyton consumers may be altered. Efforts were made at selecting numerically common univoltine species. Chironomids were monitored as well, owing to their numerically dominant role in the community.

Statistical analyses include power tests, coefficient of variation values, the Scheffe-Box test for homogeneity of variances, and 2-Way ANOVAS or Friedman 2-Way ANOVA tests comparing biological parameters within seasons over the years between and among sites. ANCOVA tests between sites were run for insect mass vs. discharge and for growth rates vs. physiological time (cumulative degree days). In-site comparisons using multiple regressions were made to relate physical factors having the highest correlation coefficients with

biological factors (See 1989 Annual Report). In 1991, E.L.F. cumulative ground field exposure values were also included in the multiple regression tests. An intervention analysis test, the B.A.C.I. (Stewart-Oaten et al. 1986) was used when pre-operational data passed Tukey's test for nonadditivity. B.A.C.I. tests use only sample means, so much of the data are lost by this method. Further, variations around mean values tend to be high in field-derived data as compared with laboratory-derived data. Dr. Abdul El-Shaarowi of the Canadian Center for Inland Waters (with whom ITTRI is consulting) is presently utilizing some of the data in this Element to improve the rigor of the test. Possibly, in the Final Report, B.A.C.I. tests, based on residuals from prior statistical tests rather than on sample means, will be completed and compared with the convential procedure for B.A.C.I. tests. Note that if pre-operational data did not pass Tukey's test for nonadditivity, a non-parametric analog, the R.I.A. test (Carpenter, 1989) was used.

In this report all statistical tests were performed on seasonal data groupings. Data are grouped into three seasons: Spring (April, May), Summer (June, July, August), and Autumn-Winter (September through November or December). Data analyses based on seasonal groupings rather than on all months together was a decided improvement (See Three-way versus Two-way ANOVAS in 1990 Annual Report) because coefficient of variation values for most of the biological parameters were lower during the summer stable period as compared with the spring and fall transition periods. 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" period.

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). For this report, post-operational data for B.A.C.I. and R.I.A. tests ran from 1990 through 1993 for the spring, from 1989 through 1993 for the summer, and from 1989 through 1992 for the fall season. Although initial activation occurred in late May of 1986, discontinuous but full power began in the summer of 1989 and full power over extended periods began in the fall of 1989. Before ELF activation data run from the fall of 1983 through the spring of 1986. In this Revised Annual Report, all the data through August, 1993 have been analyzed.

Materials and Methods

From November of 1983 through September of 1992, 60 micron Nitex° mesh lined half cylinder (18 x 28 x 10 cm) plastic sampler baskets were filled with benthic substrata and buried flush with the stream bottom at FEX and FCD. In June, 1990, a new site downstream from FEX was selected, based on E.L.F. field measurements. The new site, we call FEX.LINE is a definite improvement over the original FEX experimental site with respect to E.L.F. field intensities. However, before impact data sets are not available for this site. Data from July 1990 through August 1993 for this site appear in the graphical analyses. Data from the new site cannot be used in intervention analyses because we only after after impact data.

From May through September each year, seven replicates for each site were collected monthly, with replacement. (In April of 1992 and 1993 samples could note be retrieved from FEX.LINE, owing to high water.) 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 resulted in 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 for five of the seven samples. 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 chironomids were determined for each sample. Total sample biomass, biomass for functional feeding groups (after Merritt and Cummins 1984), percent biomass dominance for each functional group relative to total biomass, predator-prey ratios, and mean dry mass per individual (MDW/IND) values were computed. Years, stream discharge, mean water temperatures, and 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, a chart recorder recorded daily maximum - minimum temperatures at FCD.

Before 1988 when chart recorders were not used, estimates of water temperatures based on monthly visits to the sites were made for March and November each year.

Results and Discussion

Structural Community Indices

Structural community indices include taxon diversity, evenness, richness, number of individuals, and percent numerical dominance of chironomids. Analysis of trends and of coefficient of variation (CV) values for the biological parameters showed that there were clear differences among seasons. Months were coalesced into seasons, based on trends and CV values. **Spring** (April, May 1984 to 1993), **Summer** (June - August 1984 to 1993), and **Fall** (September - November 1984 to 1992) seasons were therefore analyzed separately. Because the abundance of chironomids can greatly affect H', J', and numbers of individuals in our study, we chose to exclude chironomids as a single taxonomic unit for H', J', and numbers of individuals (See 1991 Annual Report for rationale). Figures 4.1A through 4.1C show CV values for taxon diversity (H').

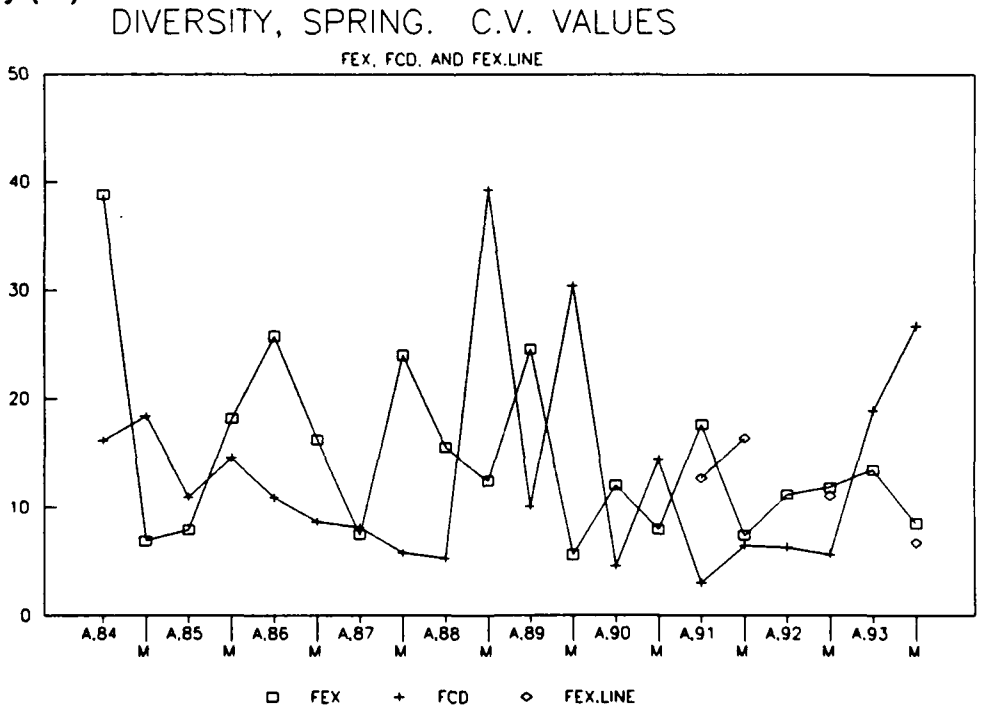

Figure 4.1A. Coefficient of variation values for diversity, without chironomids. SPRING FEX (squares), FCD (X's), FEX.LINE (diamonds). 1984-1993.

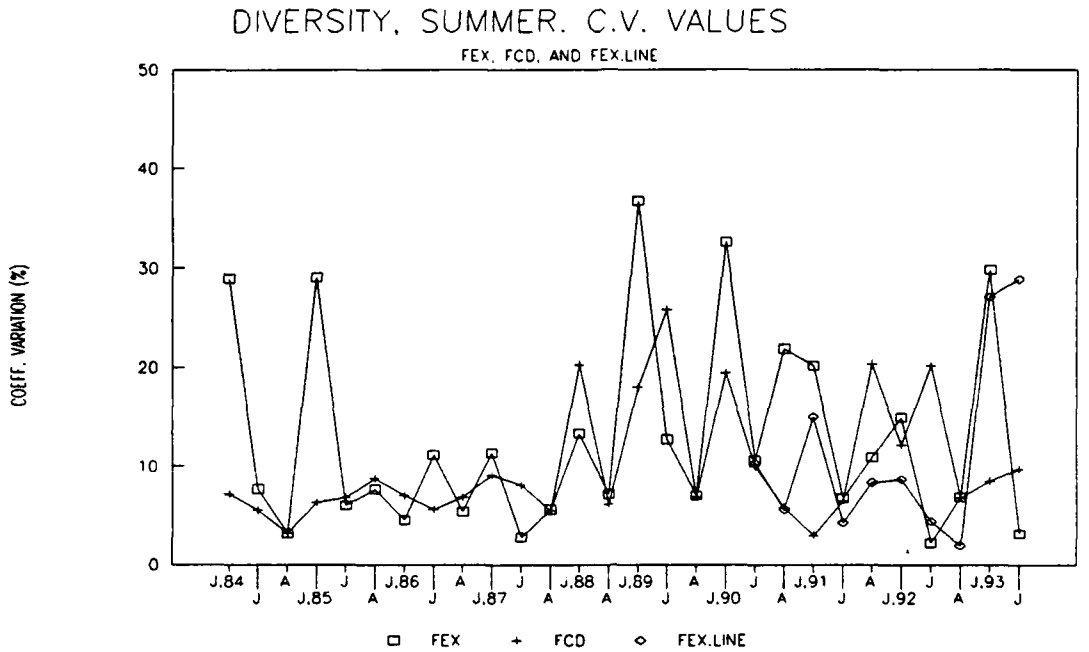

Figure 4.1B. *Coefficient of variation values for diversity, without chironomids.* SUMMER. FEX (squares), FCD (X's), FEX.LINE (diamonds). 1984-1993.

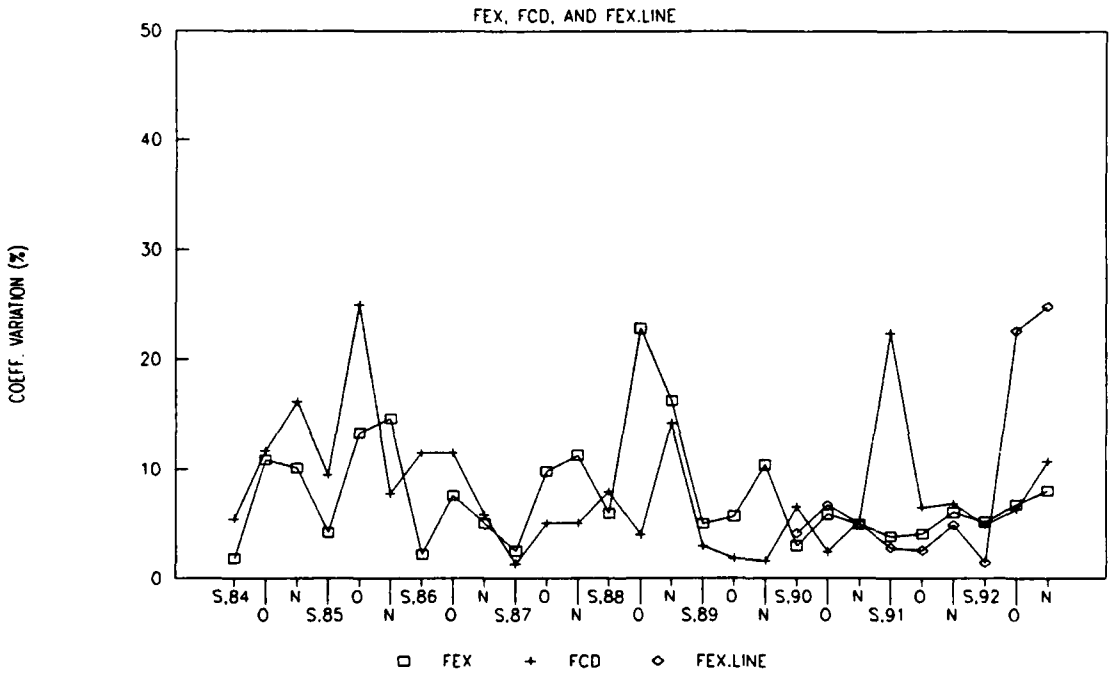

Figure 4.1C. Coefficient of variation values for diversity, without chironomids. FALL. FEX (squares), FCD (X's), FEX.LINE (diamonds). 1984-1992.

Coefficient of variation values for taxon diversity were lowest during the fall season. In the spring season, there were strong differences between FEX and FCD. Some springs, the coefficient of variation at FEX was very high relative to FCD (1984, 1986, 1987) and other springs FEX was very low relative to FCD (1988, 1989. and 1993). During the summer season, peaks in coefficient of variation values were usually higher at FEX than at FCD.

Figures 4.2A through 4.2C show CV values for taxon evenness for the spring, summer, and fall. Taxon evenness, as expected, had patterns similar to those for taxon diversity except for the spring season.

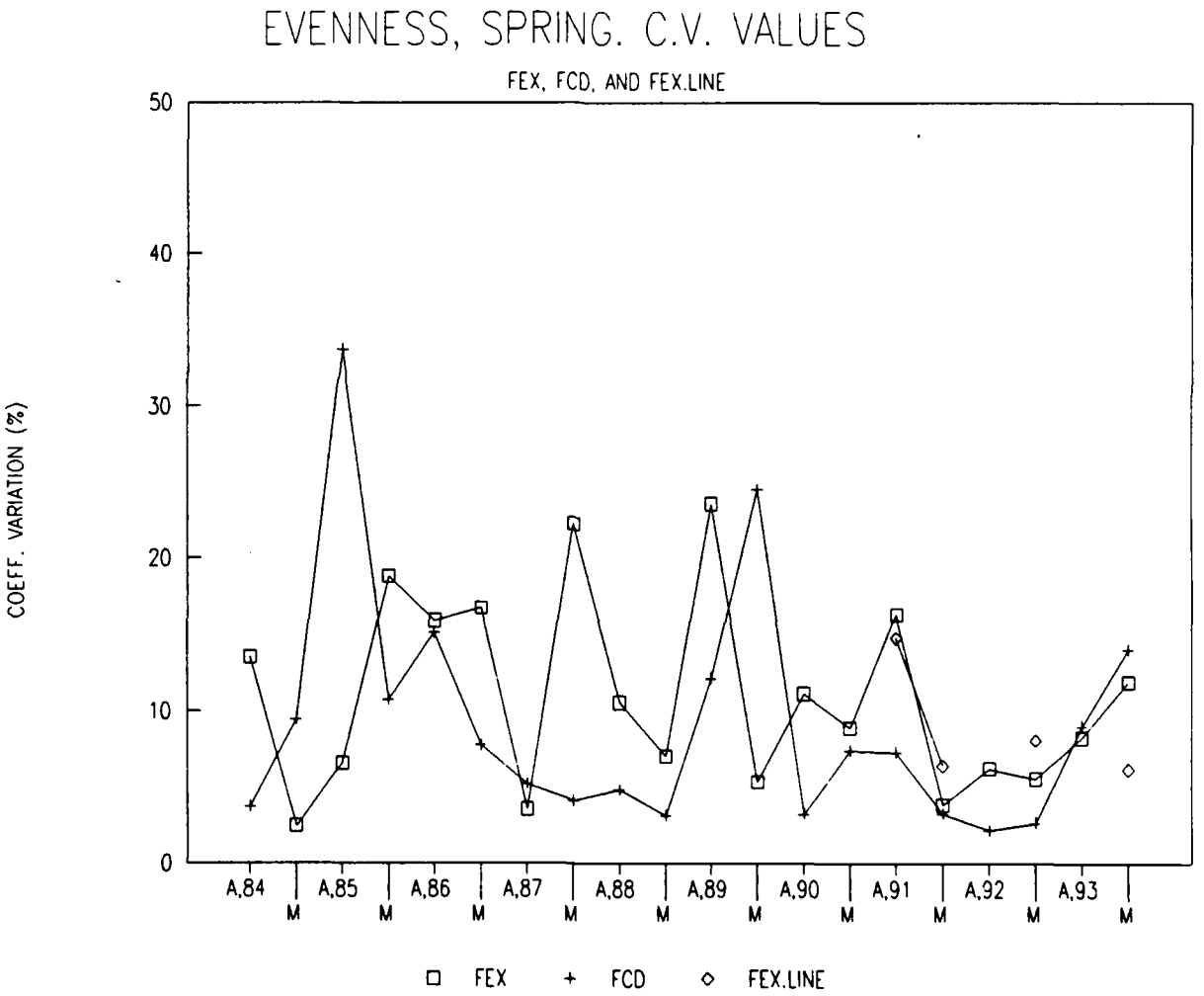

Figure 4.2A. Coefficient of variation values for evenness, without chironomids. SPRING. FEX (squares), FCD (X's), FEX.LINE (diamonds). 1984-1993.

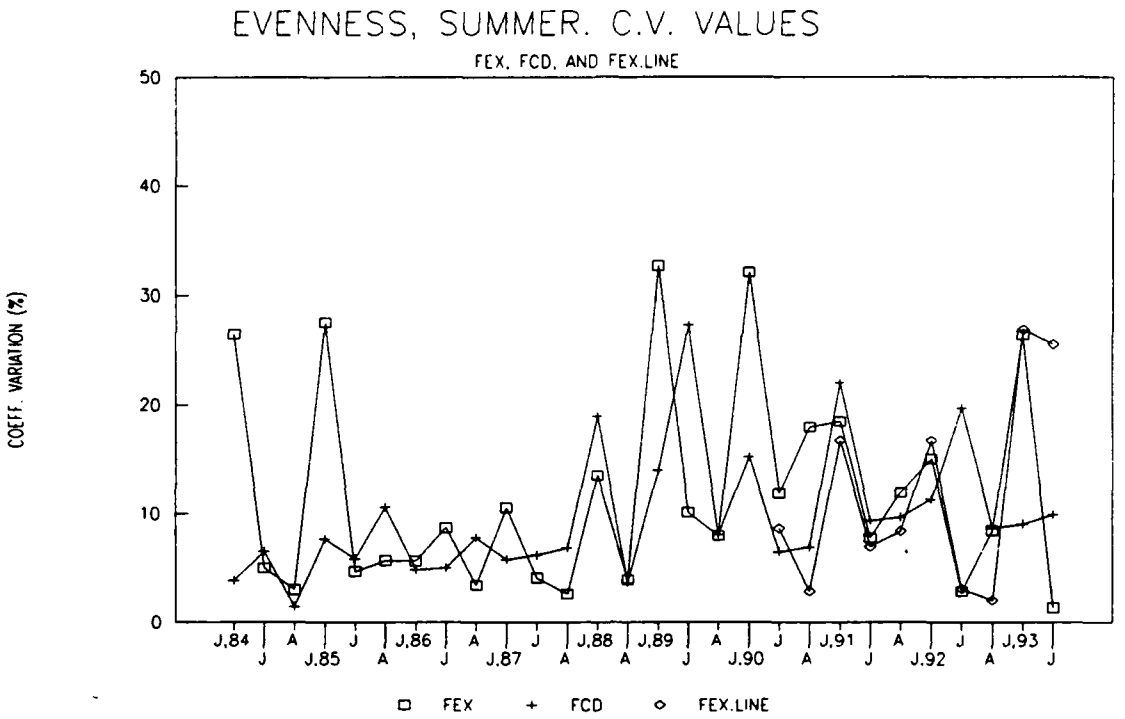

Figure 4.2B. Coefficient of variation values for evenness, without chironomids. SUMMER. FEX (squares), FCD (X's), FEX.LINE (diamonds). 1984-1993.

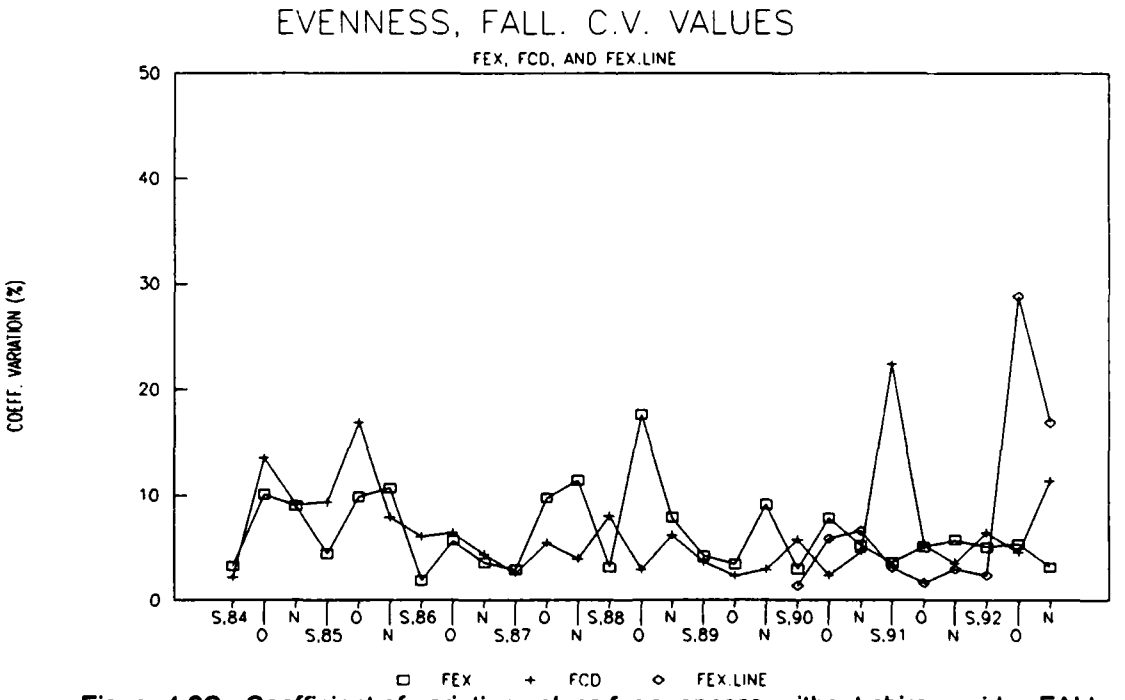

Figure 4.2C. Coefficient of variation values for evenness, without chironomids. FALL. FEX (squares), FCD (X's), FEX.LINE (diamonds). 1984-1992.

Figures 4.3A through 4.3C show CV values for richness (S') each season.

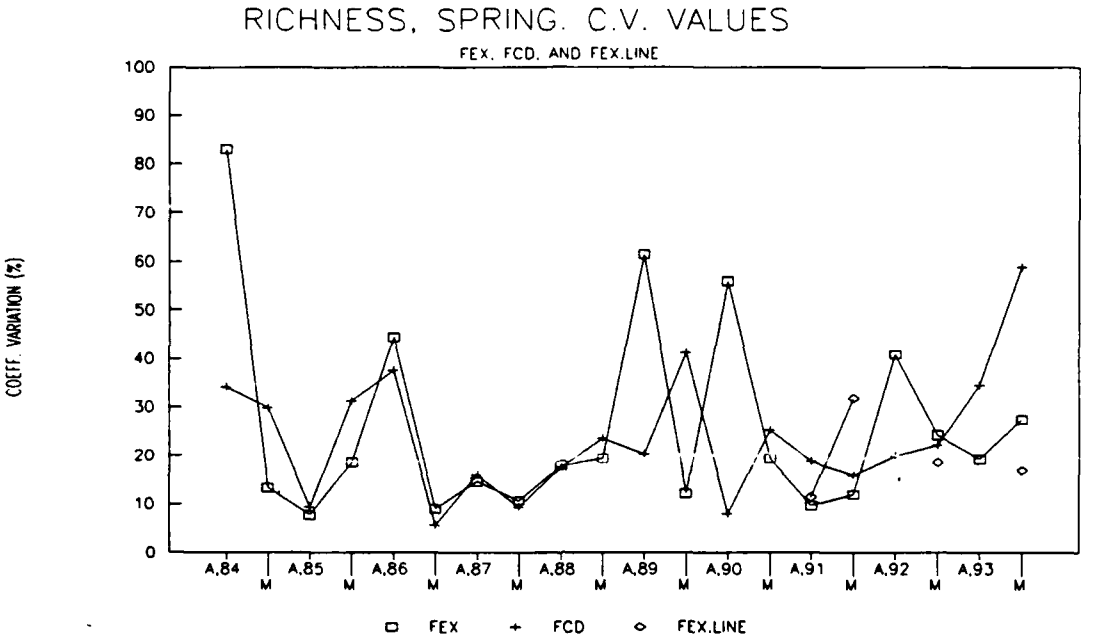

Figure 4.3A. Coefficient of variation values for richness, with chironomids. SPRING. FEX (squares), FCD (X's), FEX.LINE (diamonds). 1984-1993.

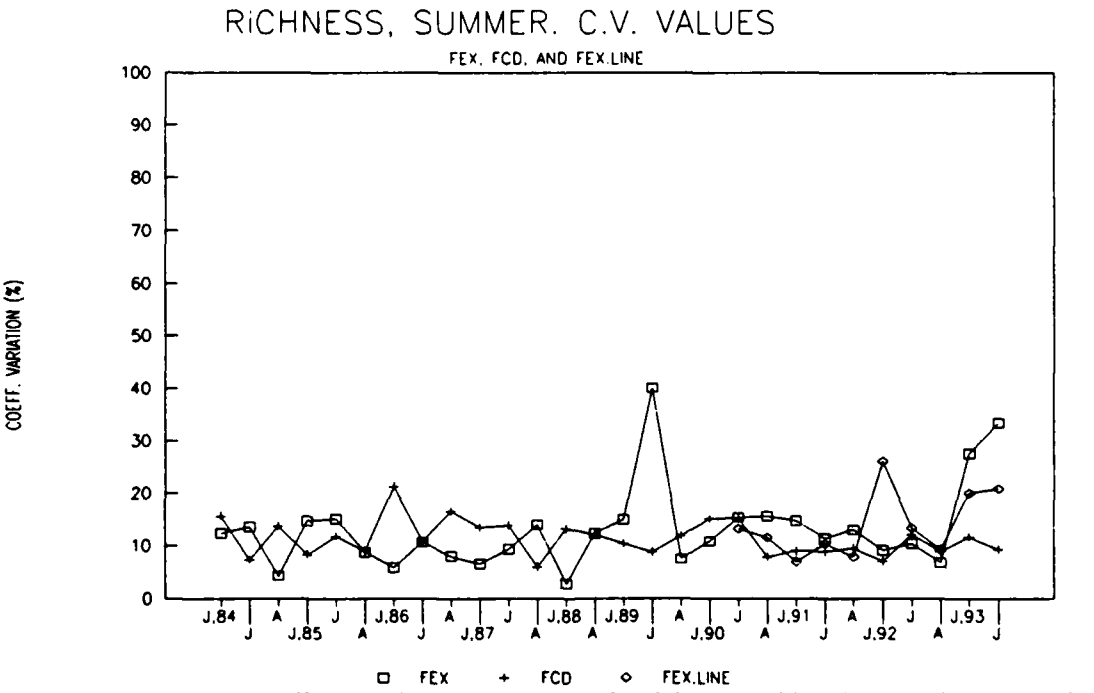

Figure 4.3B. Coefficient of variation values for richness, with chironomids. SUMMER. FEX (squares), FCD (X's), FEX.LINE (diamonds). 1984-1993.

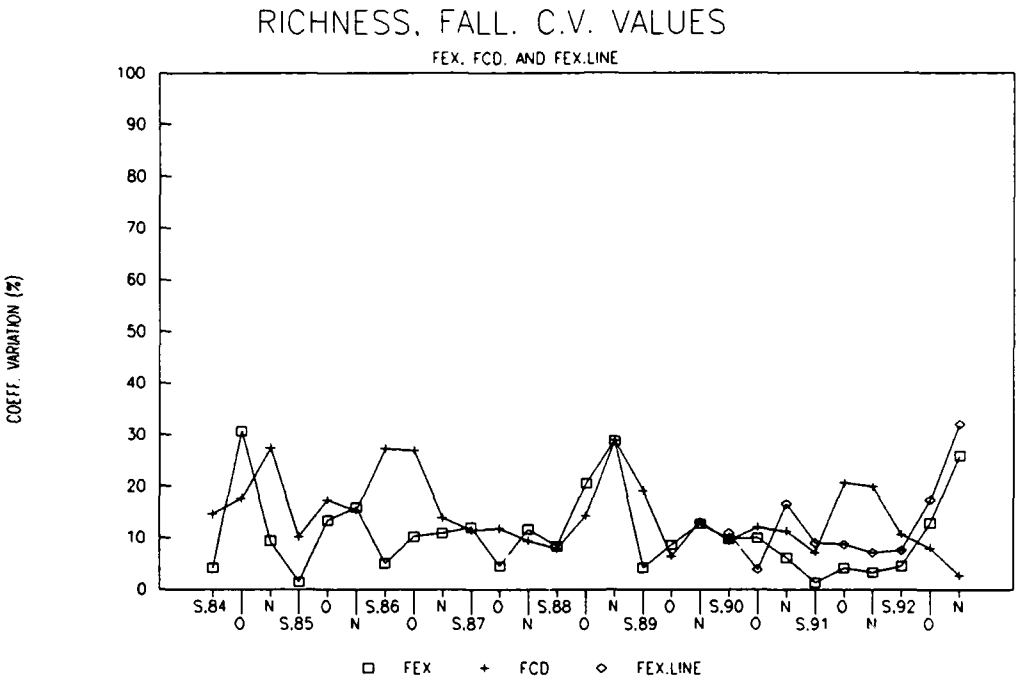

Figure 4.3C. Coefficient of variation values for richness, with chironomids. FALL. FEX (squares), FCD (X's), FEX.LINE (diamonds). 1984-1992.

Figures 4.4A through 4.4C are CV values for numbers of individuals.

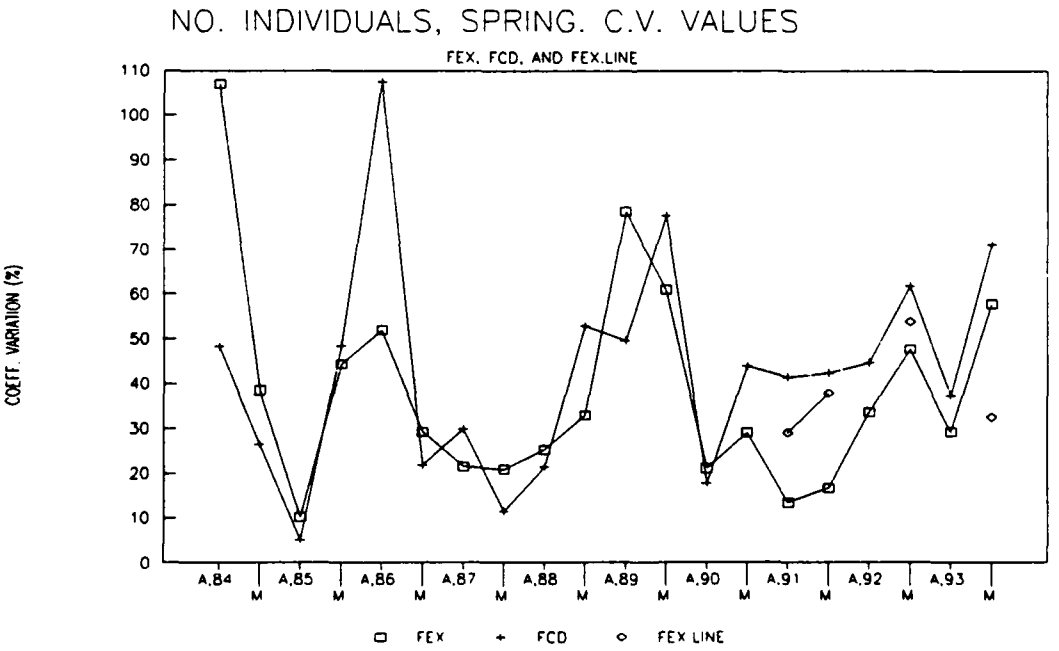

Figure 4.4A. Coefficient of variation values for numbers of individuals, without chironomids. SPRING. FEX (squares), FCD (X's), FEX.LINE (diamonds). 1984-1993.

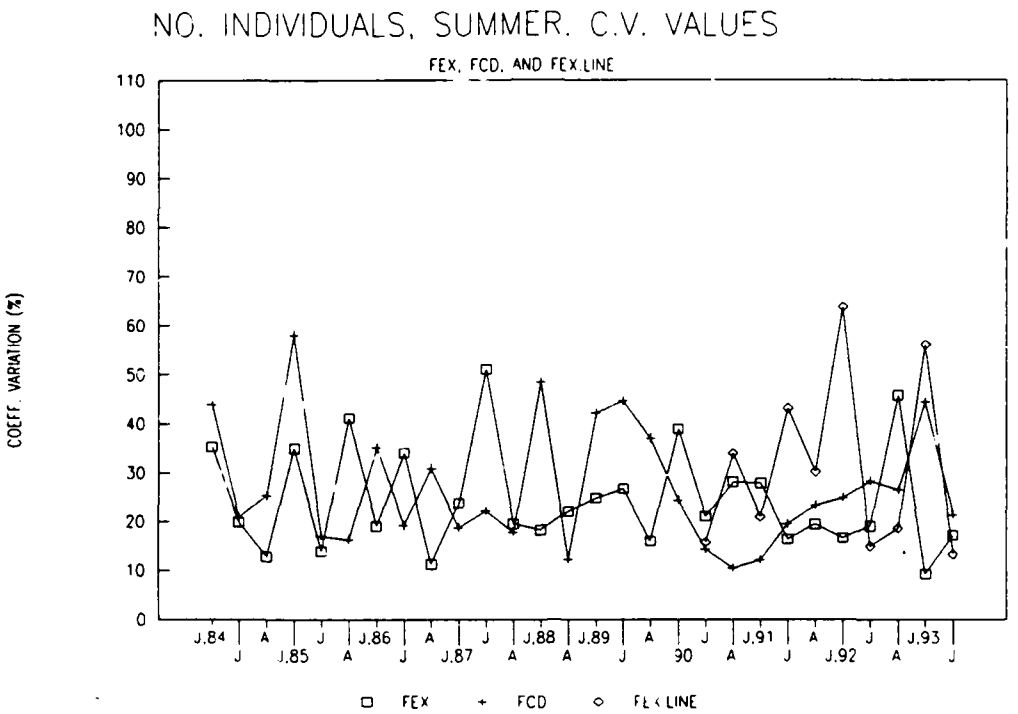

Figure 4.4B. Coefficient of variation values for numbers of individuals, without chironomids. SUMMER. FEX (squares), FCD (X's), FEX.LINE (diamonds). 1984-1993.

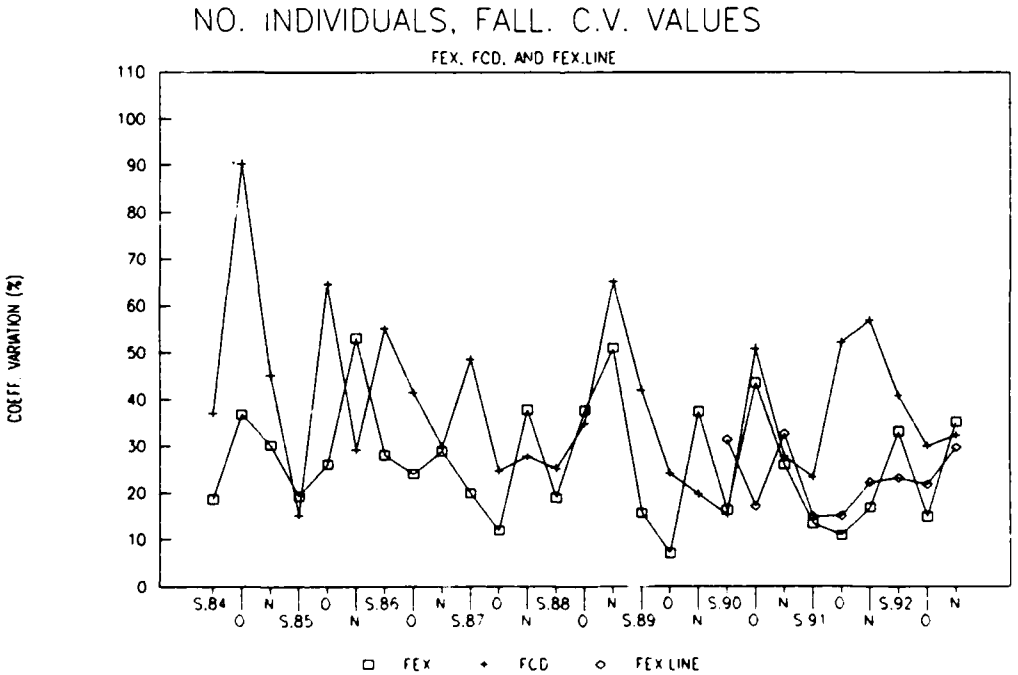

Figure 4.4C. Coefficient of variation values for numbers of individuals, without chironomids. FALL. FEX (squares), FCD (X's), FEX.LINE (diamonds). 1984-1992.

Figures 4.1A-C through 4.4A-C illustrate the differences in mean values relative to sample variances from season to season. They underscore the rationale for treating seasons separately.

Taxon Diversity (H') and evenness (J') coefficient of variation values oscillated the most during the spring season and least during the fall (figures 4.1 through 4.2) There was no consistent pattern for the sites. Some years H' and J' were higher at FEX and in other years they were higher at FCD. Both parameters at FEXLINE were more similar to those at FEX than at FCD. Coefficient of Variation values for H' and J' between the two sites, FEX and FCD, were least similar during the spring transitional period; for that season both indices failed Scheffe's Box Test for homogeneity of variances. Taxon Richness (S') and numbers of individuals had the lowest values and fewest oscillations during the summer season; those parameters were the most similar to one another at FEX and FCD during the spring (figures 4.3 through 4.4). Differences in CV values for the structural community parameters that passed tests for homogeneity of variances were not masked when ANOVA tests or multiple regression tests were run because replicates rather than sample means were used. However, B.A.C.I. tests use only sample means, and are affected by high CV values. Thus, 2-Way ANOVA tests with year and site as the main effects, and multiple regression tests relating physical factors with biological factors are presented first. B.A.C.I. tests and the nonparameteric R.I.A. tests results with a discussion of the results are presented second.

Table 4.1A shows that there were always significant site and year effects and significant interaction terms for each parameter in the spring. In the summer, only richness showed non-significance for the interaction term; all main factors were significant. In the fall, diversity, evenness, and chironomid numerical dominance showed non-signficance for the interactions term; however, all main factors showed significant differences for the FEX and FCD sites.

Because the summer season showed the lowest coefficient of variation values for most of the parameters, 2-way ANOVAS for the summer season were performed to see whether there were site differences among the three sites, FEX, FCD, and FEX.LINE. They appear in Table 4.1B. With all three sites together, there were significant site differences only for taxon evenness. There were no significant sites differences among the three sites. However, there were significant year differences for each biotic parameter. All interactions terms were significant except for taxon richness. Data for Table 4.1 extend from 1984 through 1993; whereas, data for Table 4.1B extend only four years and the data do not include before ELF activation years. It appears

to us that the value of the new site, FEX.LINE is very limited indeed. Even if it were satistically similar to FEX, one could never know whether this were true in the before ELF activation years. We feel that the graphical presentation of the data gives the reader some sense of the site. Statistical analyses, however, are of little help in interpreting results for the three sites together as they related to ELF effects.

TABLE 4.1A
2-Way ANOVA Tests for Seasonal Differences, FEX vs. FCD
Structural Community Parameters

F VALUES, LEVELS OF SIGNIFICANCE

Parameter, source	D.F.	Spring,84-93	Summer,84-93	Fall.84-92
DIVERSITY (w/o Chironomidae)				
Site	1	non-homo. var.	15.777**	6.14*
Year	9,8		7.64***	13.59***
Site, Year	9,8		2.40*	1.91 n.s.
EVENNESS, Arcsin. (w/o Chironomidae)				
Site	1	non.homo. var.	44.77***	25.45***
Year	9,8		6.76***	6.73***
Site, Year	9,8		3.54***	1.93 n.s.

RICHNESS	D.F.	Spring	Summer	Fall
Site	1	8.62***	27.65***	14.15***
Year	9,9,,8	9.56**	12.07***	21.54***
Site, Year	9,9,8	1.06*	1.22 n.s.	2.21*
NO. INDIVIDUALS (w/o Chironomids)				
Site	1	40.36***	223.10***	104.70***
Year	9,9,8	10.58***	6.36***	8.68***
Site, Year	9,9,8	4.30***	5.43***	3.49**
CHIRONOMID DOMINANCE				
Site	1	20.42***	non homo. var.	78.77***
Year	9,8	12.79***		27.00***
Site, Year	9,8	4.65***		1.67 n.s.
ERROR Degrees of Freedom		180	280	252

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

TABLE 4.1B
2-Way ANOVA Tests for Site Differences; FEX, FCD, FEX.LINE
July, August, 1990 - 1993
Structural Community Parameters

F VALUES, LEVELS OF SIGNIFICANCE

Parameter, source	D.F.	Summer
DIVERSITY (w/o Chironomidae)		
Site	2	1.155 n.s.
Year	3	10.994 ***
Site, Year	6	8.141 ***
EVENNESS, Arcsin. (w/o Chironomidae)		
Site	2	4.925 **
Year	3	18.216 ***
Site, Year	6	11.925 ***

RICHNESS	D.F.	Summer
Site	2	2.308 n.s.
Year	3	11.238 ***
Site, Year	6	0.110 n.s.
NO. INDIVIDUALS (w/o Chironomids)		
Site	2	2.730 n.s.
Year	3	14.494 ***
Site, Year	6	3.333 **
ERROR D.F. DOMINANCE	108	

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

Two-way ANOVAS, using FEX and FCD data, were not performed in the spring for diversity or evenness because the data did not have homogeneous variances. The same was true for chironomid numerical dominance in the summer months. The Friedman two-way analysis of variance was used to determine the existence of any site or year effects (Table 4.2). Differences in mean values among years and between sites were not significant for either diversity or evenness. There were significant site differences for chironomid numerical dominance in the summer.

TABLE 4.2
Friedman Two-Way Analysis of Variance for Structural Community Parameters with Heterogeneous Variances
Spring: 1984-1993; Summer: 1984-1992

Parameter, source	Season	d.f.	Friedman test statistic	P value
DIVERSITY	Spring			
Site		1	0.400	0.527
Year		9	7.855	0.549
EVENNESS	Spring			
Site		1	3.600	0.058
Year		9	9.791	0.368
CHIRONOMID DOMINANCE	Summer			
Site		1	6.400	0.011*
Year		9	10.473	0.314

* = $p < .05$

The Friedman test showed significant site differences for chironomid numerical dominance in the summer season. FEX oscillated much more than FCD, but FEX usually had proportionately fewer chironomids (see Figure 4.11B). Even though the two sites differed from one another, pattern differences were often similar over the years, resulting in no significant differences among the years (Table 4.2).

In the spring season, means of H' (Figure 4.5A) and J' (Figure 4.5B) fluctuated over the years, with FEX sometimes being higher and FCD at other times being higher. As future parameters are detailed, it will become apparent that the spring season is indeed the most highly variable season, both in terms of biotic parameters and in terms of abiotic factors. (Note that tests using the FEX.LINE site were not performed. As we were unable to collect samples in April of 1992 and 1993, statistical tests using spring data for this site will never be possible. Means for that site, however, appear in figures 4.5 through 4.12.)

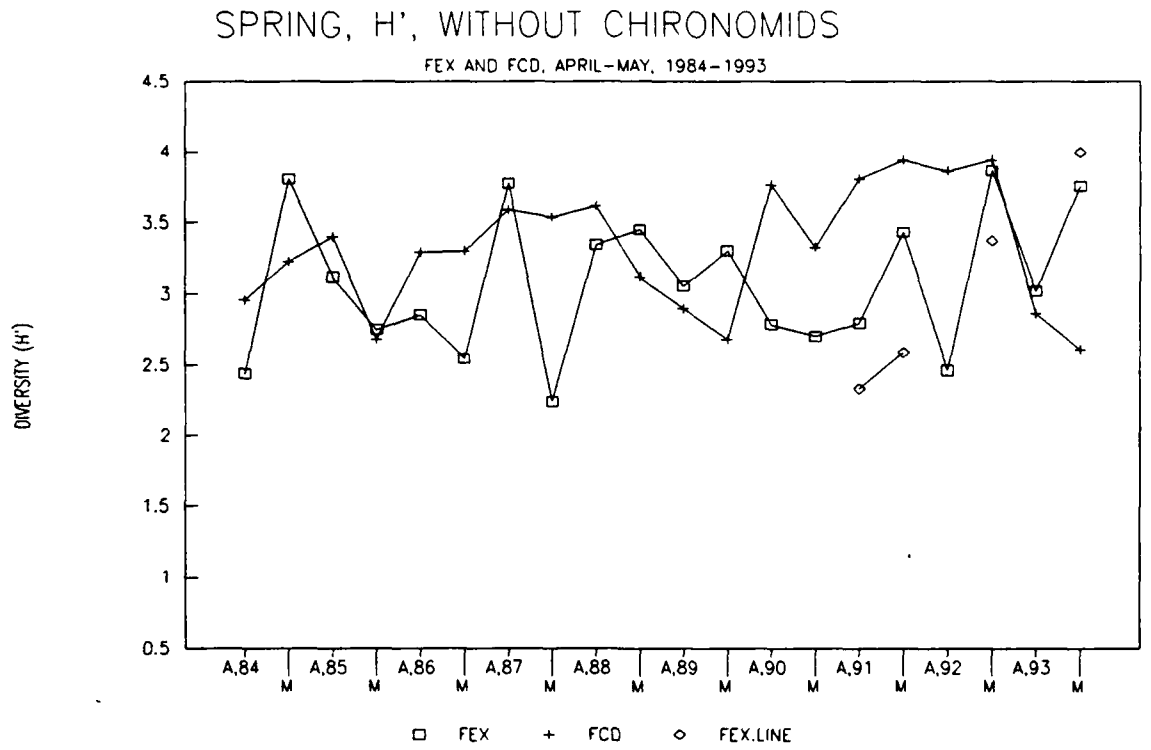

Figure 4.5A. SPRING. Means for diversity, without chironomids. 1984-1993. FEX (squares), FCD (X's), FEX.LINE (diamonds).

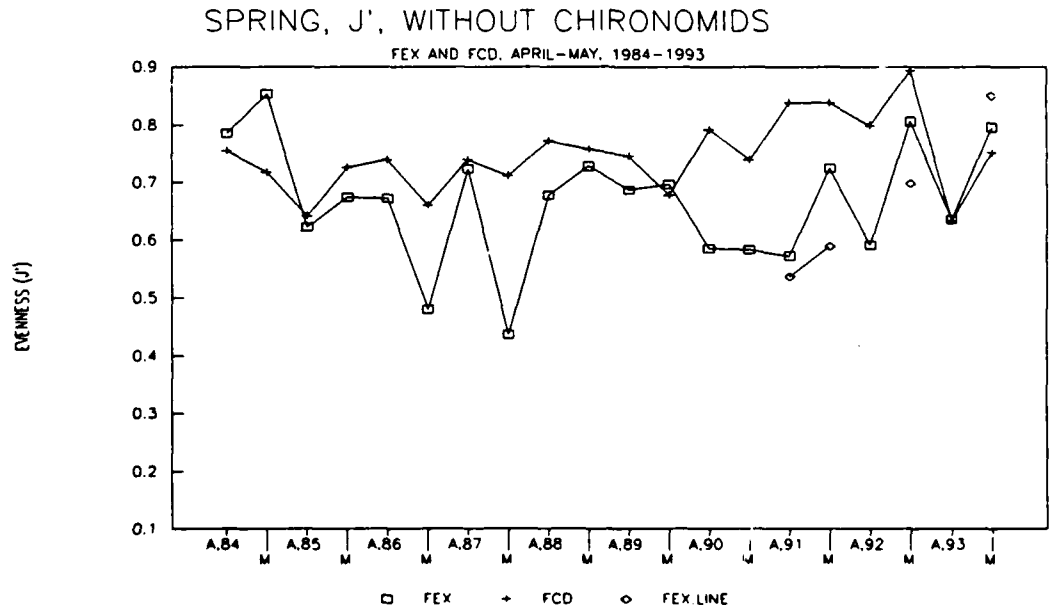

Figure 4.5B. SPRING. Means for evenness, without chironomids. 1984-1993. FEX (squares), FCD (X's), FEX.LINE (diamonds).

2-WAY ANOVAS for H' and J' in the summer and fall showed no significant interaction between sites and years. There were always significant year and site differences. Figures 4.6A and 4.6B show that in June of each year H' and J' were low at FEX. Many young capniid stoneflies are found there each year, reducing H' and J' at FEX.

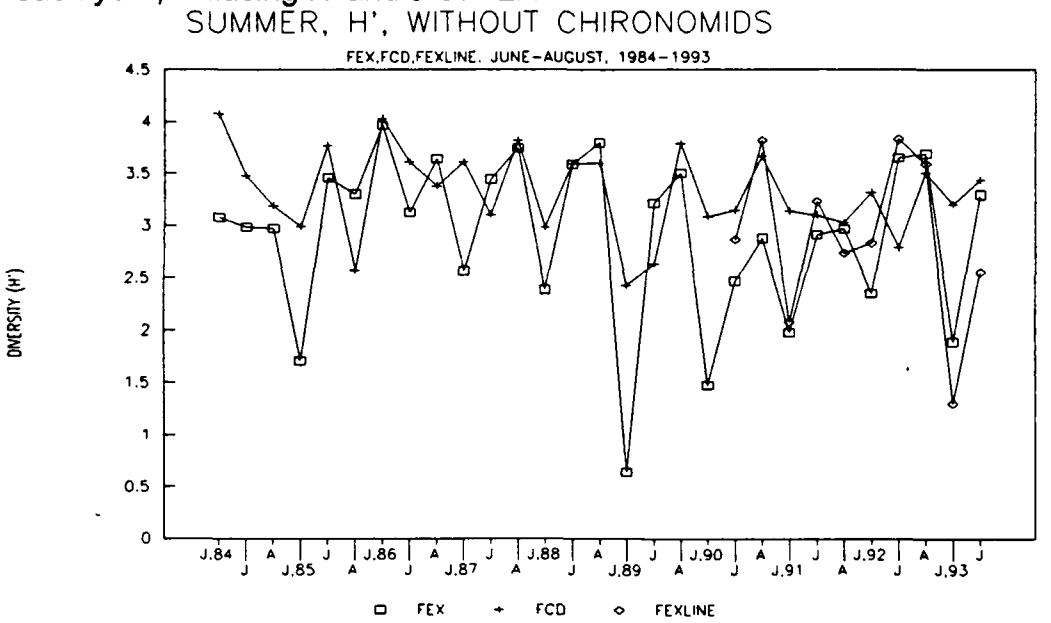

Figure 4.6A. SUMMER. Means for diversity, without chironomids. 1984-1993. FEX (squares), FCD (X's), FEX.LINE (diamonds)

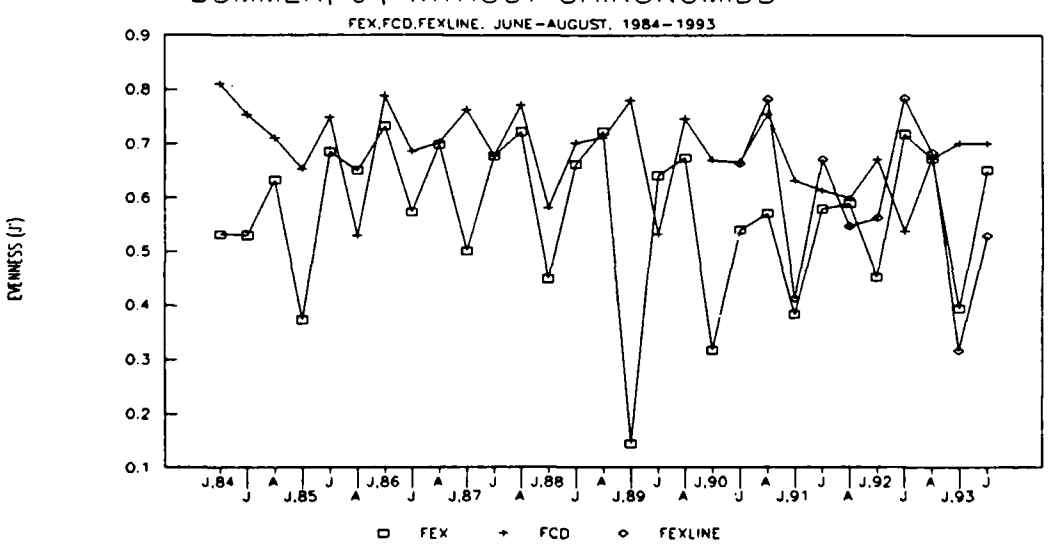

Figure 4.6B. SUMMER. Means for evenness, without chironomids. 1984-1993. FEX (squares), FCD (X's), FEX.LINE (diamonds)

During the fall, H' and J' were similar at FEX, FCD, and FEX.LINE (Figures 4.7A, 4.7B). Even though the E.L.F. lines became fully operational in the fall of 1989, seasonal patterns for H' and J' did not graphically reflect a response. However, there were significant year differences. In November of 1986 and 1987 it was very warm and the usual depressions did not occur.

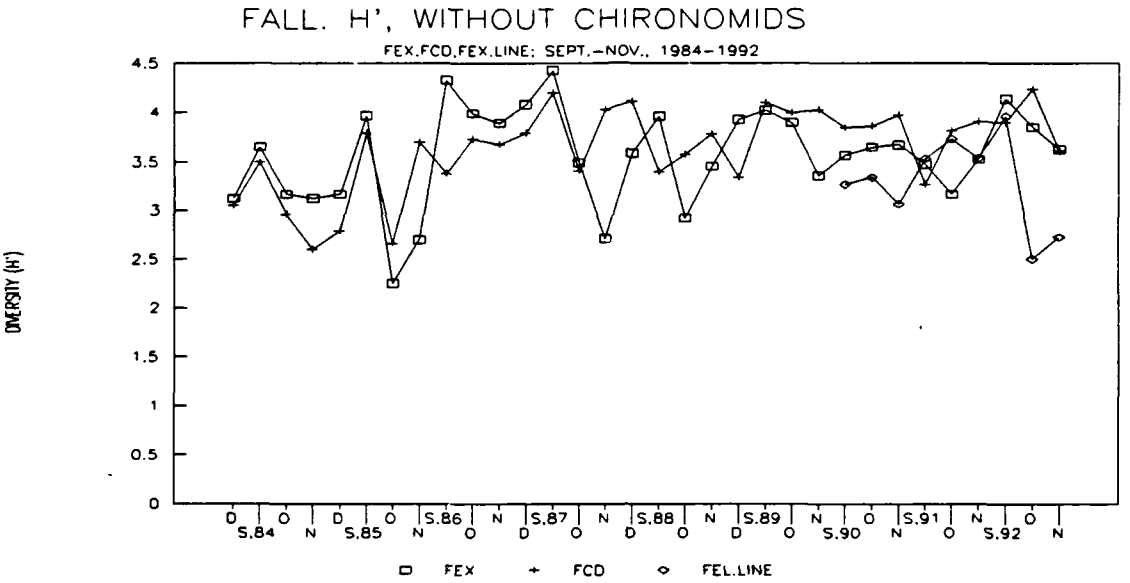

Figure 4.7A. FALL. Means for evenness, without chironomids. 1984-1993. FEX (squares), FCD (X's), FEX.LINE (diamonds)

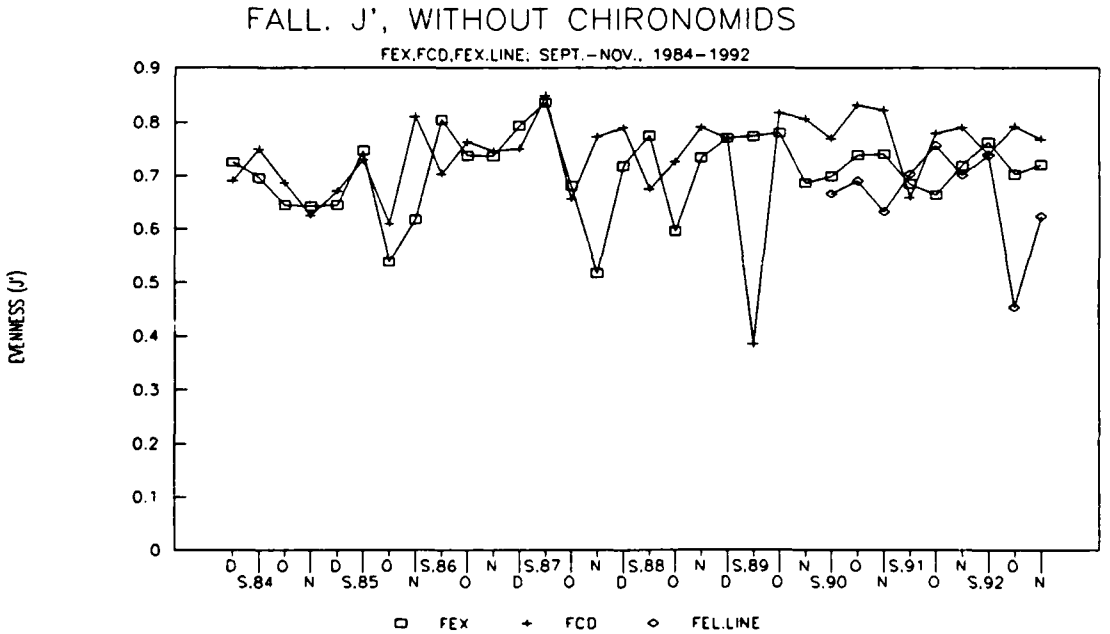

Figure 4.7B. FALL. Means for evenness, without chironomids. 1984-1993. FEX (squares), FCD (X's), FEX.LINE (diamonds)

Numbers of taxa (S') and numbers of individuals were usually higher at FEX each year (Figures 4.8 through 4.10). During the summer stable period, differences between FEX and FCD became smaller, owing to lower S' and numbers of individuals at FEX (Figures 4.9A and B). There were significant site and year differences for both parameters (Table 4.1). The more heterogeneous substrata at FEX may be the main factor relating to a numerically and taxonomically richer insect fauna.

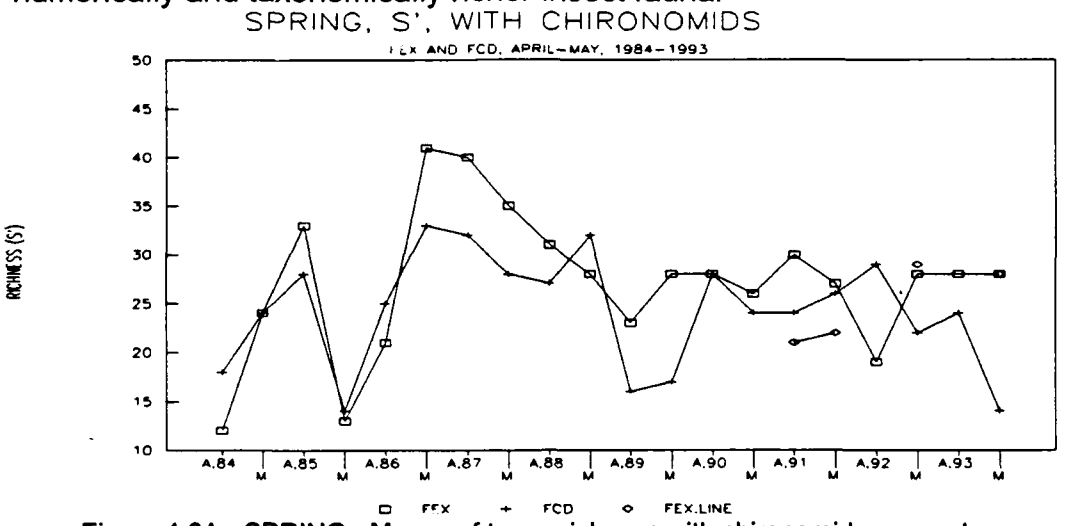

Figure 4.8A. SPRING. Means of taxon richness with chironomids as one taxon. 1984-1993. FEX (squares), FCD (X's), FEX.LINE (diamonds).

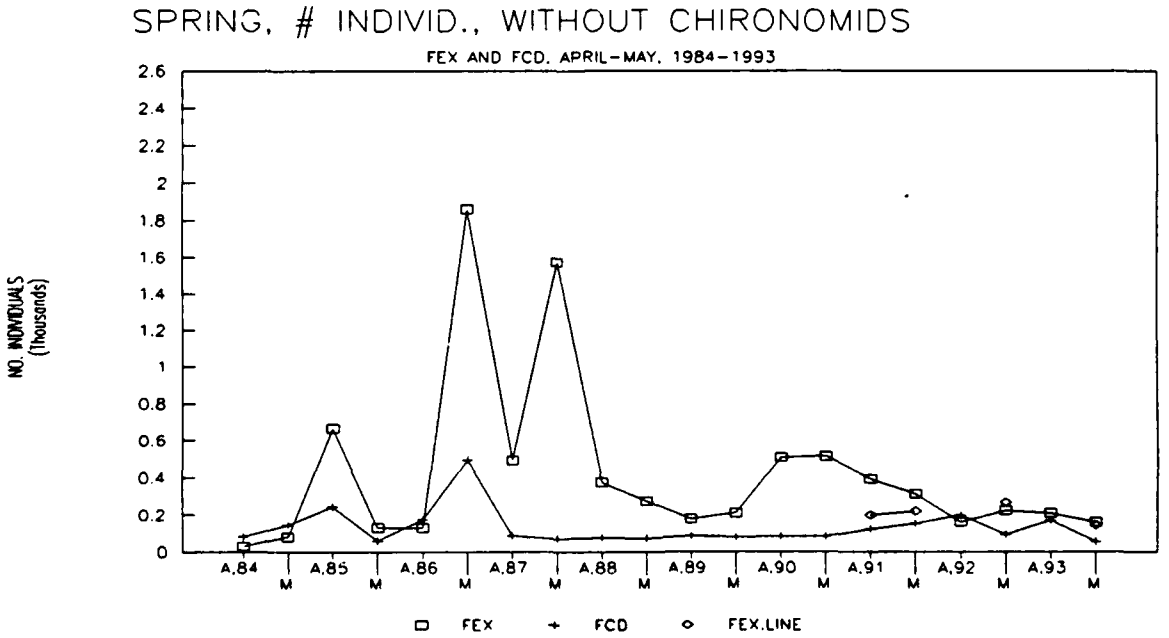

Figure 4.8B. SPRING. Means of numbers of individuals without chironomids, 1984-1993. FEX (squares), FCD (X's), FEX.LINE (diamonds).

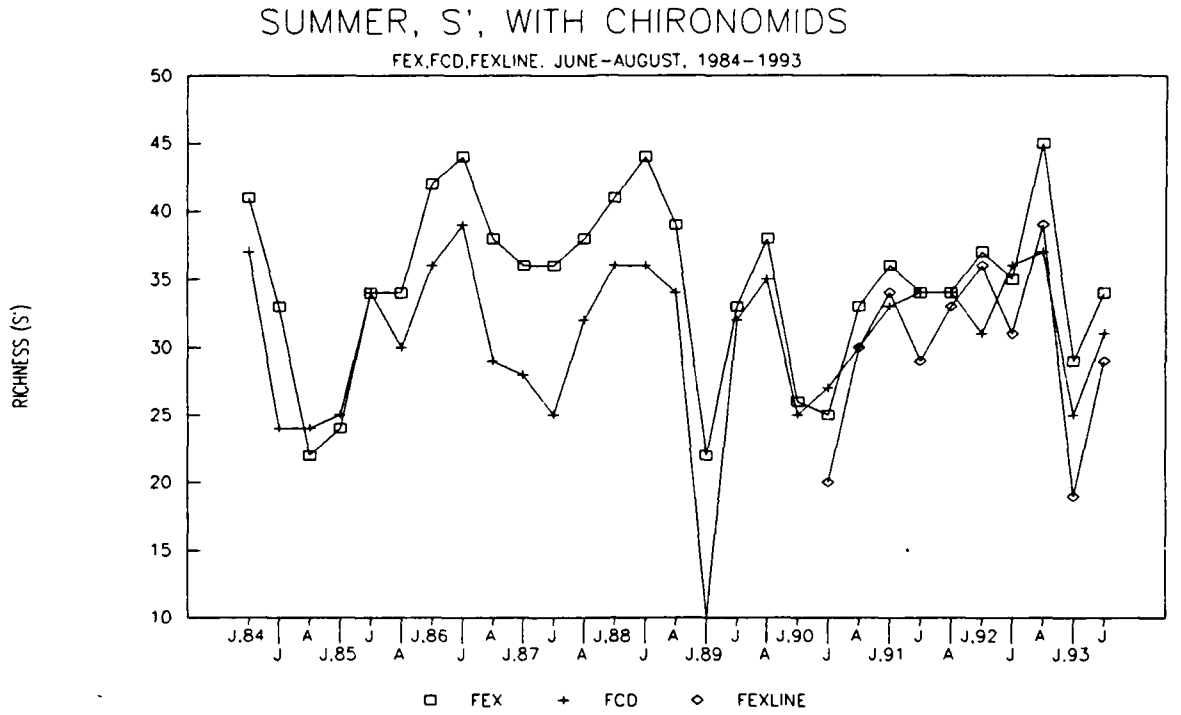

Table 4.9A. SUMMER. Taxon richness with chironomids as one taxon. 1984-1993. FEX (squares), FCD (X's), FEX.LINE (diamonds).

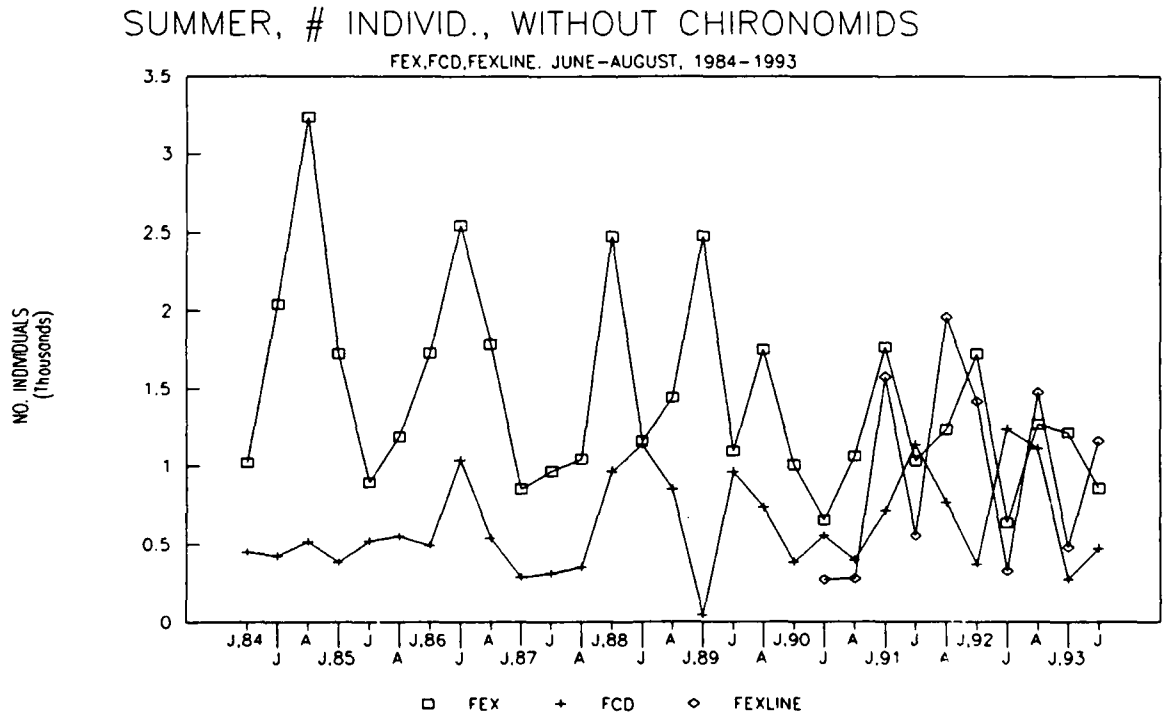

Table 4.9B. SUMMER. Numbers of individuals without chironomids. 1984-1993. FEX (squares), FCD (X's), FEX.LINE (diamonds).

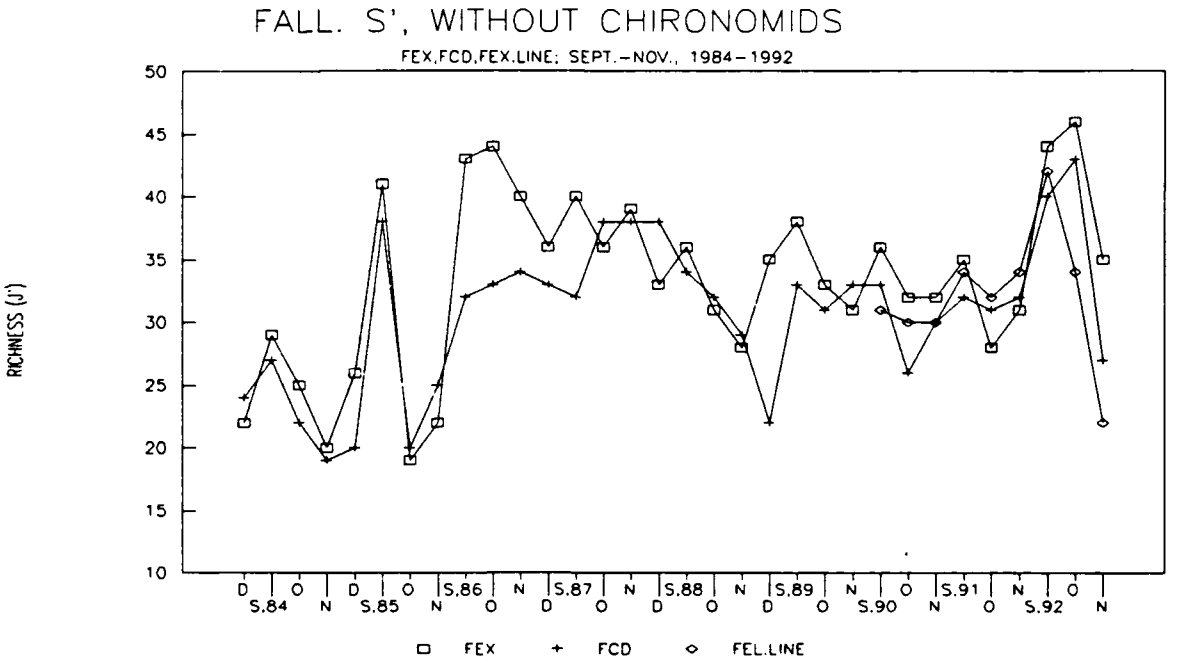

Table 4.10A. FALL. Taxon richness with chironomids as one taxon. 1984-1992. FEX (squares), FCD (X's), FEX.LINE (diamonds).

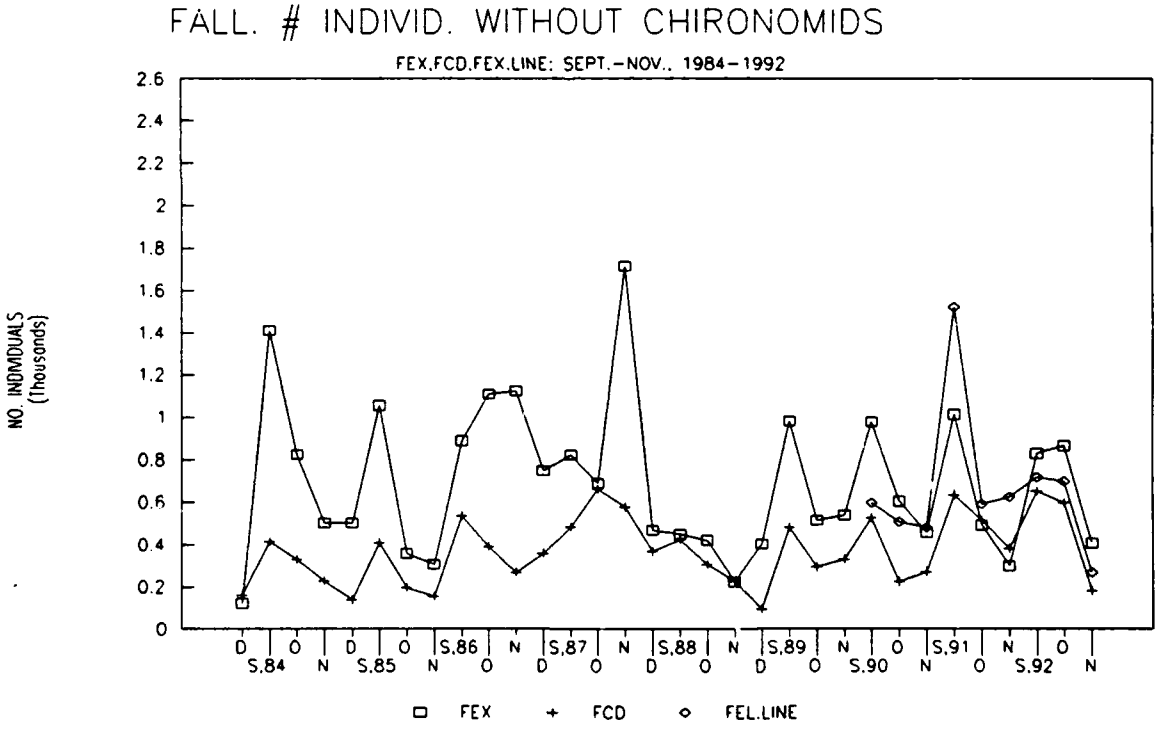

Table 4.10B. FALL. Number of individuals without chironomids as one taxon. 1984-1992. FEX (squares), FCD (X's), FEX.LINE (diamonds).

FEX and FCD sites tracked each other closely in the spring and fall seasons, with FCD usually showing the highest numerical dominance for chironomids (Figures 4.11A, 4.12). Numerical dominance of chironomids was highest during the spring. Numbers of chironomids relative to numbers of the remaining taxa fluctuated least during the spring. Both FEX and FCD sites tracked each other closely in the spring and fall, with FCD usually showing the highest numerical dominance for chironomids (Figures 4.11A, 4.12).

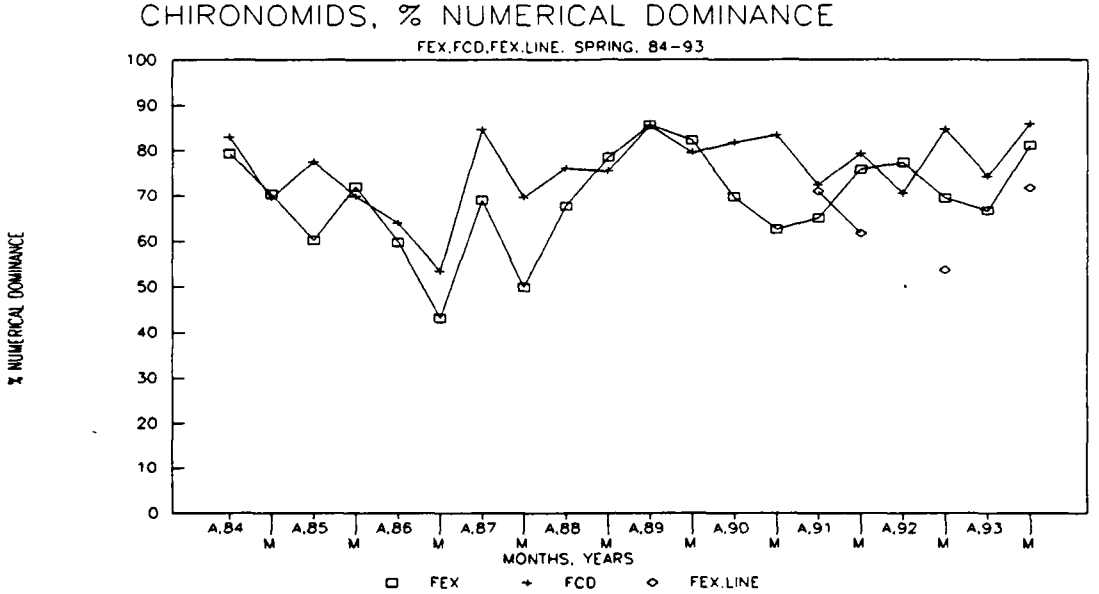

Figure 4.11A. SPRING. Chironomid numerical dominance. 1984-1993. FEX (squares), FCD (X's), FEX.LINE (diamonds).

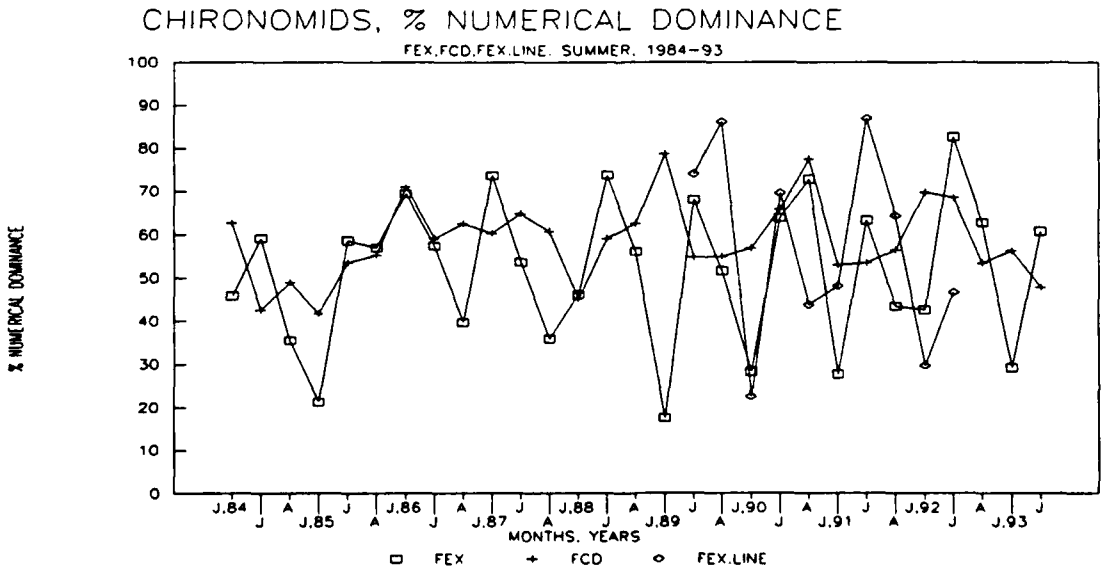

Figure 4.11B. SUMMER. Chironomid numerical dominance. 1984-1993. FEX (squares), FCD (X's), FEX.LINE (diamonds).

Chironomid numerical dominance oscillated greatly during the summer stable period, especially at FEX (Figure 4.11B). The oscillation had more to do with the fact that total numbers of individuals other than chironomids rose sharply at FEX during July and August each year, causing the numerical dominance of chironomids to decrease. Results from a Friedman two-way analysis of variance indicate that mean values for percent numerical dominance of chironomids in summer were significantly higher at FCD than at FEX (Table 4.2). When testing for year effects, however, the differences were not significant.

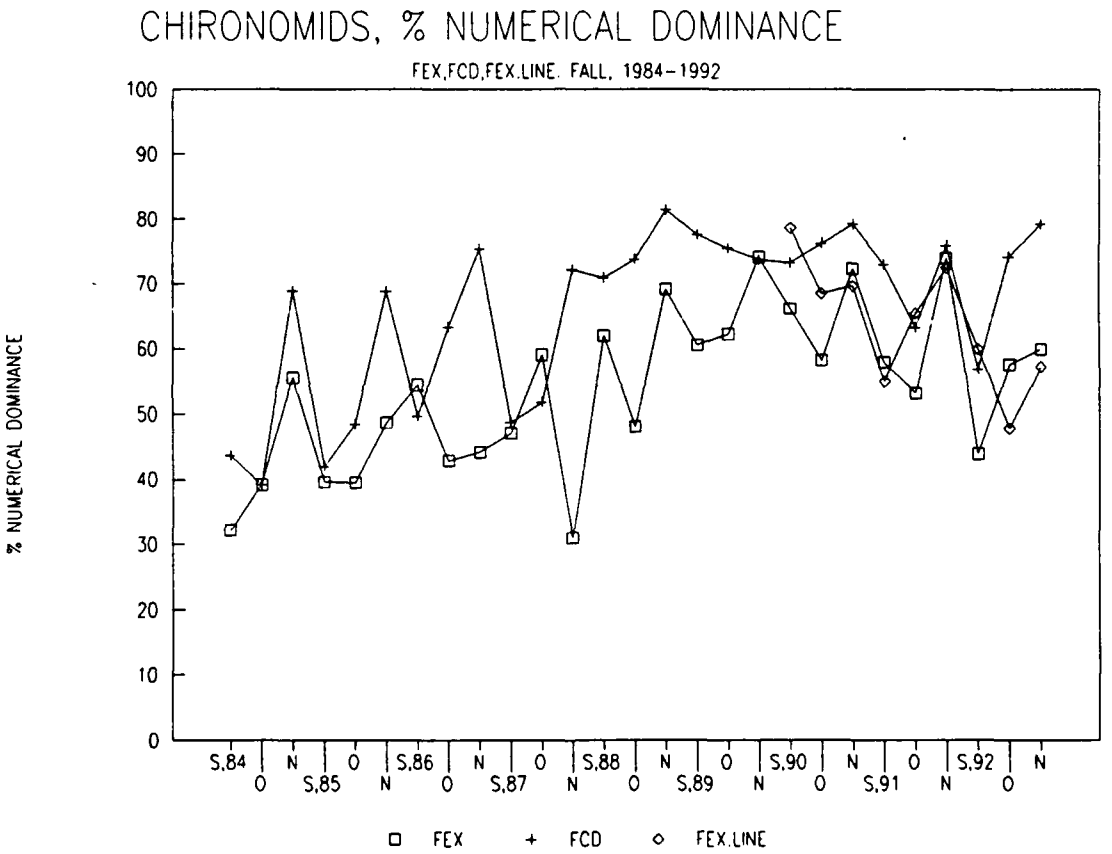

Figure 4.12. FALL. Chironomid numerical dominance. 1984-1992. FEX (squares), FCD (X's), FEX.LINE (diamonds).

In summary, the 2-Way ANOVAs for structural community parameters at FEX and FCD and then at FEX, FCD, and FEXLINE usually showed significant site and year differences but less common were significant interactions between site and year. Figures for means of the structural parameters showed no obvious changes, either after the lines were turned on in May of 1986 or after the lines became fully operational in October of 1989.

Physical Factors as Related to Structural Community Variables

After ELF activation in 1986, both intensities and durations of ELF fields increased until full power was initiated in the fall of 1989. Although ELF fields may be related to changes in structural community parameters, other physical factors may well be influential in altering those parameters. Discharge and a related physical variable, water temperature, also varied after 1986. In some seasons, namely the spring and fall, discharge was higher and water temperatures were lower before versus after ELF activation until 1990. Had we taken data only until 1990, we might have inferred that E.L.F. fields affected certain biotic parameters when in fact other, natural physical factors were more highly correlated. These physical variables must be taken into consideration when analyzing whether ELF ground field exposures affected insect structural community parameters. Figures 4.13A, B, and C show average discharge values between each substrate collection period for the three seasons at FEX and FCD. Spring discharge was low from May, 1986 until April, 1992 (Figure 4.13A); in the summer it was usually highest each June (Figure 4.13B); in the fall it was generally lower after E.L.F. activation (Figure 4.13C).

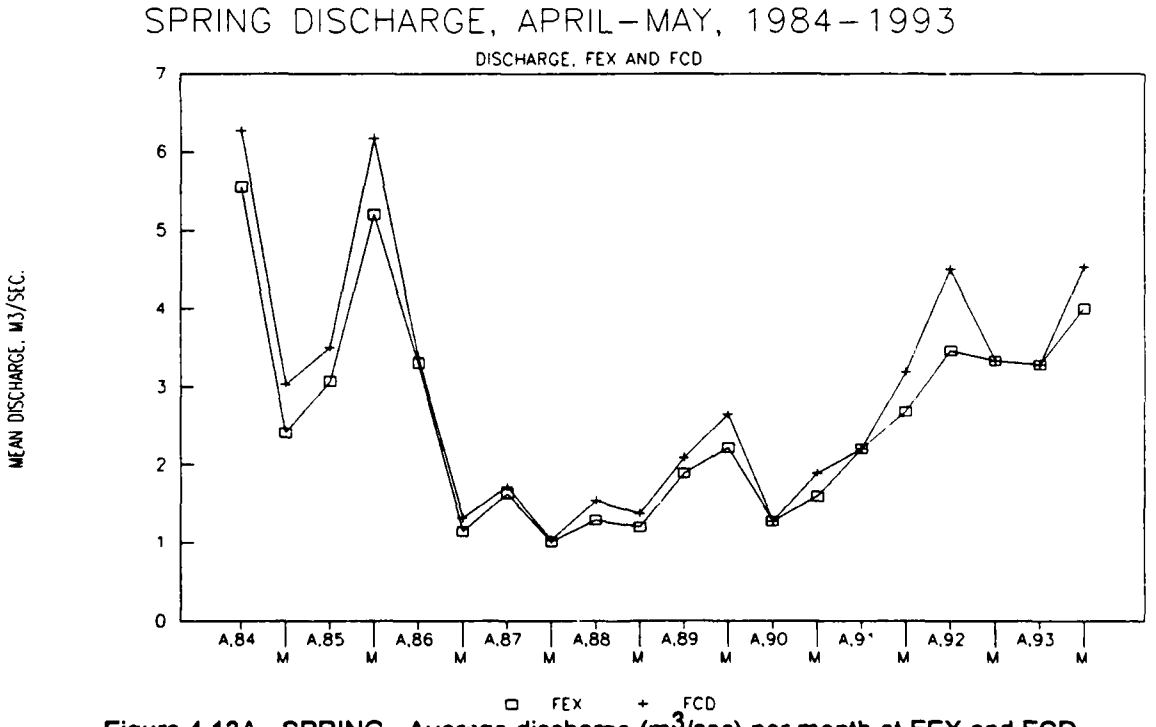

Figure 4.13A. SPRING. Average discharge (m^3/sec) per month at FEX and FCD. 1984 -1993.

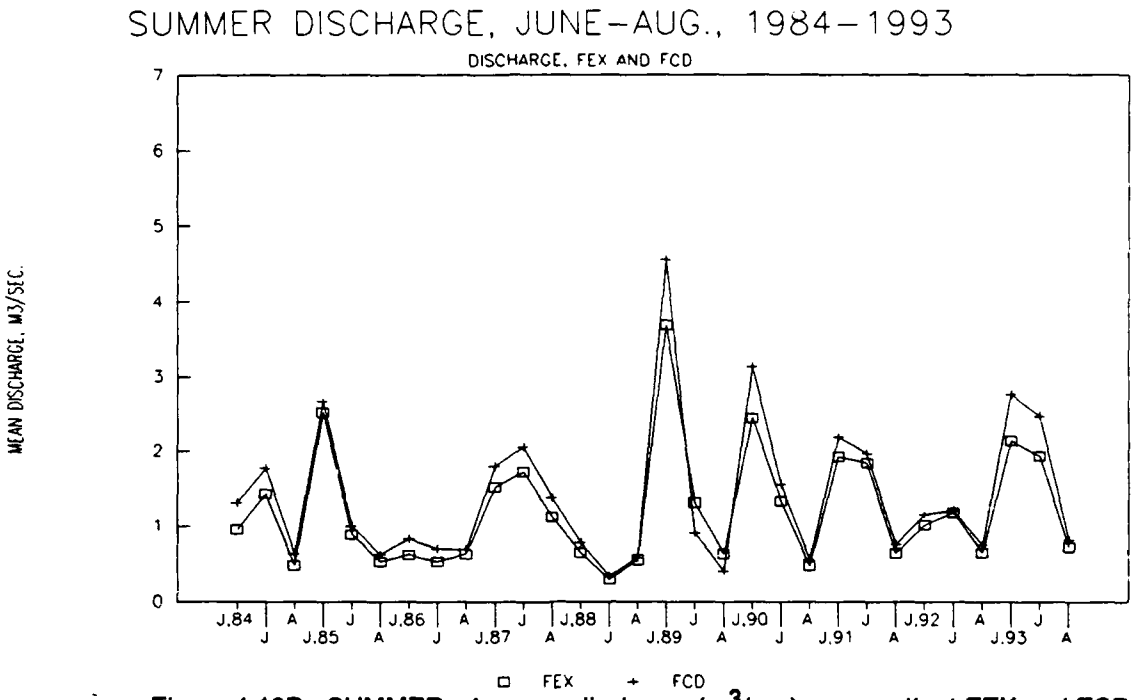

Figure 4.13B. SUMMER. Average discharge (m^3/sec) per month at FEX and FCD. 1984-1993.

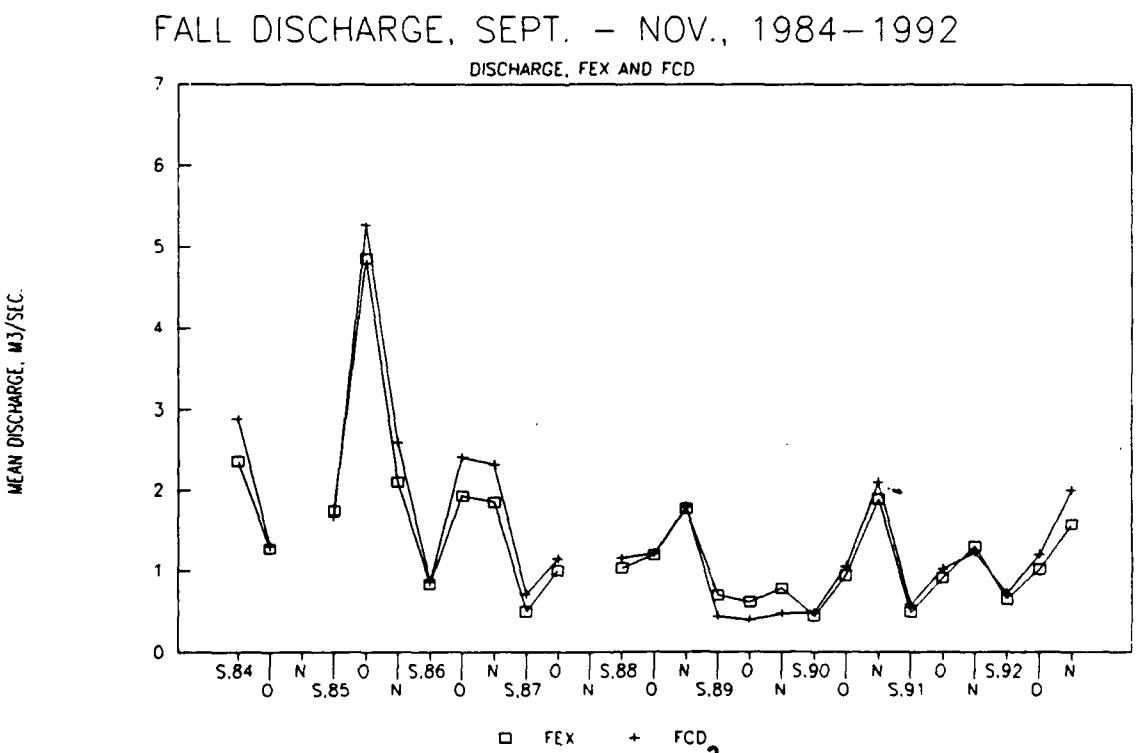

Figure 4.13C. FALL. Average discharge (m^3/sec) per month at FEX and FCD. 1984-1992.

Daily maximum and minimum water temperatures were used for cumulating degree days (threshold of 2◦C). Cumulative degree days from April of 1984 through August of 1993 for each season appear in Figures 4.14A, B, and C. Each May, until 1988, cumulative degree days continued to rise. From May 1988 through May 1990 temperatures were similar. In 1991 and 1992 they were at their lowest since the beginning of the study . In 1993 water temperatures were similar to 1985 and 1988 through 1990 (Figure 4.14A). In the summertime, the maximum cumulative water temperatures occurred in August of 1988. The lowest summer water temperatures were recorded in 1992 and in the beginning of the summer of 1993 (Figure 4.14B). There has been a wide range of summer water temperatures since E.L.F. activation, which is important for separating whether cumulative water temperature or cumulative E.L.F. ground fields correlate most with the biotic parameters under study. The fall season generally increased in cumulative degree days over the years until September of 1989, the time when ELF was fully operational. The extremely cool fall of 1992 should also help to separate whether E.L.F. or water temperatures are correlated with biotic parameters.

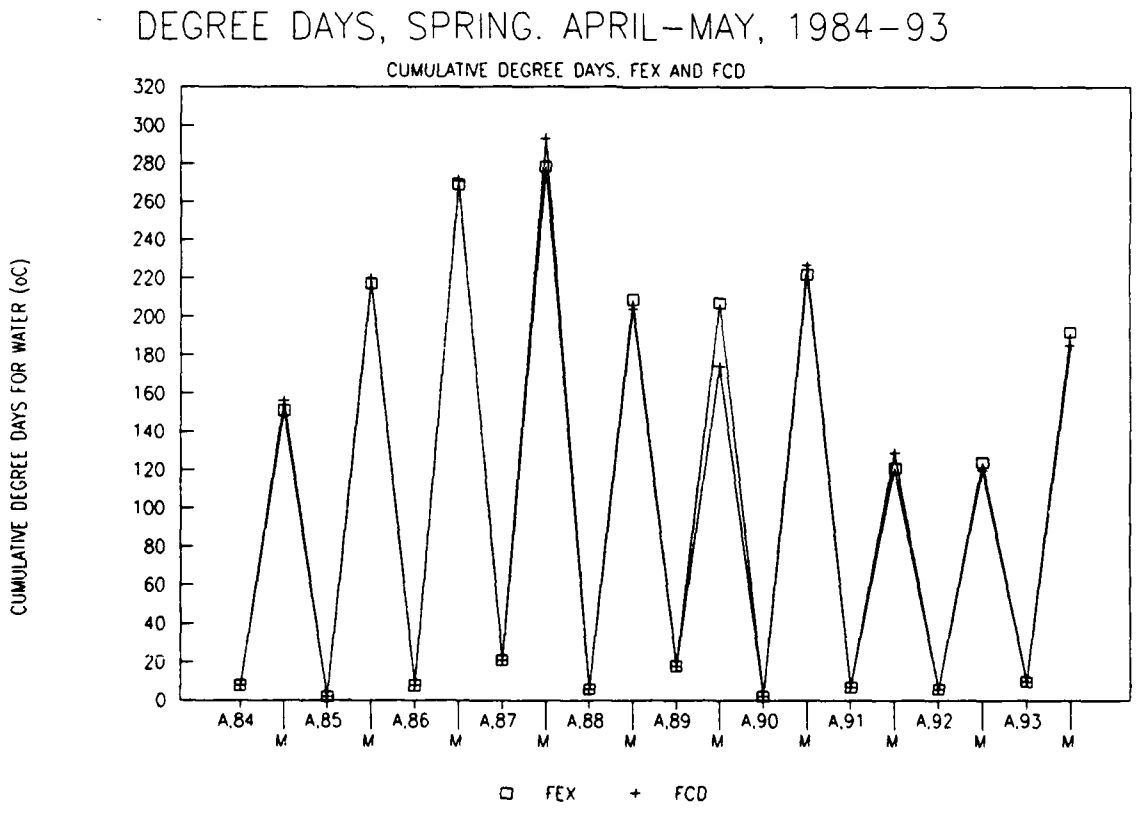

Figure 4.14A. SPRING. Cumulative degree days (°C) in April and May at FEX and FCD. 1984 - 1993.

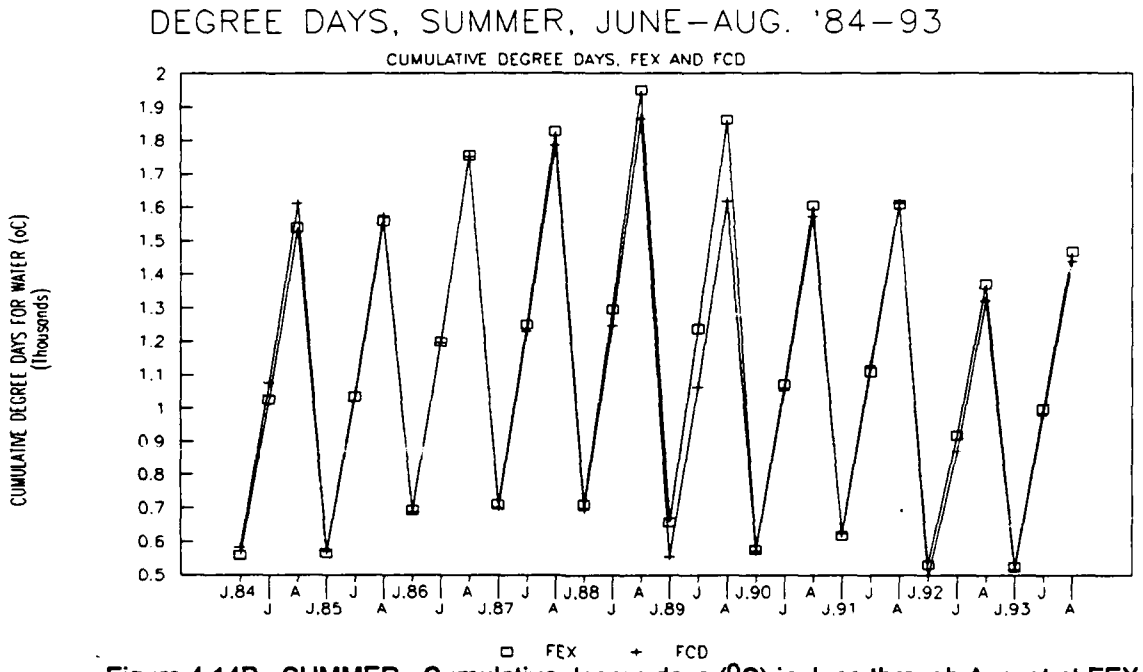

Figure 4.14B. SUMMER. Cumulative degree days (^{o}C) in June through August at FEX and FCD. 1984 - 1993.

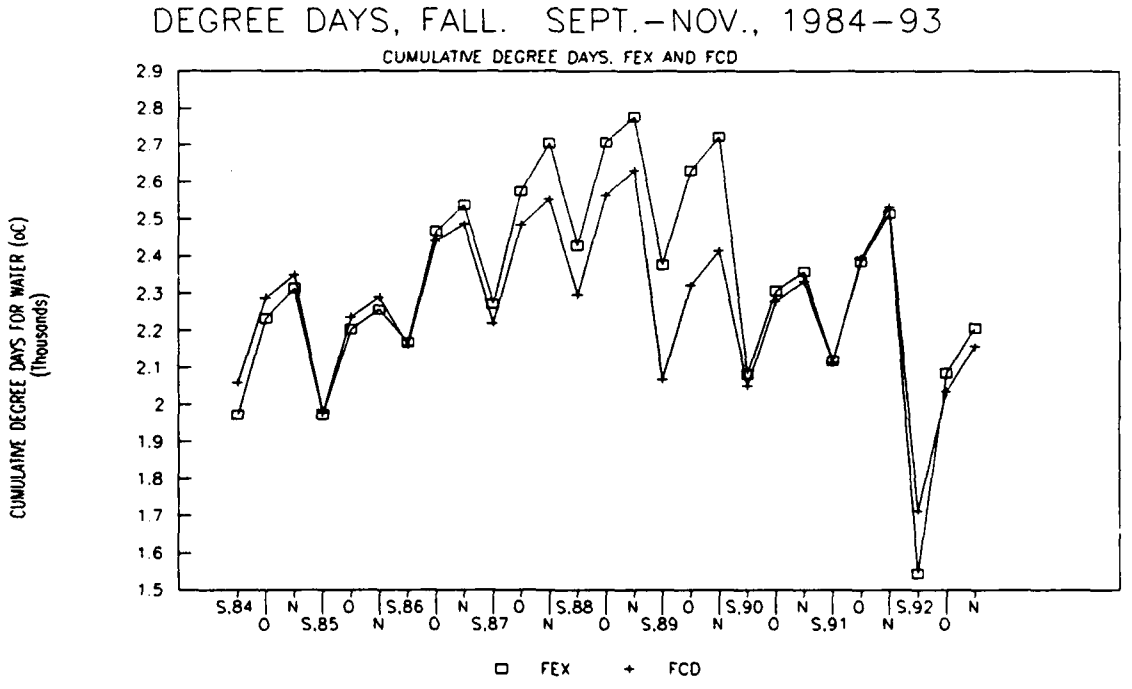

Figure 4.14C. FALL. Cumulative degree days (^{o}C) in September through November at FEX and FCD. 1984 - 1992.

Cumulative E.L.F. ground field exposure to the insects 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 would have been in samplers at the sites from mid-September of the previous year. Figure 4.15 presents the data in arithmetic form.

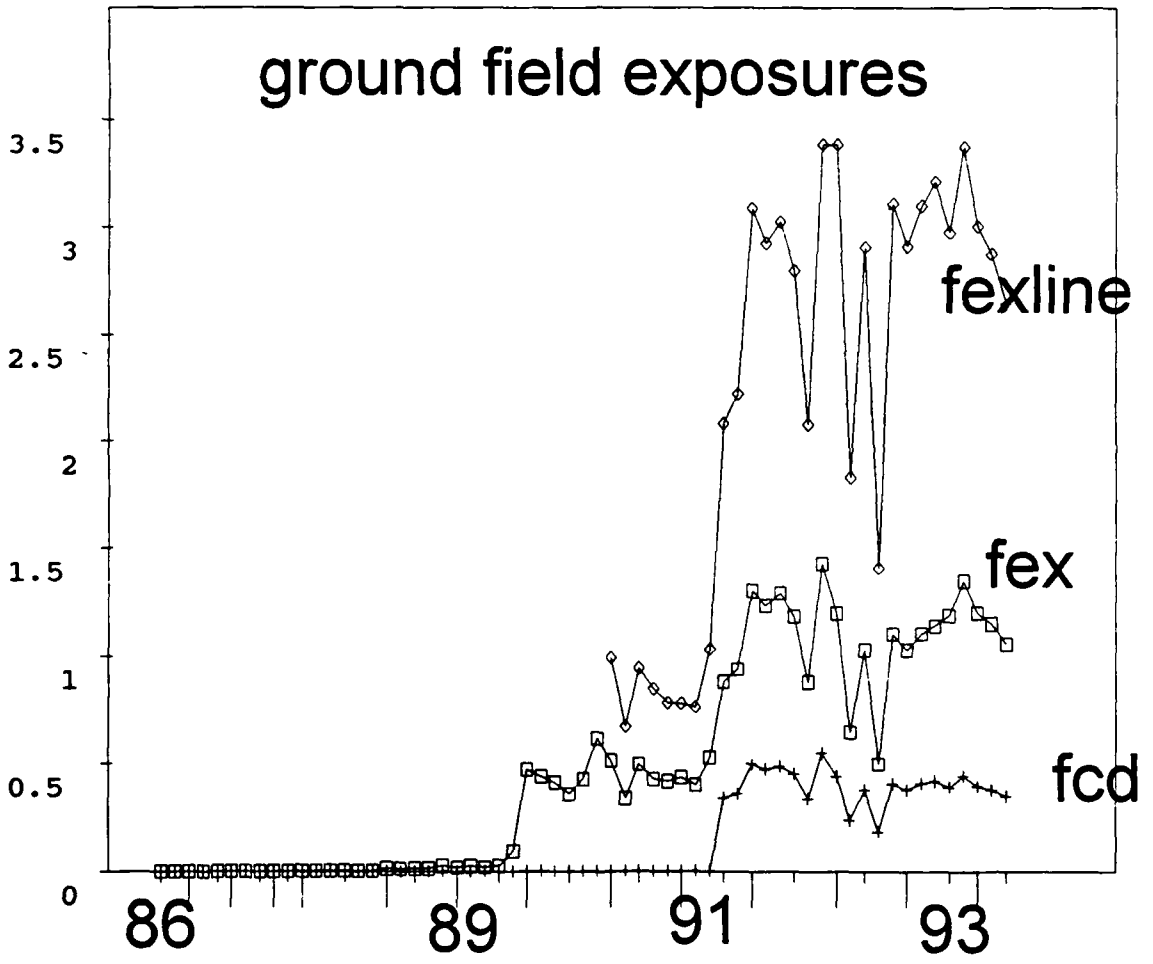

Figure 4.15. Cumulative E.L.F. ground field exposures (millivolts/day^{millions}) April 86 - Aug 93.

Multiple regressions included years, discharge, and cumulative degree days for each of the five structural community parameters each season and site (Tables 4.3A, B, C). Years were included because they represent a progression similar to that found for increases of E.L.F. ground field exposure values. We wanted to see whether there were any trends with increasing years without having to use E.L.F. exposure values for these regressions.

Diversity, evenness, and numbers of individuals in multiple regression tests excluded chironomids. Taxon richness included chironomids as one taxon. Percent numerical chironomid dominance was the ratio of numbers of chironomids to total numbers of individuals. Evenness values were transformed (arc sine of square root of Y) as well as percent dominance (arc sine of square root of Y/100). Table 4.3A gives both overall regression coefficients and standard partial regression coefficients for each dependent parameter from 1984 through 1993 during the spring season (April, May).

TABLE 4.3A
Multiple Linear Regressions for Biotic Parameters versus
Years, Discharge, and Cumulative Degree Days, Spring (1984-93)

SPRING

Dependent Variables,
R^2 and Standard Partial Regression Coefficients

Independent Variables	H'	J'	S'	# Individ.	Chiro. Dom.%
FEX					
R^2	N/A	N/A	0.33	0.38	0.28
Years			+.09	-0.22	0.36
Discharge			-0.56	-0.56	0.40
Cum.D.Days			0.01	0.19	-0.11
FCD					
R^2	N/A	N/A	0.26	0.33	0.18
Years			-0.11	-0.27	0.31
Discharge			-0.48	-0.55	0.25
Cum.D.Days			-0.15	-0.03	-0.18

Spring: Discharge usually accounted for most of the variation in the biological variables. In the 1991 Annual Report numbers of individuals and percent numerical dominance by chironomids at FEX and at FCD had R^2 values above 0.50 when data included only those years after E.L.F. activation and

when E.L.F. cumulative ground field exposure was included and years were excluded. This year when years replaced cumulative E.L.F. ground exposures there were no R^2 values above 0.38. Sometimes years had moderate standard partial regression coefficients. Even so, standard partial regression coefficients were always higher for discharge than for years, suggesting to us that discharge was more important than increasing years (or E.L.F. exposure) in accounting for the variability in the biotic parameters.

A correlation coefficient matrix for mean taxon richness at FEX and FCD combined was negatively correlated with discharge and positively correlated with mean water temperature for all three seasons collapsed together (correlation coefficients: 0.28 for temperature and -0.69 for discharge, n = 70). Spring can be a physically challenging time for insects, owing to river spating by melted snow as well as by heavy spring rains.

Taxon richness should therefore be most affected by discharge and to a lesser extent, temperature. We regressed S' against discharge over all months (Figure 4.16A). When May data only were used, the R^2 was .61, T_8= -3.54, p <0.01 (Figure 4.16B).

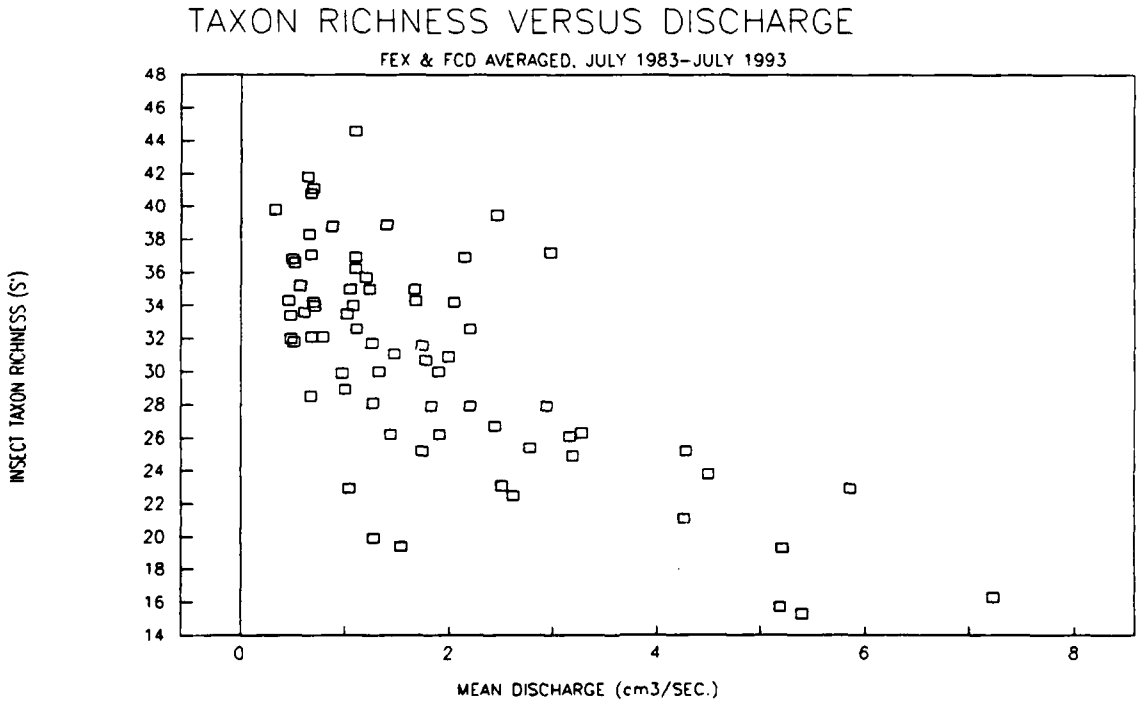

Figure 4.16A. Insect richness versus discharge over all seasons (FEX and FCD averaged together). 1984 -1993.

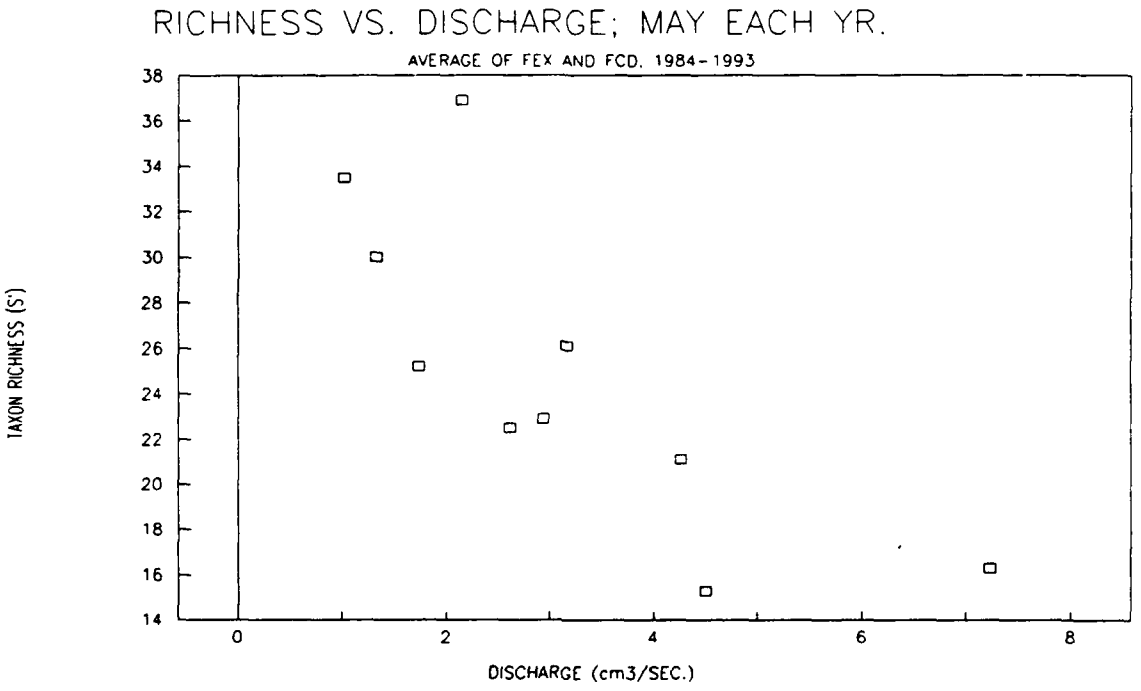

Figure 4.16B. Insect richness versus discharge for MAY of each year (FEX and FCD averaged together). 1984 -1993. $R^2 = 0.61$.

Taxon richness (average for FEX and FCD) was regressed against average water temperatures over the year (Figure 4.17A) and for May of each year (Figure 4.17B). The R^2 value for richness versus water temperature over the year was very low (0.07). In the spring, however, the cue of steeply rising water temperatures may be very important to various species of insects. Certainly, the correlation between taxon richness and water temperatures was high for that season. The R^2 value for May alone was .85, $T_8 = 6.77$, $p = 0.001$.

Because the ordering of years was random with respect to water temperature and water discharge but E.L.F. exposure was not, it is reasonable to suggest that temperature and flow rates play more important roles for aquatic insect taxon richness than does E.L.F. exposure.

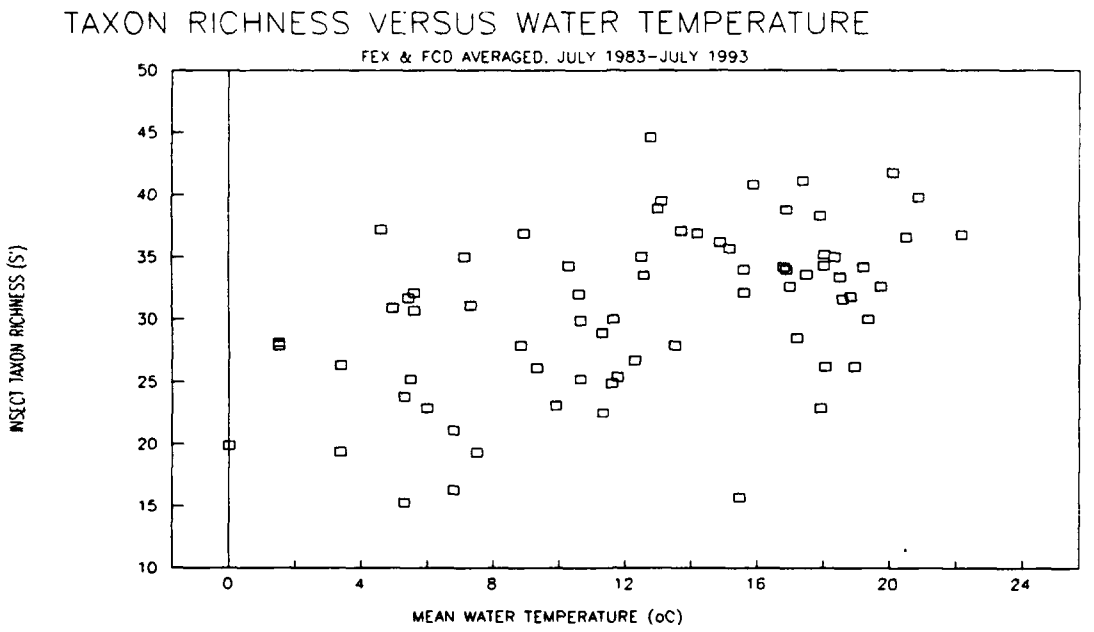

Figure 4.17A. Insect richness versus water temperature (FEX and FCD averaged). April 1984 through July 1993.

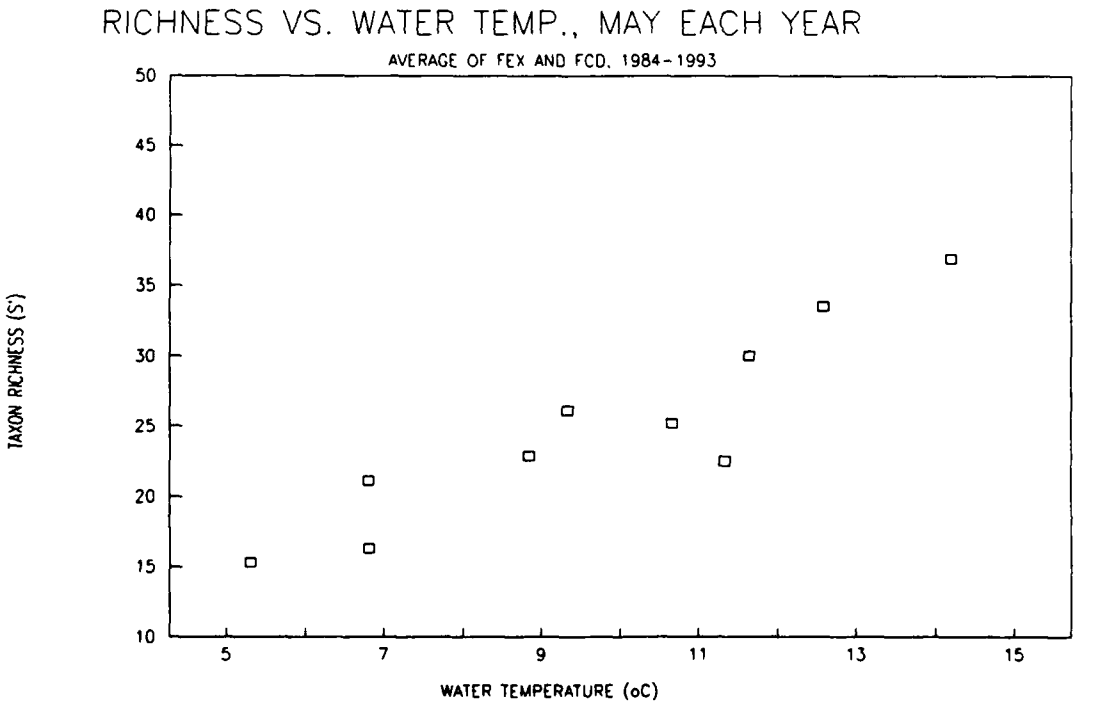

Figure 4.17B. Insect richness versus water temperature (FEX and FCD averaged). MAY 1984 - MAY 1993.

Summer: Coefficient of Multiple Determination values were above 0.50 for two of the five biotic parameters at FEX (H' and J') and for two at FCD (S' and number of individuals, Table 4.3B). At FEX, there were high standard partial regression values for discharge versus H', J', and S'. At FCD, there were high partial regression values for discharge versus S' and number of individuals lacking chironomids. Note that the dependent variable, years, had low partial regression values when the overall coefficient of multiple determination values were above 0.30. Summer discharge varied over the years, with peak discharges occurring in June of 1989 and June of 1990 (Figure 4.13B). Taxon diversity, J', and numbers of individuals (figures 4.6A, 4.6B, and 4.9B) dropped dramatically for summer months having high discharge. Cumulative degree days increased until August of 1988 and then descended again until 1990, with a final low occurring in August of 1992 (Figure 4.14B). Again, the value of a long-term study cannot be overemphasized. The variance in discharge and water temperatures after E.L.F. activation and/or E.L.F. full power operation will be essential for separating natural from anthropogenic factors in this study.

TABLE 4.3B

Multiple Linear Regressions for Biotic Parameters versus Years, Discharge, and Cumulative Degree Days Summer, 1984 - 1993

SUMMER

Dependent Variables

R^2 and Standard Partial Regression Coefficients

Independent Variables	*H'*	*J'*	*S'*	*# Individ.*	*Chiro. Dom.%*
FEX					
R^2	***0.57***	***0.57***	***0.36***	*0.06*	***N/A***
Years	*-0.01*	*-0.06*	*0.20*	*-0.25*	
Discharge	*-0.53*	*-0.47*	*-0.65*	*-0.01*	
Cum.D.Days	*0.31*	*0.35*	*-0.08*	*-0.02*	
FCD					
R^2	*0.25*	*0.23*	***0.52***	*0.35*	***N/A***
Years	*-0.32*	*-0.48*	*0.30*	*0.39*	
Discharge	*-0.38*	*0.13*	*-0.81*	*-0.53*	
Cum.D.Days	*-0.07*	*0.05*	*-0.19*	*-0.02*	

Discharge became more important compared with cumulative degree days for this Annual Report. The cooler summers of 1991 and 1992 accounted for

even less of the variance in H', J', S', and numbers of individuals at both FEX and FCD, as compared with the results for the 1991 Annual Report. Site comparisons for means of H' (Figure 4.6A), J' (Figure 4.6B), S' (Figure 4.9A), and numbers of individuals (Figure 4.9B) are more similar to one another from 1990 through 1993. Note that coefficient of variation values for those parameters did not differ appreciably as compared with previous years (Figures 4.1B through 4.4B).

Fall: The FEX site had relatively higher R^2 values than did FCD (Table 4.3C). Discharge was the predominant covariate accounting for variation in H', J', S', and numbers of individuals. With few exceptions, H' (Figure 4.7A), J' (Figure 4.7B), S' (Figure 4.10A), and numbers of individuals (Figure 4.10B) declined over the years. Figure 4.13C shows that fall discharge from 1986 through 1991 tended to decrease over the years. Years were important in accounting for the variation in chironomid numerical dominance at the sites. Chironomid dominance (Figure 4.12) increased over the years. These pattern changes over the years in the biotic parameters resulted in relatively high standardized partial regressions coefficients for discharge versus H', J', and numbers of individuals; and for years for chironomid numerical dominance.

TABLE 4.3C

Multiple Linear Regressions for Biotic Parameters versus
Years, Discharge, and Cumulative Degree Days
Fall, 1984 - 1992

FALL

Dependent Variables

R^2 and Standard Partial Regression Coefficients

Independent Variables	*H'*	*J'*	*S'*	*# Individ.*	*Chiro. Dom.%*
FEX					
R^2	***0.32***	***0.26***	***0.26***	***0.34***	***0.49***
Years	*-0.10*	*-0.15*	*-0.01*	*-0.45*	*0.55*
Discharge	*-0.58*	*-0.55*	*-0.44*	*-0.35*	*-0.10*
Cum.D.Days	*-0.17*	*-0.11*	*-0.23*	*-0.44*	*0.46*
FCD					
R^2	***0.22***	***0.08***	***0.20***	***0.18***	***0.28***
Years	*0.23*	*0.02*	*0.24*	*0.15*	*0.56*
Discharge	*-0.31*	*-0.29*	*-0.26*	*-0.29*	*0.07*
Cum.D.Days	*-0.08*	*-0.12*	*0.18*	*0.21*	*0.01*

In summary, after ELF activation, biotic parameters in the spring were more related to discharge; in the summer they were related to discharge and/or cumulative degree days, and in the fall they were related to discharge or to years. The most harsh non-anthropogenic factor to rheophilic aquatic insect communities is often flooding. If flooding occurs during the summer or the fall, one can expect to see biotic responses, which were seen in June of 1989 and 1990 and during the fall period in the early years of this study.

One type of intervention analysis, the B.A.C.I. method, was used to see whether there were systematic differences before versus after ELF activation. In this parametric test, before impact data from 1984 to the end of the spring of 1986 were used, and after impact data began in the summer of 1989 and extended to the end of the summer of 1993. Data between those periods were considered as intermediate in impact and were excluded from the analyses, the rationale being that if major changes occur they should be most obvious after the E.L.F. fields became nearly to fully operational in duration and intensity. One drawback of the B.A.C.I. method is that only sample means are used. When variance is high, as is often the case for field-derived data, the B.A.C.I. does not take into account those variances. The B.A.C.I. procedure certainly avoids the problem of pseudoreplication (see Hurlbert, 1984), but the costs of that gain are the losses in incorporation of variation among samples.

Table 4.4 presents results of B.A.C.I. tests. The primary value in using B.A.C.I. tests is that one can detect a before versus after effect. In order to run the tests, the dataset prior to impact must pass the test of nonadditivity, 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 for diversity and evenness in the spring, for numbers of individuals without chironomids in the summer and fall, and for percent numerical dominance by chironomids in the fall.

Random Intervention Analysis (R.I.A.) non-parametric tests were performed on those datasets. It is preferable to have at least 40 data points for the R.I.A. tests (Carpenter, et al., 1989) but because we separate our data into three seasons, our numbers are lower. That must be taken into account when interpreting the results, owing to higher confidence intervals under conditions of small datasets.

TABLE 4.4

Results of B.A.C.I. or R.I.A. Comparisons for Structural Community Parameters; Spring, Summer, Fall (H', J', # Individuals without Chironomids)

Spring BEFORE: 1984-1986, AFTER: 1990-1993; Summer BEFORE: 1984-1985, AFTER: 1989-1993; Fall BEFORE: 1983-1985, AFTER: 1989-1992

Parameter,	Trans-form	d.f.	Tukey's Test for Nonadditiv	d.f.	t-test, signif.	d.f.	R.I.A. Test
H',SPRING	NONE	4	51.57***		N/A	14	0.216
SUMMER	NONE	4	3.64	19	-0.752		
FALL	NONE	7	0.30	19	-1.211		
J',SPRING	ARCSN	4	21.06***		N/A	14	0.135
SUMMER	ARCSN	4	4.63	19	0.002		
FALL	ARCSN	7	0.756	19	1.518		
S', SPRING	NONE	4	7.63	12	-0.504		
SUMMER	NONE	4	6.54	19	-0.199		
FALL	NONE	7	1.72	19	-1.286		
# INDIV.,SPG	LG(X+1)	4	5.71	12	-1.065		
SUMMER	LG(X+1)	4	135.43***		N/A	21	557.50***
FALL	LG(X+1)	7	21.17***		N/A	18	195.92***
CHIRO D.SPG	NONE	4	7.70	12	-3.908**		
SUMMER	NONE	4	4.60	19	0.456		
FALL	ARCSN	7	68.70***		N/A	21	7.04***

* = <.05, ** = <.01, *** = <.001 **N/A** = not appropriate

There was significance for percent chironomid dominance (spring; $p < .05$). Figure 4.11A shows that FCD was usually higher before E.L.F. activation. During the transition period, 1986 - 1989, which was not included in the B.A.C.I. tests, FCD also was higher. The 'After' period shows that chironomid dominance was higher at FEX several times (Figure 4.11A,B, and C), resulting in significance for the B.A.C.I. test.

R.I.A. tests for diversity and evenness in the spring were not significant; however, numbers of individuals excluding chironomids were significantly different before versus after impact in the summer and fall. Figure 4.9B shows that numbers of individuals were much lower at FCD than at FEX during the summer. By 1990, the differences were smaller. Numbers at FCD were high and numbers at FEX had fallen, and sometimes they were below those for FCD. In the fall (Figure 4.10B), the difference between the two sites was greater before impact than after impact. After impact, numbers at FEX were lower and numbers at FCD were higher, resulting in significance for the R.I.A. tests. Figure 4.18 shows that numbers of individuals at FEX were higher over the years; however, another trend is apparent: Differences diminished over the

years, especially during the summer and fall. Before impact percent numerical dominance of chironomids was usually higher at FCD (Figures 4.11A, B, C). After impact, chironomid dominance was high at both sites (Figure 4.11B).

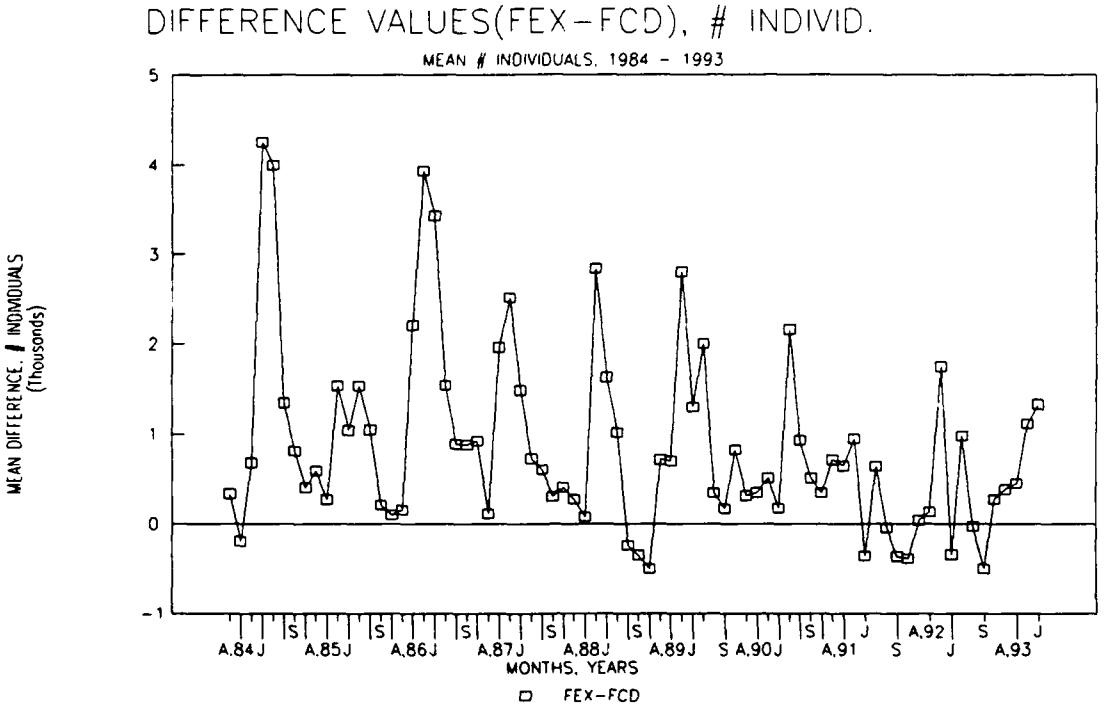

Figure 4.18. Differences between mean numbers of insects, including chironomids, at FEX and FCD. April, 1984 through August, 1993.

These results show we cannot rule out possible E.L.F. effects after full power and continuous operation began. Even so, there are other possibilities. The site at FEX seems to have become more sandy since we began our studies in 1983. A flooding event resulting in a change of course or of large debris washes, or beaver activities may have changed the character at FEX, making it more similar to the FCD site. We wish to repeat a substrate particle size study to determine if the substrates are more similar today than they were before E.L.F. lines were activated.

Functional Community Indices

Total Insect Mass and Functional Feeding Group Mass:

For this and last year's Annual Report, two additional biotic parameters were added for analysis; namely, chironomid mass dominance and collector-gatherer mass dominance. Chironomids, even though they are small, are

numerous and account for a large portion of the total biomass. Many of the species of insects we follow for changes in mean dry weight per individual over time are collector-gatherers, and that functional feeding group is expected to respond to any losses in periphyton that might be caused by ELF exposure.

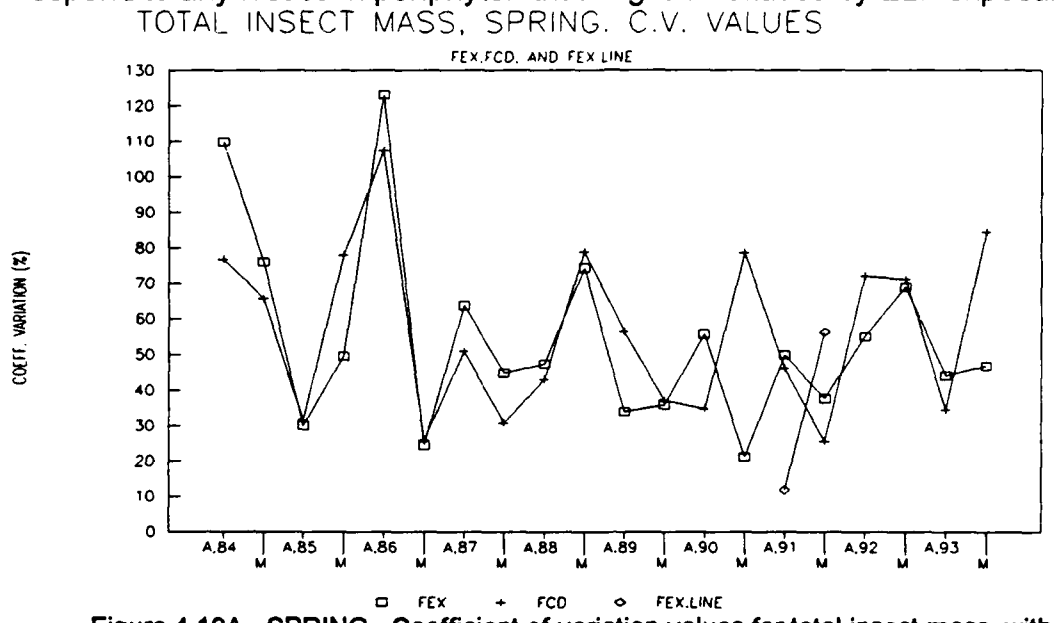

Figure 4.19A. SPRING. Coefficient of variation values for total insect mass, with chironomids. 1984-1993. FEX (squares), FCD (pluses), FEX.LINE (diamonds).

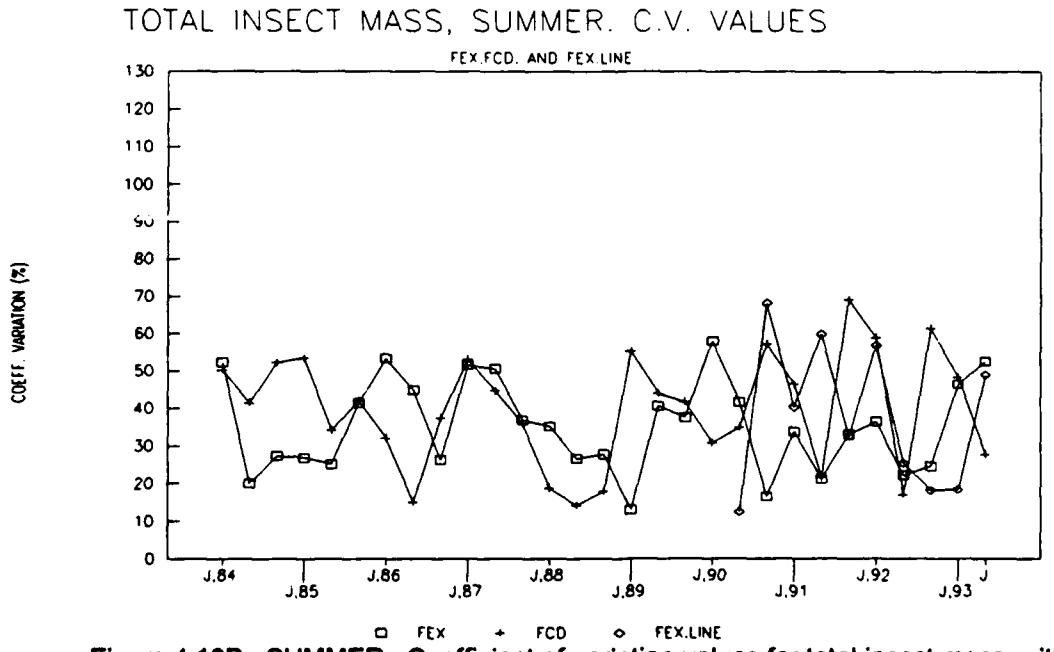

Figure 4.19B. SUMMER. Coefficient of variation values for total insect mass, with chironomids. 1984-1993. FEX (squares), FCD (pluses), FEX.LINE (diamonds).

The spring period showed the highest CV values for total insect mass (Figure 4.19A). High variances relative to the means are related to the high spring discharge values (Figure 4.13A), especially in April of 1984, May of 1985, and April of 1992. Coefficient of variation values for total insect mass were lower and fluctuated less during the summer season (Figure 4.19B) than during the spring or fall season (Figures4.19A,C).

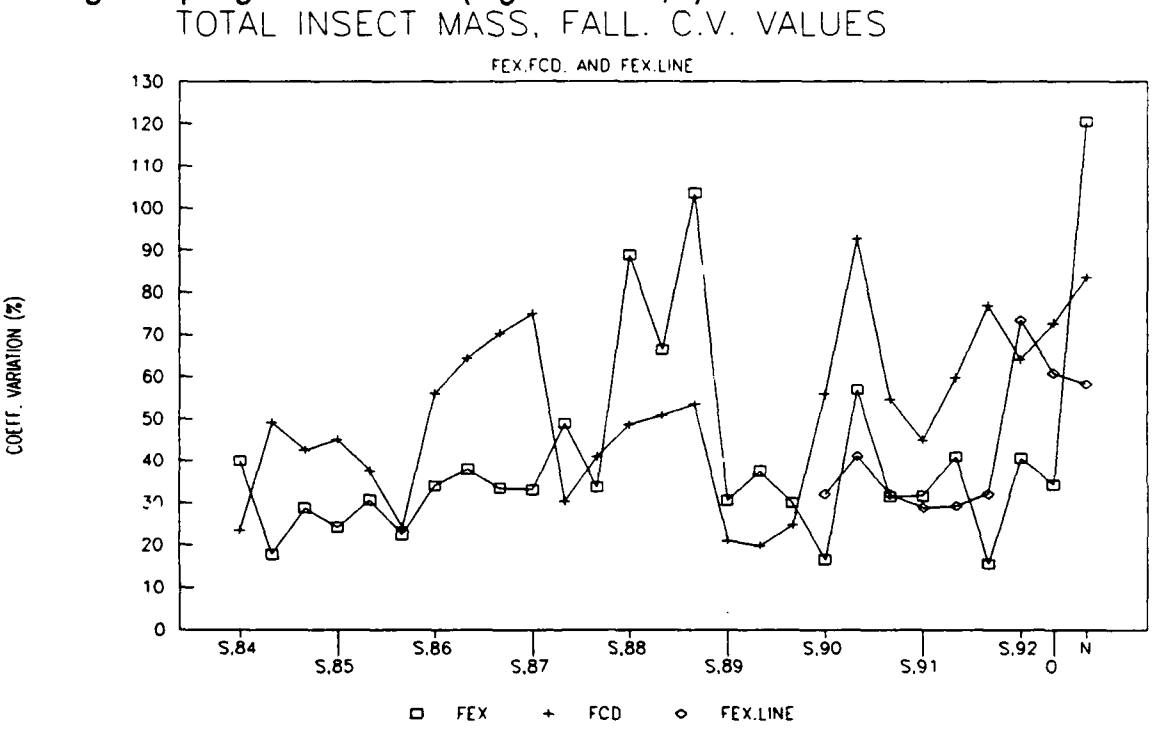

Figure 4.19C. FALL. Coefficient of variation values for total insect mass with chironomids. FEX (squares), FCD (pluses), FEX.LINE (diamonds). 1984 - 1992.

Figure 4.20 is a plot of the mean difference between FEX and FCD for total insect mass and 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 time when CV were relatively low. The majority of the points are above the zero line and indicate that total insect mass was usually higher at FEX than at FCD until 1990. Large differences between the sites are usually attributable to a few large predators (see Figure 4.21A). The most common predator was Ophiogomphus colubrinus, a dragonfly whose movements we studied for the past several years. A paper for that study was

recently published and It appeared in the 1992 Annual Report. During the mild fall and winters of 1986 - 1987, the difference between FEX and FCD remained high. Collector-gatherers (Figure 4.22A) and collector-filterers (Figure 4.23A) comprised a large bulk of the higher biomass at FEX during those mild periods.

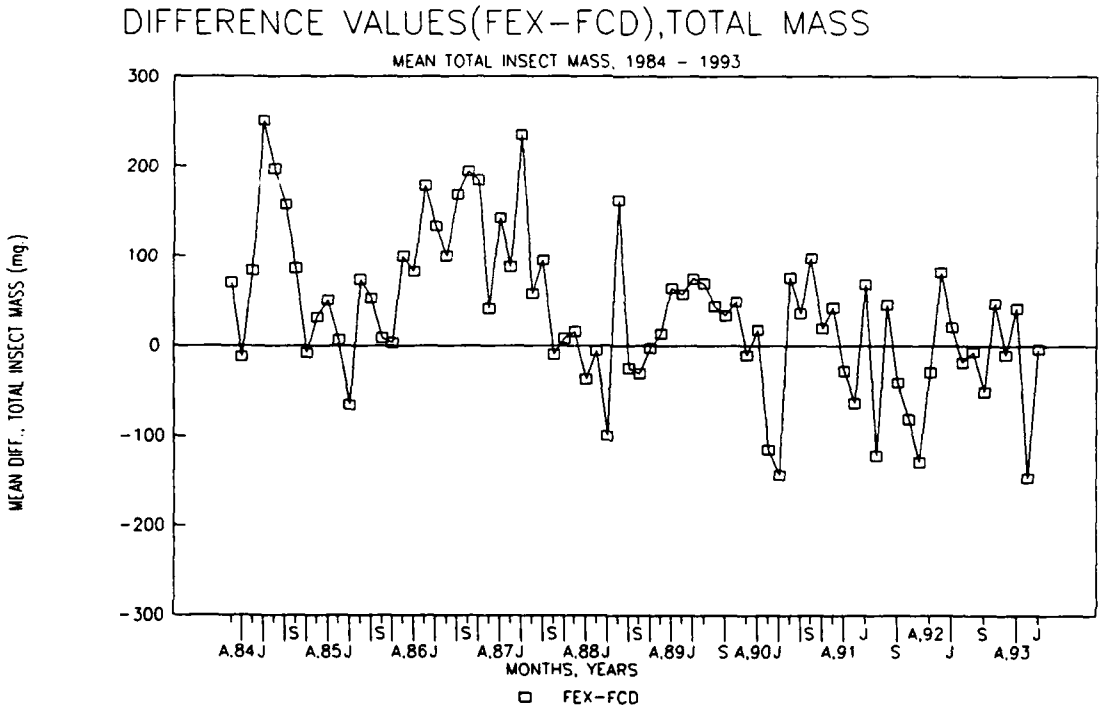

Figure 4.20. Differences in mean total insect mass (mg.) for FEX versus FCD. April 1984 through August 1993.

The following four pairs of graphs present mean differences between sites for four functional feeding groups (Figures 4.21 - 4.24) in two ways. The first graph of each pair shows mean difference values; the second plot takes the difference of the percent of total mass for the particular functional feeding group between the two sites; e.g., predator mass/total mass X 100 at FEX minus predator mass/total mass X 100 at FCD. We call the second plot percent dominance for the particular functional feeding group.

Percent dominance differences between sites for each functional feeding group was used for our analyses. This procedure was better than using raw values because FEX usually had higher total insect mass and higher functional feeding group masses (compare Figures 4.21A through 4.24A with the proportional figures in 4.21B through 4.24B). Percentages reduced the bias in having one site different in total mass over the years before and after E.L.F. activation.

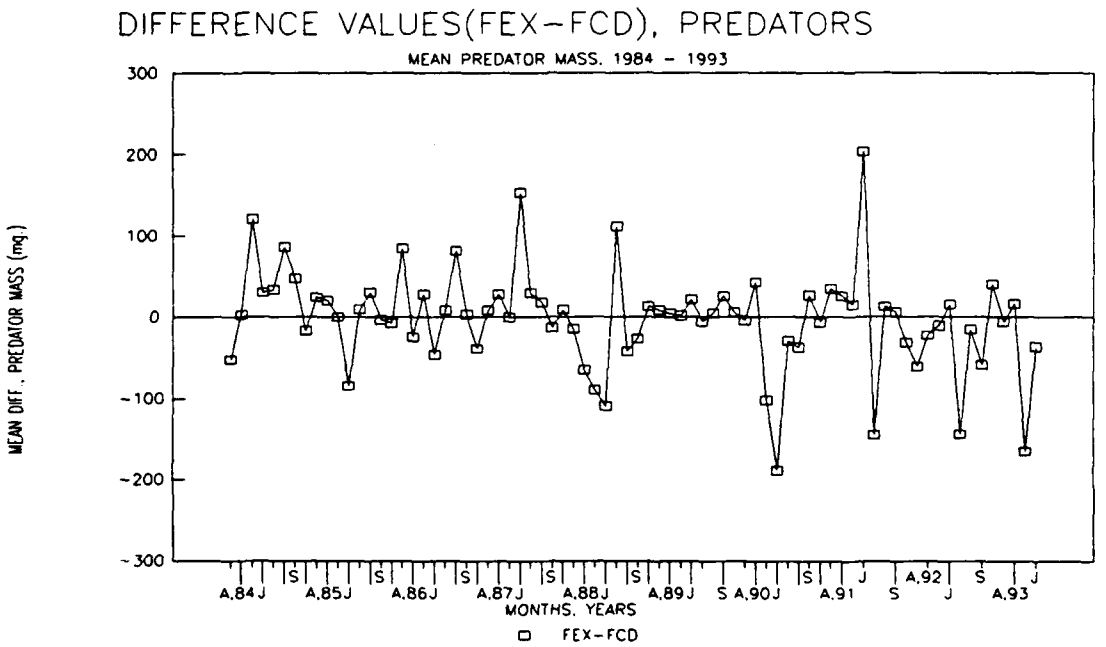

Figure 4.21A. Differences in mean predator mass (mg.). FEX minus FCD. April 1984 through August 1993.

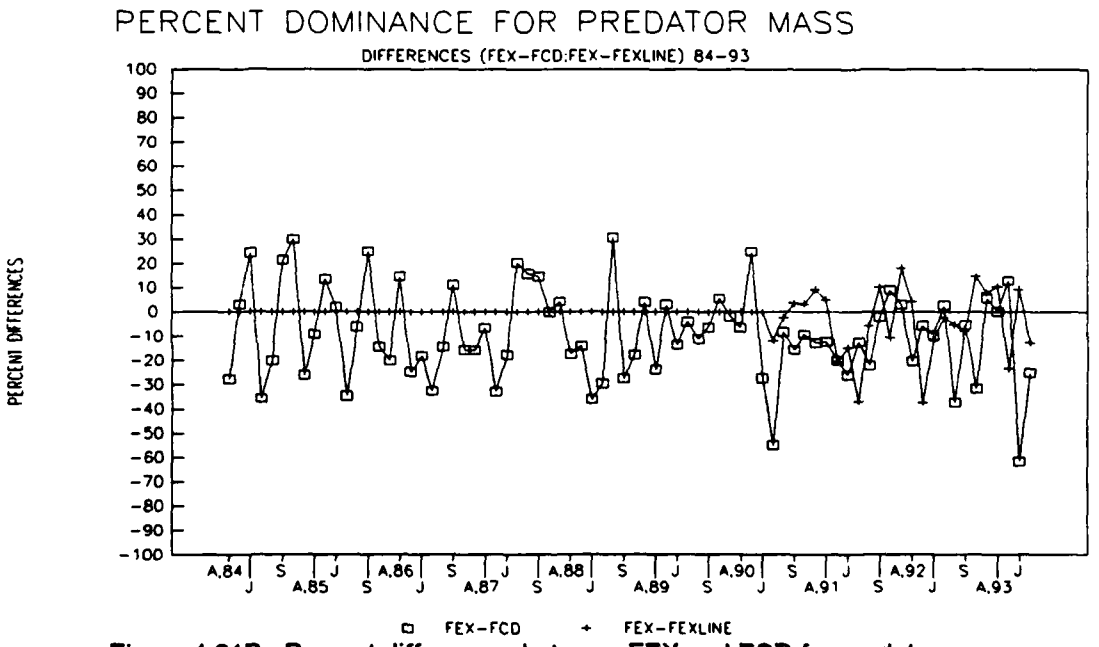

Figure 4.21B. Percent differences between FEX and FCD for predator mass dominance ratios. April 1984 through August 1993.

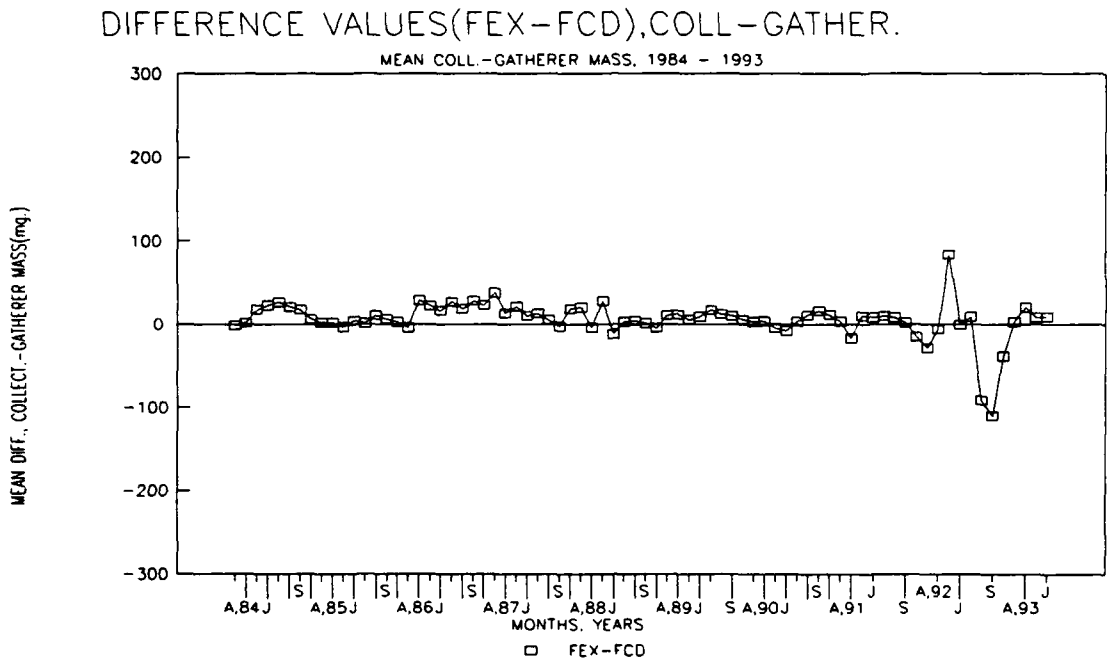

Figure 4.22A. Differences between FEX and FCD for mean collector-gatherer mass. April 1984 through August 1993.

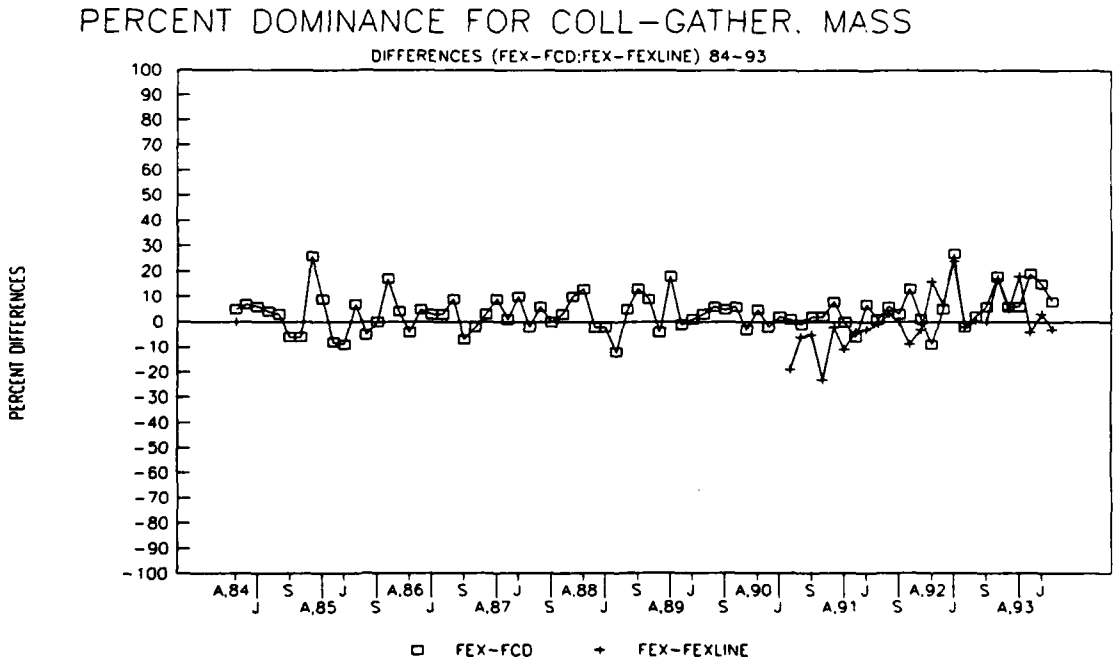

Figure 4.22B. Percent differences between FEX and FCD for collector-gatherer mass dominance. April 1984 through August 1993.

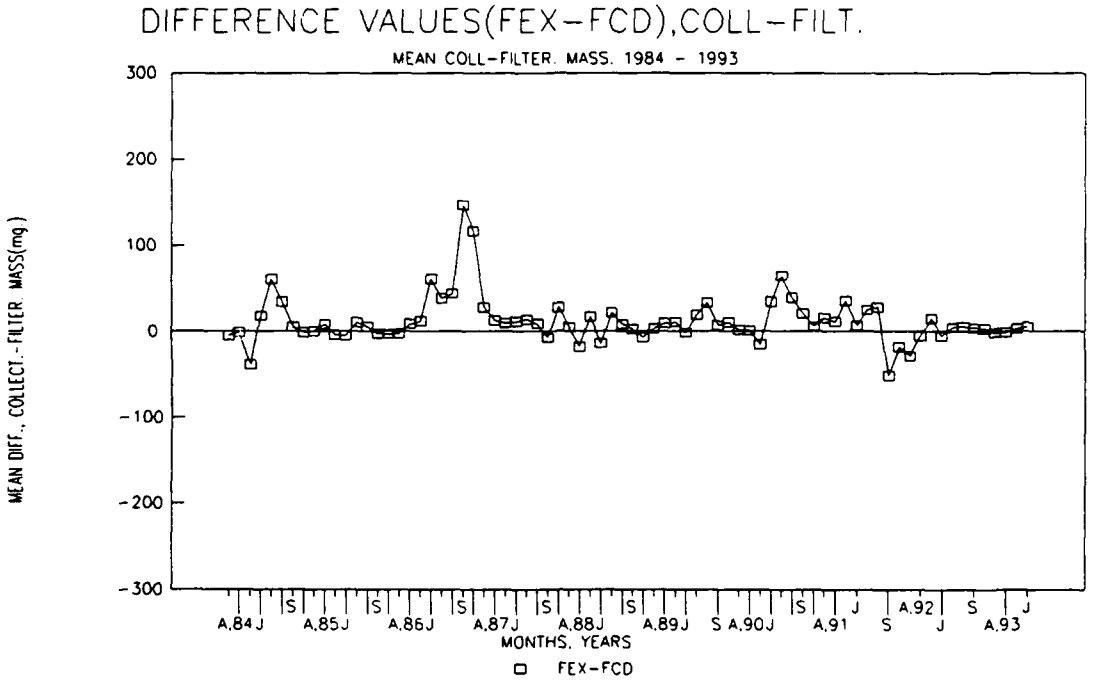

Figure 4.23A. Differences in mean collector-filterer mass (mg.). FEX minus FCD. April 1984 through August 1993.

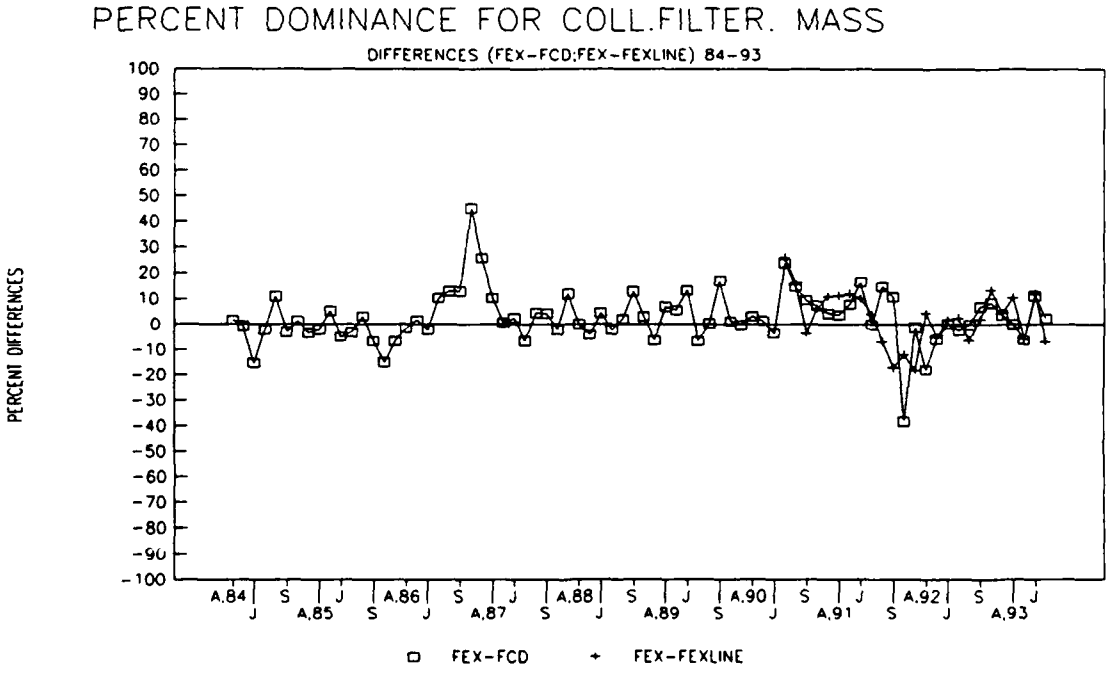

Figure 4.23B. Percent differences between FEX and FCD for collector-filterer mass dominance. April 1984 through August 1993.

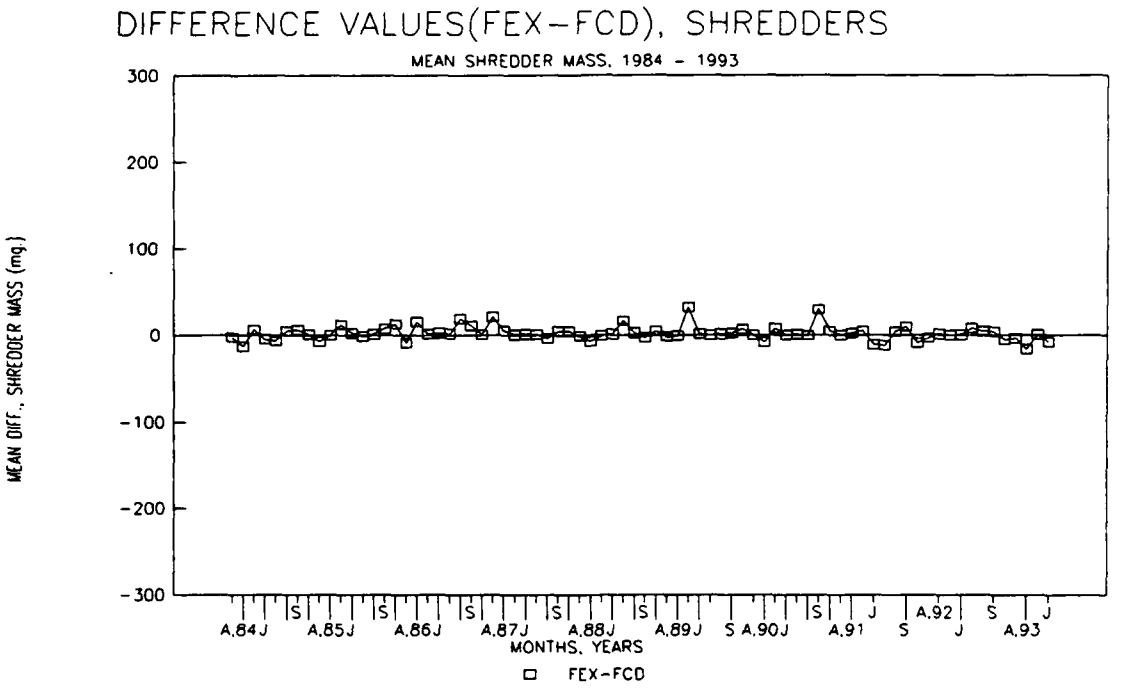

Figure 4.24A. Percent differences between FEX and FCD for mean shredder mass dominance. April 1984 through August 1993.

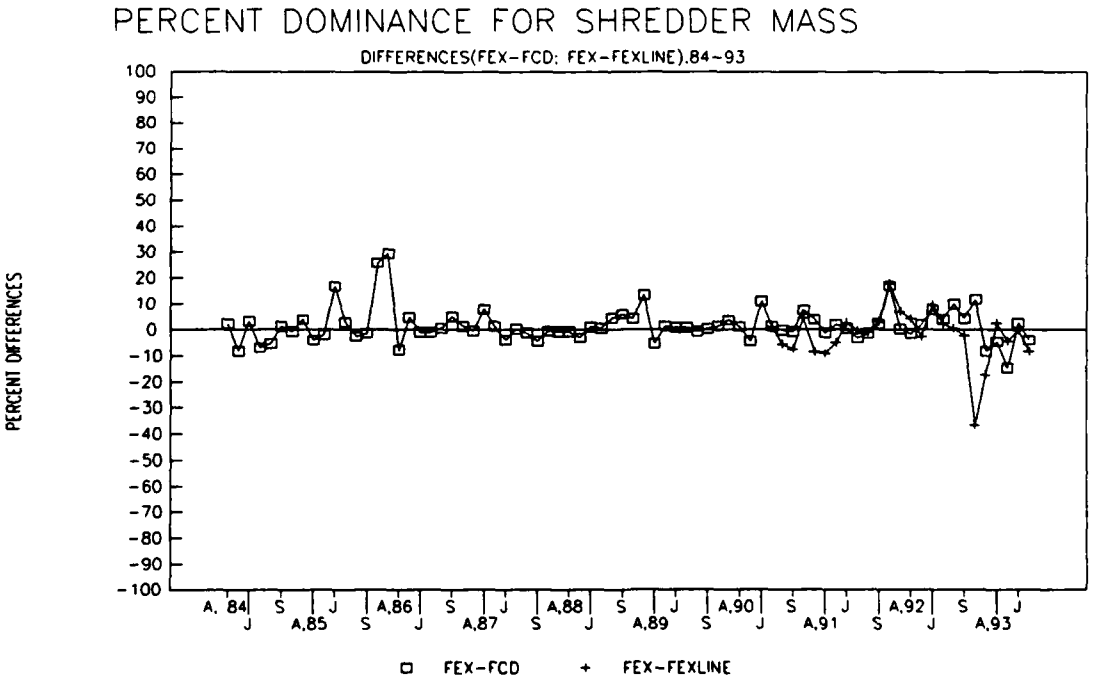

Figure 4.24B. Percent differences for FEX and FCD for shredder dominance. April 1984 through August 1993

As shown for structural community parameters in figures 4.11A,B,C, chironomids comprise a large portion of insect numbers in samples at both sites. Although the mass of an individual chironomid is small, numbers of chironomids are large. That family contributes much mass to total insect mass. In this report, chironomid mass dominance was also added to the analysis. Figure 4.25 shows the difference between the two sites by percent mass dominance. Peak differences where FEX values were high usually occurred in July of each year. It was in the fall that FCD values were usually higher. These patterns occurred over the nine years of study (before and after E.L.F. activation). Chironomid mass dominance was consistently low at FEX.LINE, relative to FEX or FCD (Figure 4.25). Had FEX.LINE been part of the study throughout the study, we would have had a better idea as to whether E.L.F. activation had reduced chironomid abundances at that site.

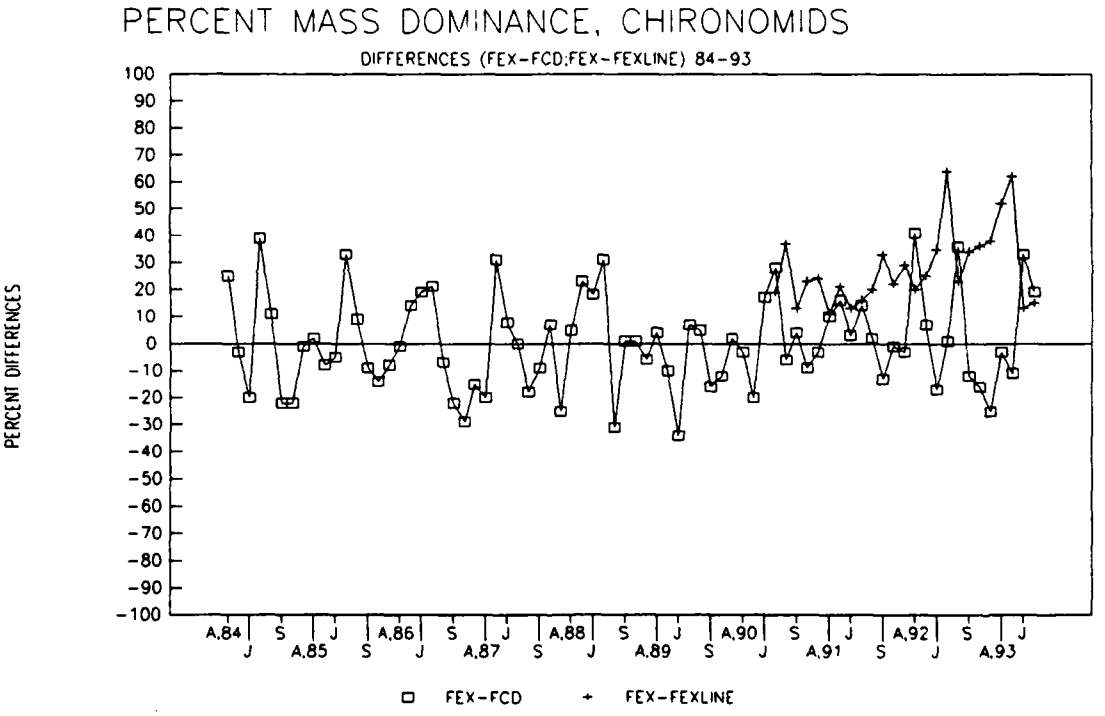

Figure 4.25. Percent difference between FEX and FCD (squares) and between FEX and FEX.LINE (pluses) for numerical dominance of chironomids. April 1984 through August 1993.

Another parameter which is biologically meaningful in community analyses is the relationship between predators and their prey (Figure 4.26A). Differences in predator/prey mass ratios between FEX and FCD were small except for the spring of 1986 when many predatory stoneflies were collected at FEX. Because this parameter can tell so much about any particular site,

additional comparisons between pairs of sites are included. In this comparison, FEX and FEX.LINE are more similar to one another (squares) than are either of the other two comparisons (FEX and FCD or FCD and FEX.LINE). This makes intuitive sense, as FEX and FEX.LINE are in close proximity to one another than are either of the other pairwise comparisons.

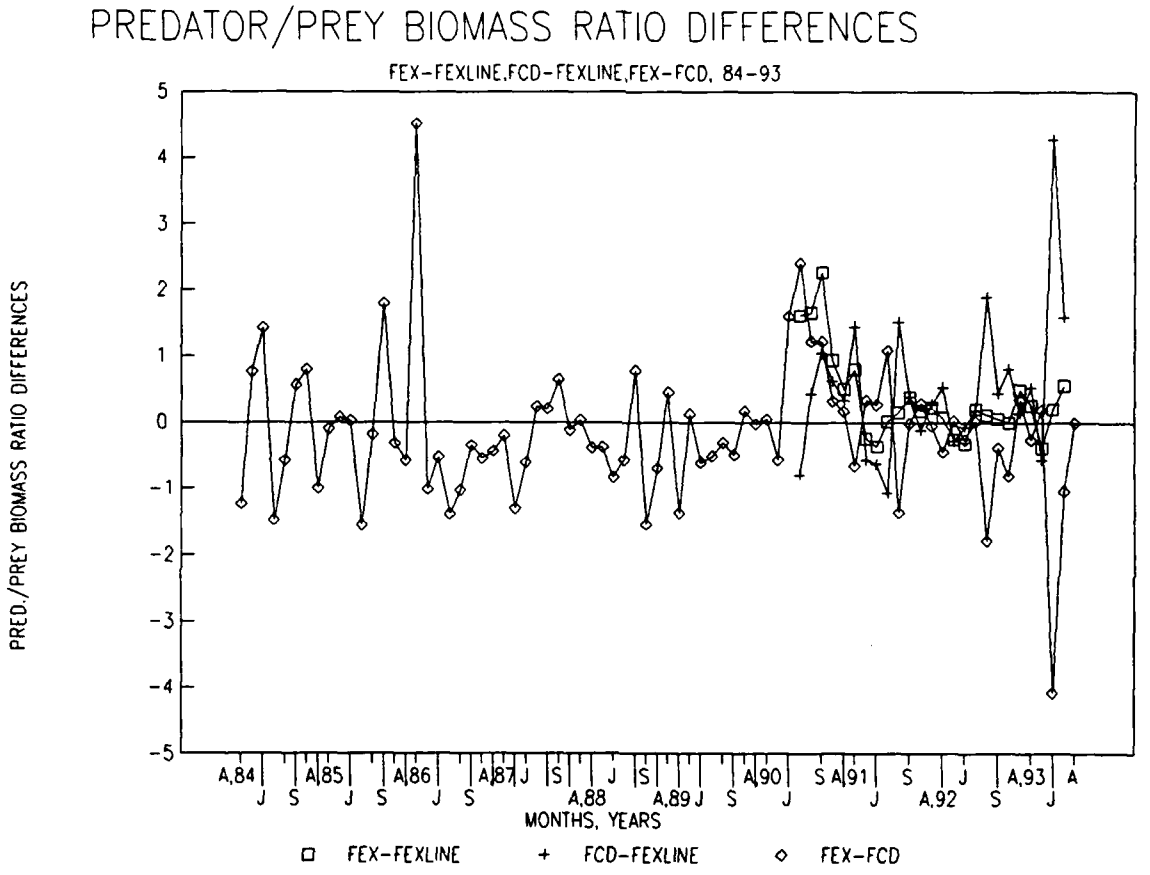

Figure 4.26. Differences between FEX and FCD (diamonds), between FEX and FEX.LINE (squares), and between FCD and FEX.LINE (pluses) for predator/prey ratios. April 1984 through August 1993.

Four functional feeding group parameters were used for statistical analysis: Total mass, percent dominance for chironomid mass, percent collector-gatherer dominance, and predator/prey ratios. The data were separated into seasons to determine statistical patterns based on naturally grouped data. Two-Way ANOVA tests for FEX and FCD appear in Table 4.5A. Two-Way ANOVA tests for FEX, FCD, and FEXLINE appear in Table 4.5B. Table 4.5A shows that in only three of the possible 12 cases were there significant interactions between site and year (total mass in the summer and

fall and predator/prey ratios in the summer) when FEX and FCD were used. Table 4.5B shows that for the summer season comparison for FEX, FCD, and FEXLINE only collector gatherer percent dominance showed a significant interaction term. Total insect mass and collector gatherer percent dominance showed non-significant site differences among the three sites from 1990 through 1993 (Table 4.5B). When FEX and FCD data from 1984 through 1993 were used for the summer data, there were significant site differences for these two biotic variables. The major site differences between FEX and FCD occurred before 1990 (Figure 4.32). After 1989, all three sites were similar.

TABLE 4.5A
2-Way ANOVA Tests for Seasonal Differences, FEX vs. FCD
Functional Community Parameters, WITH CHIRONOMIDS

F VALUES, LEVELS OF SIGNIFICANCE

PARAMETER, SOURCE	D.F.	SPRING	SUMMER	FALL
TOTAL MASS				
Site	1	1.58 n.s.	10.99 ***	15.93 ***
Year	9	7.71 ***	11.38 ***	12.23 ***
Site, Year	9	1.32 n.s.	3.83 ***	4.58 ***
% DOMINANCE, COLL-GATHERER MASS				
Site	1	7.98*	15.44 ***	18.20 ***
Year	9	3.50 ***	6.27 ***	3.52 **
Site, Year	9	1.72 n.s.	0.90 n.s.	0.96 n.s.
% DOMINANCE, CHIRONOMID MASS				
Site	1	3.18 n.s.	16.16***	9.00 ** !
Year	9	4.42 ***	6.86 ***	8.27 n.s.!
Site, Year	9	1.48 n.s.	1.81 n.s.	N/A
PREDATOR/PREY MASS RATIO				
Site	1	0.02 n.s.	24.17 ***	4.18 *
Year	9	2.72 *	5.07 ***	4.12 ***
Site, Year	9	1.00 n.s.	2.54 **	1.10 n.s.
Error, D.F.		**180**	**280**	**252**

p <.05 = *; p < .01 = **; p < .001 = *** N/A = not appropriate
! = Friedman 2-WAY ANOVA test

Total mass showed significant interaction terms in the summer months, even though there were low coefficient of variation values then (Figure 4.19B). In the 1991 Annual Report there were no significant site, year, nor interaction terms. Figure 4.20 shows a rather different relationship between FEX and FCD for total insect mass after April of 1989. Not only did the relatively higher mass

of insects go down at FEX, but often relative mass abundances were higher at FCD than at FEX.

TABLE 4.5B
2-Way ANOVA Tests for Summer Differences for FEX, FCD, and FEXLINE
Functional Community Parameters, WITH CHIRONOMIDS
July, August 1990 - 1993

F VALUES, LEVELS OF SIGNIFICANCE

PARAMETER, SOURCE	D.F.	SUMMER
TOTAL MASS		
Site	2	3.096 n.s.
Year	3	7.828 ***
Site, Year	6	0.631 n.s.
% DOMINANCE, COLL-GATHERER MASS		
Site	2	2.667 n.s.
Year	3	7.828 ***
Site, Yeai	6	0.631 n.s.
% DOMINANCE, CHIRONOMID MASS		
Site	2	16.157 ***
Year	3	23.075 ***
Site, Year	6	0.223 n.s.
PREDATOR/PREY MASS RATIO		
Site	2	8.198 ***
Year	3	8.280 ***
Site, Year	6	1.853 n.s.
Error, D.F.		**108**

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

Dr. Abdul El-Shaarawi analyzed the insect mass data from 1984 through 1991 using the change point method. His analysis showed that a change occurred after August 20, 1987. Figure 4.20 shows also that the difference between the two sites for insect mass became smaller after 1988. Figure 4.31 shows that there was a decided relative decrease in insect mass at FEX in the spring. Figure 4.32 shows that in the summer, total mass increased at FCD after 1989. Note that from August of 1986 through August of 1989 FCD had a higher mean insect mass than did FEX six times (Figure 4.20). This happened 16 times from August 1989 through August of 1993. Overall, the two sites have become more similar to one another in the summer since 1989 (Figure 4.32). There is no distinct pattern difference for the fall period (Figure 4.33).

Because E.L.F. fields became fully operational in the fall of 1989 and these changes occurred close to that time, it is essential that all other physical data be used to see the importance of those data as related to changes in total insect mass.

Although collector-gatherer dominance data had no significant interaction terms for each of the three seasons, there were significant site effects and year effects in the summer and fall seasons. Differences between FEX and FCD for this parameter oscillated a great deal in the summer and fall of 1992 (Figures 4.22A,B).

Chironomid mass dominance oscillated very much in the summer (Figure 4.25), resulting in significant site effects (Table 4.5). The fall data did not pass the test for homogeneity of variances. The Friedman two-way analysis of variance, showed that there was a significantly greater mean chironomid mass dominance at FCD as compared with FEX ($p < 0.005$). Yearly differences were not significant ($p = 0.41$). In some years, the spring and summer FEX samples supported a greater number of large chironomids than the FCD samples, resulting in larger mass values at FEX. Year effects were significant for those seasons (Table 4.5).

There was no consistent pattern change with respect to chironomid mass dominance over the years, leading one to suggest that E.L.F. activation did not affect absolute chironomid masses at either the experimental or reference site.

In the spring and fall, predator-prey ratios were similar at the sites, but in the summers, large differences between the sites occurred, owing to large dragonflies and predaceous stoneflies that were usually, but not always, more abundant at FEX (Figure 4.26A). Wide-ranging differences during the summer probably accounted for the highly significant main effects (Table 4.5).

Physical Factors as Related to Functional Community Variables

Discharge and water temperature were shown to be related to structural community variables (Tables 4.3A,B,C). Those physical variables were expected to be related to functional community variables as well. Table 4.6 gives correlation coefficient (CC) values for insect mass, discharge, and water temperatures from October 1983 through August, 1993. Both discharge and water temperatures were significantly correlated with insect mass. Table 4.6 and 4.7 show that insect mass was always more correlated with discharge than with water temperature. Taxon richness was more correlated with discharge

with all months combined, but it was more correlated with water temperature in May of each year (Figure 4.16, 4.17).

TABLE 4.6
Correlation Coefficients for Biological and Physical Parameters from October 1983 through August, 1993.

	Ln Insect Biomass mg X 10-1	Water Temp. °C.	Discharge Rate M3/Sec.
Ln Insect	1.00		
Water Temp.	.40	1.00	
Discharge	-.50	-.21	1.00

Critical value (2-tail, .05) = ± 0.24

Figure 4.27 is a regression of ln of the average total insect mass at both sites combined x 10^{-1} versus discharge (m^3/sec) for all seasons together. Figure 4.28 shows a regression of ln of the total insect mass versus discharge for May of each year.

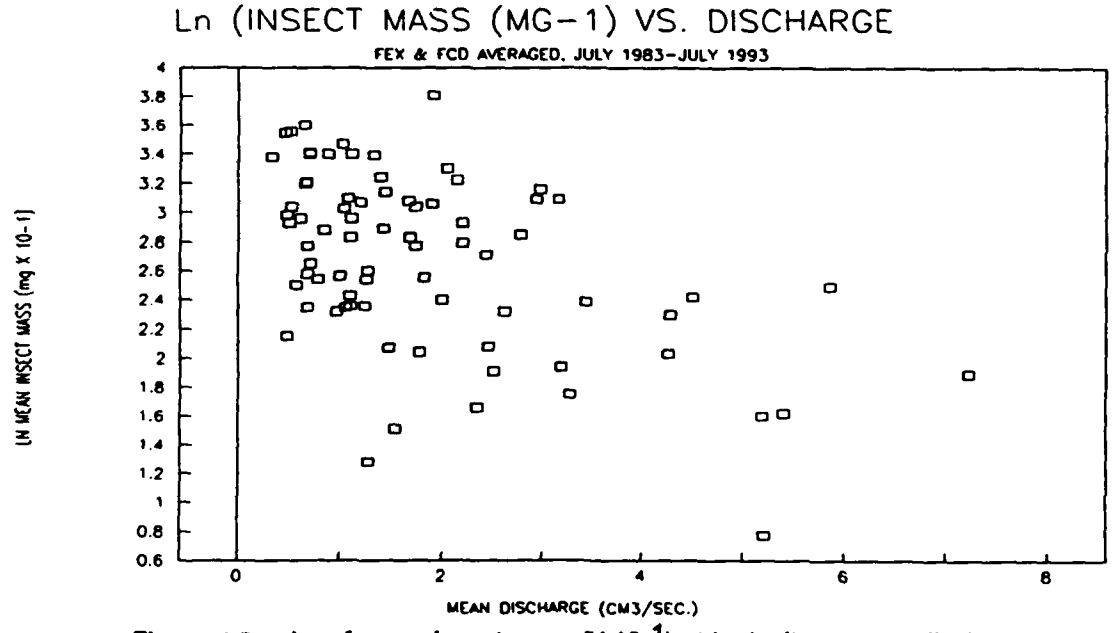

Figure 4.27. Ln of mean insect mass (X 10^{-1}) at both sites versus discharge (M^3/sec) for all seasons. July 1983 - August 1993. (r^2 = .25)

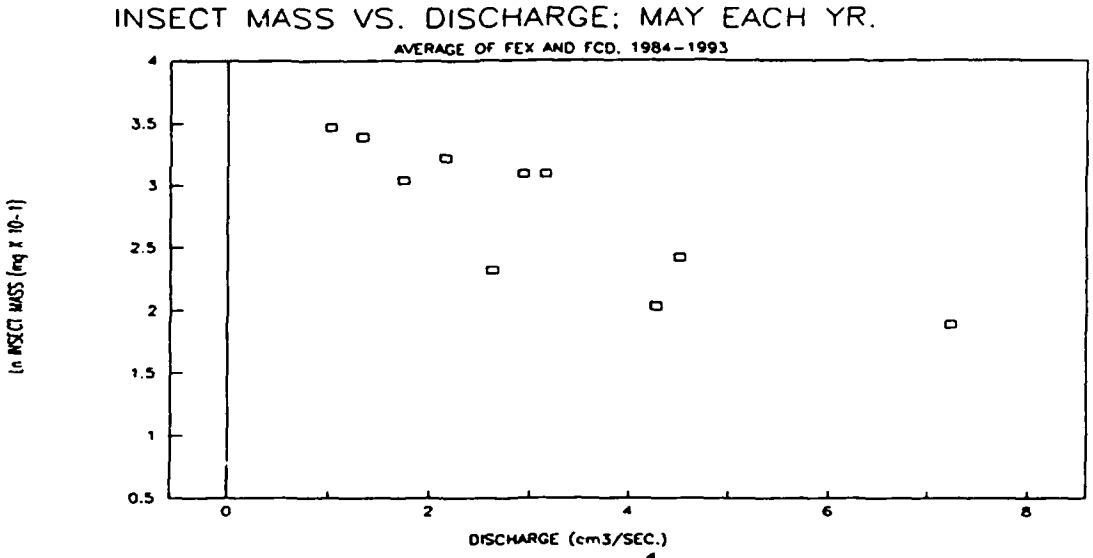

Figure 4.28. Ln of mean insect mass (X 10^{-1}) at both sites versus discharge (M^3/sec) for MAY of each year, 1984 - 1993. (r^2 = .74)

Figures 4.27 and 4.28 show that the negative relationship between discharge and insect biomass is very strong when only May is considered ($F_{1,9}$: 20.42, p = .002). In May both insect mass and periphyton density have a potential for being high. However, discharge intensities can fluctuate, depending on past snow cover and the timing of the influx of melt waters. May values for each year are highly variable. A regression of periphyton density versus discharge through May of 1992 showed a highly significant relationship as well ($F_{1,8}$: 14.33, p = .007, r^2 = .67).

Table 4.7 gives a correlation matrix for insect mass, mean water temperature, and mean discharge values for the month of May each year.

TABLE 4.7
Correlation Coefficients for Biological
and Physical Parameters, MAY 1984-1993

	Ln Insect Biomass mg X 10-1	Water Temp. °C.	Discharge Rate M³/Sec.
Ln Insect	1.00		
Water Temp.	.72	1.00	
Discharge	-.85	-.78	1.00

Critical value (2-tail, .05) = ± 0.63

The average water temperature the aquatic insects experience between collection periods is important in explaining the variation in several of their biotic parameters over chronological time. But because many of the insects live more than one month and have accumulated a history (often from summer through to the next spring), physiological time as reflected by cumulative degree days can be a more precise tool by which to measure their environment. This study is now in its tenth year. Over that period daily maximum and minimum water temperatures have been recorded in the spring, summer and fall. Those data were used to calculate cumulative degree days each year (using a threshold for insect response of 2°C). The several generations of insects have experienced cool to warm springs, summers, and falls. We have been fortunate in this study to have had one of the hottest summer and falls recorded (1988), and one of the coolest summer and falls recorded (1992). Cumulative water temperatures should be of great help in determining whether highly varying natural or systematically increasing anthropogenic factors such as E.L.F. fields play a major role in insect responses.

The following four degree day figures present monthly deviations each year from the grand means of ten values, representing ten years of data. Figure 4.29 includes data before E.L.F. activation and Figure 4.30 includes data after full activation of E.L.F. fields. An obvious pattern arises when comparing pre- and transitional years to post-operational years: the pre-operational years were very cool as compared with the transitional years. Had it not been for 1990 and 1992 we could have facetiously suggested that intermediate E.L.F. power causes 'global warming'. Another pattern is revealed when monthly comparisons are made. The angle of the slopes reflects the deviations from other years with respect to a particular month. For example, Figure 4.29 shows that July 15th to August 15th of 1984 was very warm as compared with the other five years. (We, in the 'field' can appreciate and remember the difference.) 1988 was consistently very warm each month. Figure 4.30 shows that the summers of 1992 and 1993 were very cold. In 1992, the cooler temperatures had an impact on crops in Michigan (Michigan Department of Agriculture bulletins), and it may well have had an impact on insects in the Ford River. As of this writing, crops have not been harvested. It could well be that the 1993 cooler and wetter spring and summer may also have a negative effect on crops. Certainly, the total mass of insects in our samples from the Fort River was low in the spring (Figure 4.31) and summer (Figure 4.32). 1990 was the most average year for temperature; figure 4.30 shows that mean deviations each month hovered very close to the zero differences line.

In summary, the pre-operational years (1983 - 1985) were cooler than average, the transition years (1986 - 1989) were warmer than average, and the full power years (1990 - 1993) were cooler than average, with the exception of 1991. In our B.A.C.I. analyses, we compared 1984 through mid-1986 as pre-operational with the full power years, fall of 1989 through the summer of 1993. These two sets of years were more similar to each other than was the transition period, with respect to water temperatures.

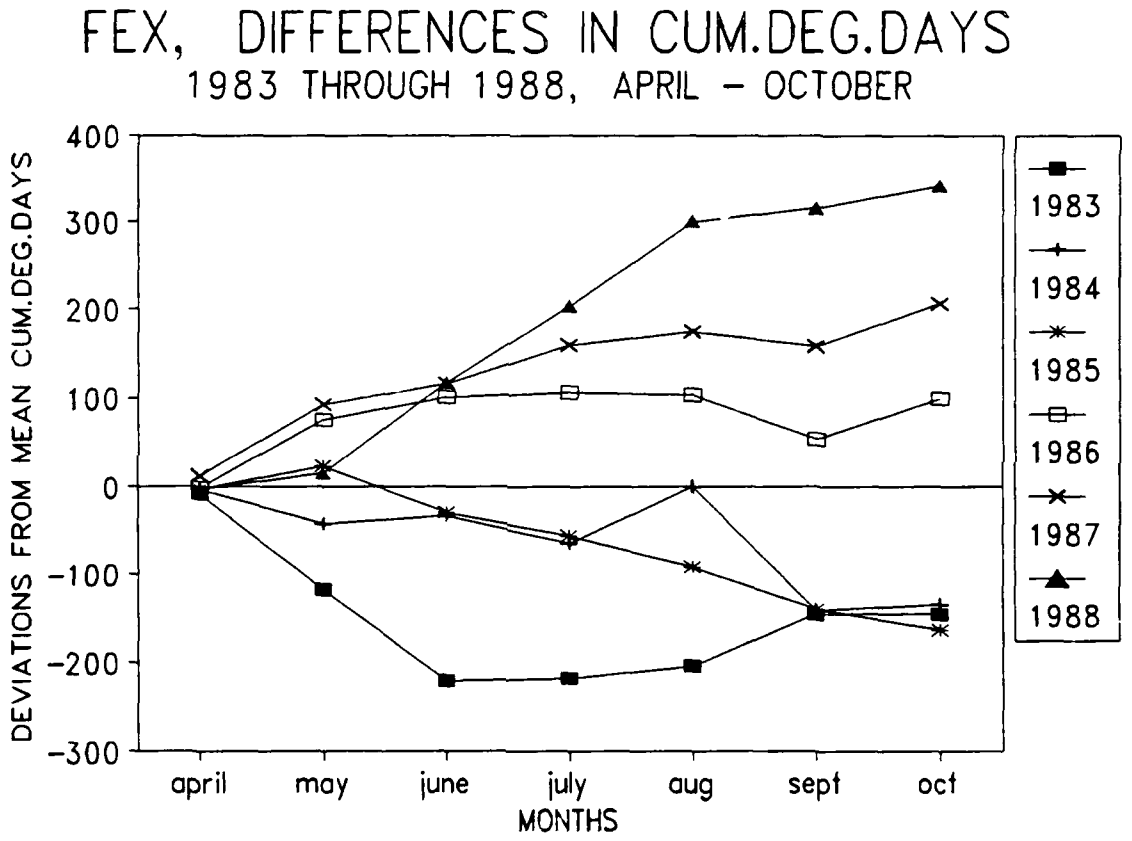

Figure 4.29 Deviations in monthly mean values for cumulative degree days. BEFORE: 1983-1985; TRANSITION: 1986-1988.

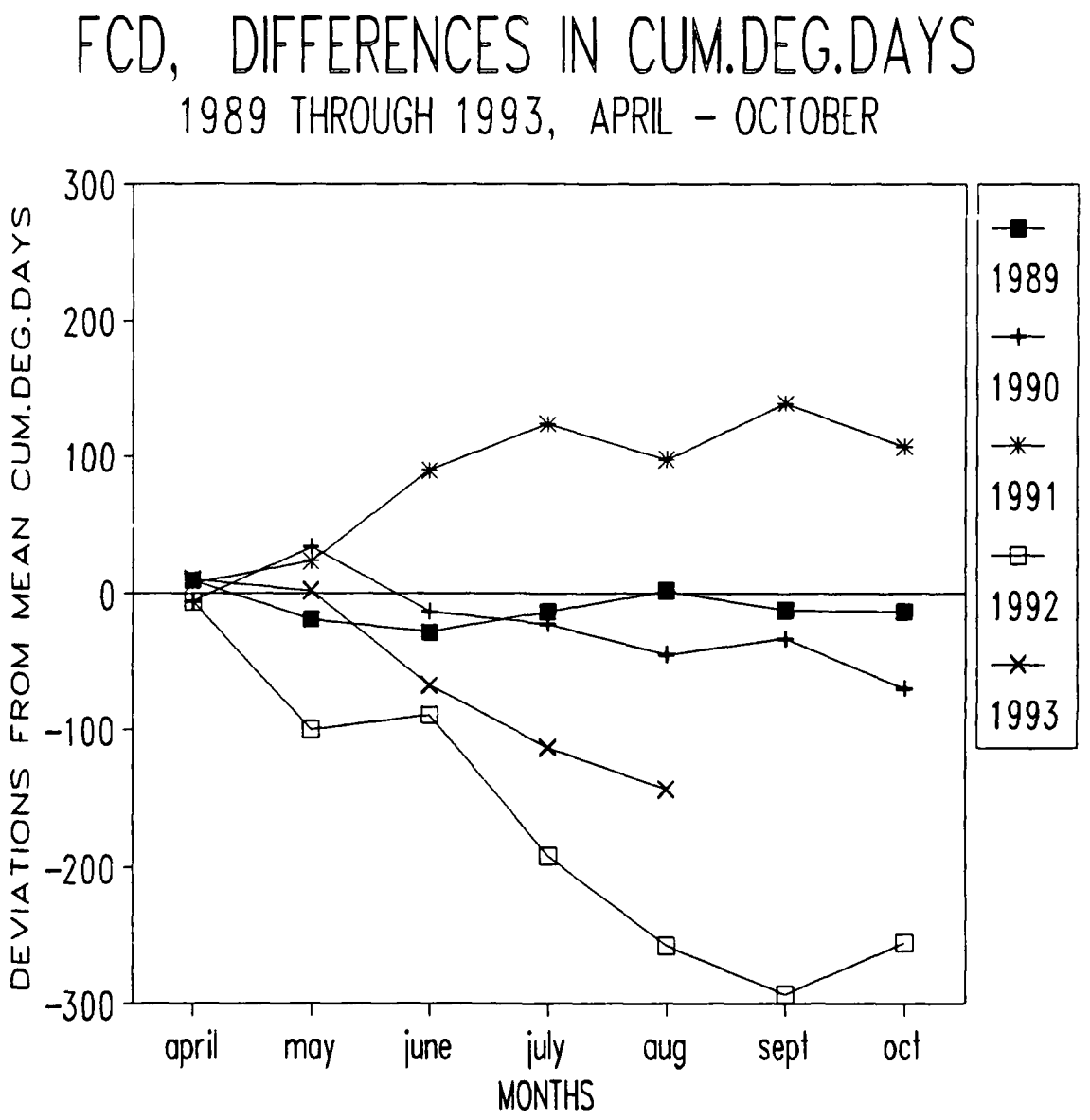

Figure 4.30. Deviations in monthly mean values for cumulative degree days. AFTER: 1989 - 1993.

Because discharge and cumulative degree days for water temperature correlated with our functional community parameters, these physical variables as well as years were used as independent variables for multiple regressions on each site for total mass, percent biomass dominance by chironomids, percent biomass dominance by collector-gatherers, and predator/prey ratios. The data were grouped by season (Tables 4.8A, B, and C). Percent data for the dependent parameters were transformed (arc sine of square root of Y/100) as were ratio data (arc sine of square root of Y).

TABLE 4.8A

Multiple Regressions for Biotic Parameters versus
Years, Discharge, and Cumulative Degree Days
Spring (1984 - 1993)

Dependent Variables

R^2 and Standard Partial Regression Coefficients

Independent Vars.	*Total Mass*	*% Chiro Dom.*	*% C-G Dom.*	*Pred/ Prey R.*
FEX				
R^2	***0.33***	***0.06***	***0.04***	***0.04***
Years	*-0.12*	*0.08*	*0.03*	*-0.16*
Discharge	*-0.50*	*0.23*	*-0.06*	*0.05*
Cum.D.Days	*0.28*	*0.06*	*-0.18*	*0.10*
FCD				
R^2	***0.12***	***0.03***	***0.01***	***0.07***
Years	*0.01*	*0.07*	*0.01*	*-0.25*
Discharge	*-0.33*	*0.15*	*0.06*	*-0.09*
Cum.D.Days	*0.08*	*0.05*	*-0.08*	*0.08*

Spring: The coefficient of multiple regression values were all below .35 for the spring data (Table 4.8A). R^2 values had been high for discharge and for total mass at both sites until the 1991 and 1992 data were added. After the data were added for total insect mass, the R^2 value for total insect mass dropped precipitously at FCD. Although discharges were average in 1991 and high in 1992 (Figure 4.13A), total insect mass at FCD was higher than expected (Figure 4.31). Total insect mass at the two sites was high in April and May of 1987 and 1988 (Figure 4.31) when discharge was low. From 1990 through 1992, insect mass continued to rise at FCD even though there were high discharge events in 1992! On the other hand, even though insect mass in the spring steadily rose at FEX from 1990 through 1992, it did fall in April of 1992 when the highest spring discharge events occurred since E.L.F.

activation. This probably accounts for the higher R^2 and standard regression coefficient for discharge at FEX as compared with FCD.

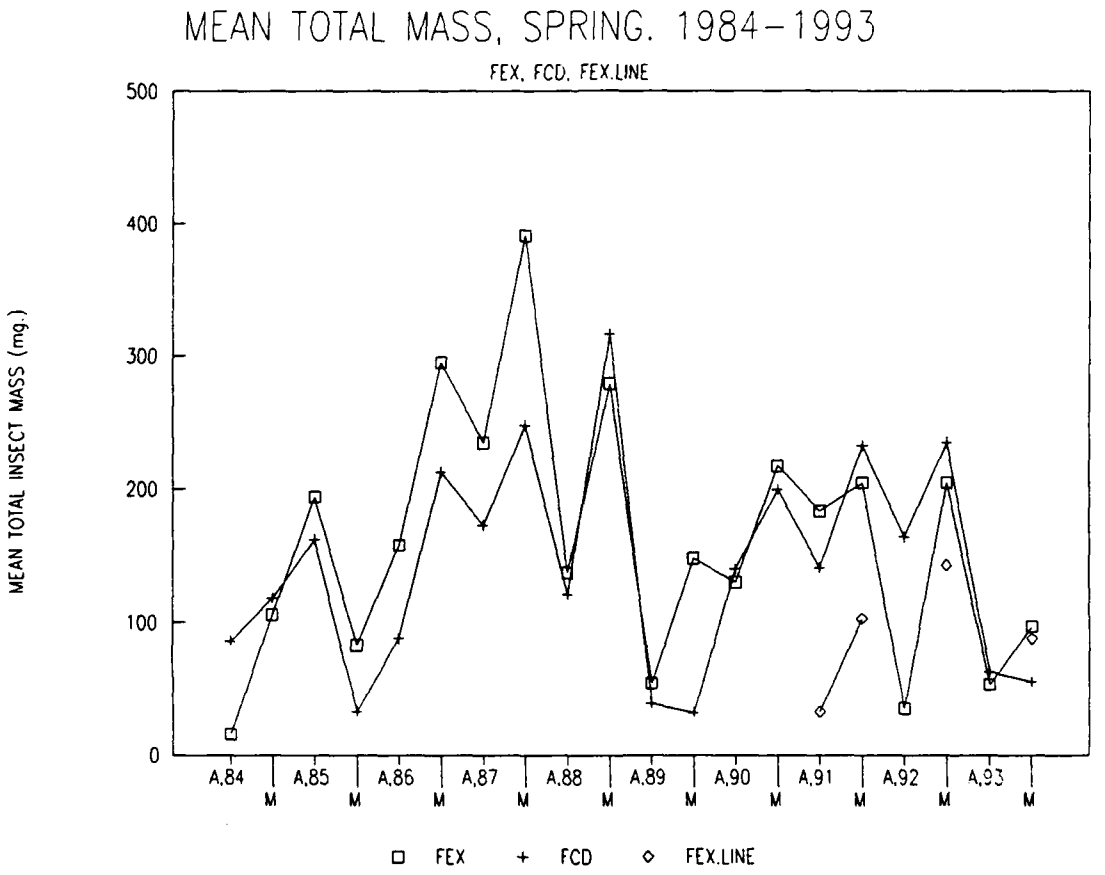

Figure 4.31. SPRING. Mean total insect (mg.) at FEX (squares), FCD (pluses), and FEX.LINE (diamonds). 1984 through 1993.

Summer: Discharge and/or cumulative degree days accounted for most of the explained variation in total insect mass at FEX (Table 4.8B). In the 1992 Annual Report, R^2 values for total mass were 0.11 and 0.25 for FEX and FCD, respectively. There were peak discharges in June of 1989, 1990, and 1991 (Figure 4.13B). The severity was highest in 1989 and lowest in 1991. Insect mass in June, 1989 was very low, intermediate in 1990 and higher in 1991, as expected (Figure 4.32). Even though insect mass fell in June of 1991, it was relatively high, especially at FCD (Figure 4.32). Those high values helped to account for the lower R^2 values. The variance in percent dominance of chironomid mass and predator/prey ratios could not be explained in any way by the dependent variables used Table 4.8B).

TABLE 4.8B
Multiple Regressions for Biotic Parameters versus
Years, Discharge, and Cumulative Degree Days
Summer (1984 - 1993)
Dependent Variables

R^2 and Standard Partial Regression Coefficients

Independent Vars.	***Total Mass***	***% Chiro Dom.***	***% C-G Dom.***	***Pred/ Prey R.***
FEX				
R^2	***0.14***	***0.05***	***0.17***	***0.01***
Years	*0.02*	*-0.04*	*-0.05*	*-0.01*
Discharge	*-0.36*	*0.26*	*-0.09*	*0.01*
Cum.D.Days	*0.02*	*0.10*	*-0.43*	*0.06*
FCD				
R^2	***0.24***	***0.04***	***0.06***	***0.05***
Years	*0.40*	*-0.11*	*-0.13*	*-0.20*
Discharge	*-0.42*	*0.11*	*-0.01*	*-0.05*
Cum.D.Days	*-0.20*	*0.21*	*-0.23*	*-0.02*

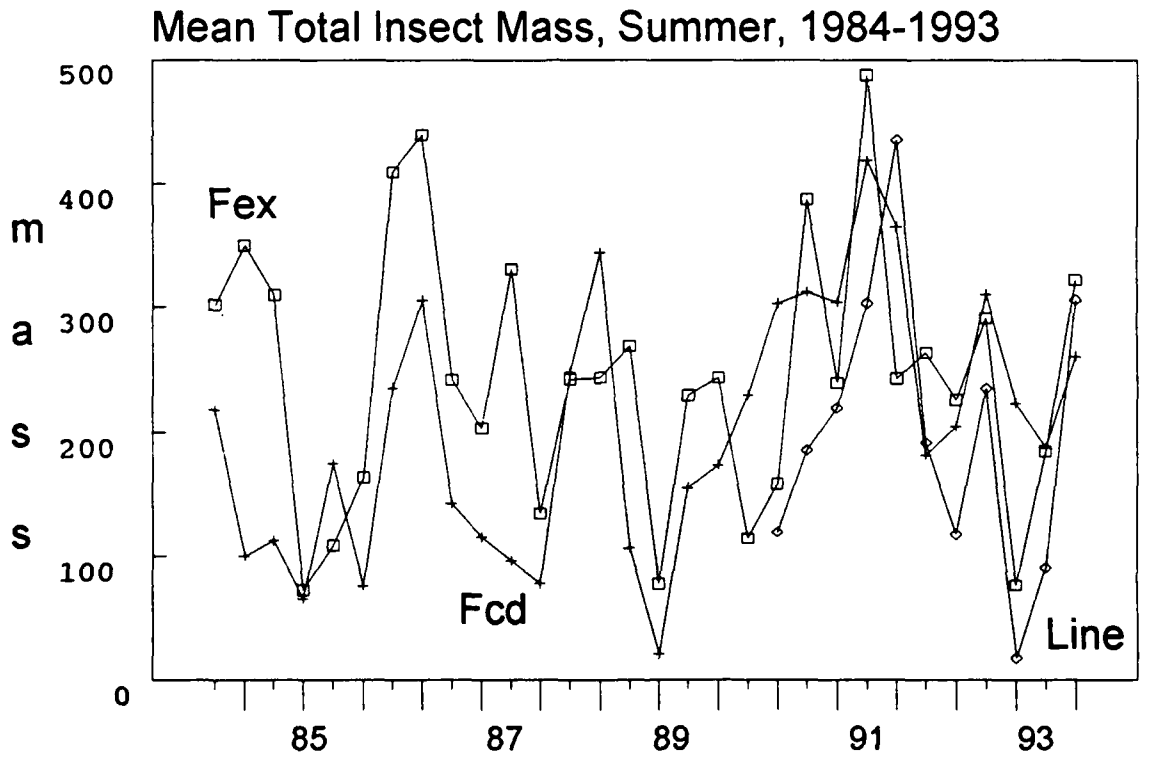

Figure 4.32 SUMMER. Mean total insect mass (mg.) at FEX (squares), FCD (pluses) and FEXLINE (diamonds). June 1984 - August 1993.

Summer is the most stable season. High discharge events and major swings in water temperatures are rare so any large storm event can have large statistical power. Large storms occurred in June of 1989, 1990, 1991,and 1993. Even so, when all the years through 1993 were used in an ANCOVA for total insect mass versus discharge, there were no significant slope (responses to discharge) differences between sites with respect to insect mass ($F_{1,266}$ = 0.05), although there were mean mass differences ($F_{1,267}$ = 9.782), FCD usually having a lower mass than FEX during the summer months.

Table 4.8C presents the data for the fall season, a period in which there is high variability in the biological parameters.

TABLE 4.8C
Multiple Regressions for Biotic Parameters versus
Years, Discharge, Cumulative Degree Days
Fall (1984 - 1992)

Dependent Variables

R^2 and Standard Partial Regression Coefficients

Independent Vars.	***Total Mass***	***% C-G Dom.***	***Pred/ Prey R.***
FEX, R^2	***0.12***	***0.04***	***0.03***
Years	*-0.27*	*0.10*	*-0.13*
Discharge	*-0.38*	*0.23*	*-0.19*
Cum.D.Days	*-0.09*	*0.02*	*-0.04*
FCD, R^2	***0.19***	***0.12***	***0.03***
Years	*0.32*	*-0.39*	*0.04*
Discharge	*-0.16*	*-0.19*	*-0.11*
Cum.D.Days	*-0.20*	*0.08*	*-0.09*

Fall: The R^2 values for all parameters are very low, even for total insect mass. Discharge and cumulative degree days accounts for most of the explained variation at FEX; yet, it was years that accounted for most of the explained variation at FCD. Insect mass has increased at FCD over the years and the physical factors we used cannot explain much of the variance. Figure 4.14C shows that cumulative water temperatures in the fall were high and insect mass was low from 1987 through 1989 (Figure 4.33). Temperatures were low in 1990 and very low in 1992. Insect mass in the fall of 1990 was the highest since the study began, but was low in 1992. One would have expected a high mass that fall if high insect mass were only associated with low

discharges in the fall. That summer, discharges were low (Figure 4.13B) and insect mass was moderate at both sites (Figure 4.32). It appears that phenomena other than fall discharge accounted for insect mass.

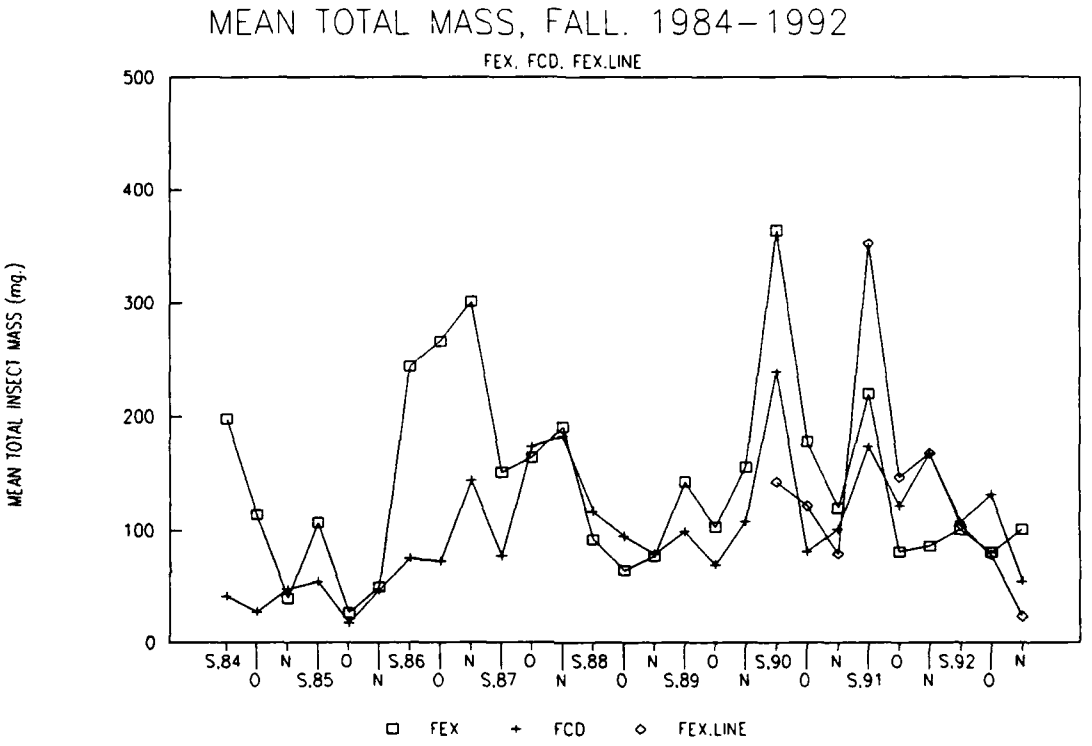

Figure 4.33. FALL. Mean total insect mass (mg.) at FEX (squares), FCD (pluses), and FEX.LINE (diamonds). 1984 - 1992.

In summary, discharge was the 'most important' independent variable for the spring functional community parameters; discharge and cumulative degrees for the summer; but very little of the variation in biotic parameters could be explained by physical factors for the fall data set. Structural community parameters showed the same pattern. Major discharge events which occur primarily in the spring can have immediate effect on the insect community. Major increases and decreases in water temperatures in the spring and fall can have historical effects on growth and maturation of insects in the summer, fall, and the following spring.

B.A.C.I. tests were performed on mean total insect mass, percent chironomid biomass dominance, percent collector-gatherer biomass dominance, and predator/prey ratios to determine if there were before versus after E.L.F. activation effects. Before Impact data extended from 1984 through

1986 for the **spring**, from 1984 through 1985 for the **summer**, and from 1983 through 1985 for the **fall**. From the summer of 1986 to the summer of 1989, the duration and intensity of E.L.F. fields increased. Cumulative E.L.F. exposure rose sharply in the summer of 1989 even though it was October of that year that the line was fully operational (Figure 4.15). Thus, our AFTER data set this year includes data from June of 1989 through August of 1993. Table 4.9 presents results of the B.A.C.I. tests and R.I.A. test for the functional community parameters.

TABLE 4.9

Results of B.A.C.I. and R.I.A. Tests for Functional Community Parameters at FEX vs. FCD. Spring, Summer, Fall

Index, Comparison	Trans-form Type	Tukey's Test		t-test, Signif.		R.I.A. Test	
		df.	F, sig.	df.	T, sig.	df.	T sig.
TOTAL MASS							
Spring	LOG	4	2.41	12	0.20		
Summer	LOG	4	11.79*			9	97.92***
Fall	ln(LOG)	7	3.96	16	0.95		
% CHIRONOMID DOMINANCE							
Spring	RATIO	4	2.05	12	-0.03		
Summer	RATIO	4	3.66	19	0.70		
Fall	Arcsin	7	1.39	16	-0.88		
% COLLECTOR-GATHER DOMINANCE							
Spring	RATIO	4	2.73	12	0.03		
Summer	RATIO	4	2.32	19	-1.19		
Fall	RATIO	7	3.25	16	0.17		
PREDATOR/PREY RATIOS							
Spring	LOG(X+1)	4	6.73	12	0.06		
Summer	LOG(X+1)	4	0.72	19	0.34		
Fall	LOG(X+1)	7	0.64	16	-0.09		

All except summer total insect mass passed Tukey's test. There were no significant before versus after differences for those passing Tukey's test for any season. Although there were significant site and year differences in some cases when all the replicates were used in 2-Way ANOVA tests (Table 4.5), B.A.C.I. tests revealed no significant differences before as compared with after ELF activation.

Total insect mass in the summer months did not pass Tukey's test because the BEFORE data are bimodal and no transformation will alter that distribution. The nonparametric R.I.A. test was performed, and the result was highly significant. That result may not be free of a Type I statistical error; moreover, caution must be used because the degrees of freedom for the test is much lower than what is recommended by Carpenter et al. (1989). We cannot say that E.L.F. fields had no impact on total insect mass in the summer. Other, natural physical factors were studied to see whether they varied through the years, by chance, in a manner similar to that of E.L.F. field activities.

Mean total insect mass in the summer was regressed against discharge. Before-E.L.F. data are denoted by black boxes and after-E.L.F. data are denoted by open squares; Figures 4.34A 4.34B are plots for FEX and FCD, respectively.

There was no pattern consistent with before versus after E.L.F. activity for insect mass versus discharge, and so this independent parameter cannot be invoked to account for the significant R.I.A. result.

Figures 4.35A and 4.35B show plots of summer insect mass versus average water temperatures at FEX and FCD, respectively.

Again, there was no consistent pattern relative to BEFORE versus AFTER data points that, by chance alone, would have shown that insect mass versus water temperature happened to vary with E.L.F. activity. Water temperatures had been high during the transition years of E.L.F. operation (1986 - 1988), but there were no appreciable differences in water temperature in 1984 and 1985 as compared with 1990 through 1993 (Figures 4.30A and 4.30B).

Water temperatures in 1993 were warmer than in 1992 but cooler than the other post-operational years (1989-1991; figures 4.29B, 4.30B). Discharge in the summer of 1993 was moderately high (Figure 4.13B).

Insect mass at the two sites was moderate in the summer of 1993 (Figure 4.32). The trend for insect mass being higher at FCD relative to FEX in recent years could be related to subtle changes, or to changes in substrate over the years.

Total insect mass in the summer months did not pass Tukey's test because the BEFORE data are bimodal and no transformation will alter that distribution. The nonparametric R.I.A. test was performed, and the result was highly significant. That result may not be free of a Type I statistical error; moreover, caution must be used because the degrees of freedom for the test is much lower than what is recommended by Carpenter et al. (1989). We cannot say that E.L.F. fields had no impact on total insect mass in the summer. Other, natural physical factors were studied to see whether they varied through the years, by chance, in a manner similar to that of E.L.F. field activities.

Water temperatures in 1993 were warmer than in 1992 but cooler than the other post-operational years (1989-1991; figures 4.29B, 4.30B). Discharge in the summer of 1993 was moderately high (Figure 4.13B).

Insect mass at the two sites was moderate in the summer of 1993 (Figure 4.32). The trend for insect mass being higher at FCD relative to FEX in recent years could be related to subtle changes, or to changes in substrate over the years.

We ran a series of multiple linear regressions, adding successive years of data for each run to see if we could detect a change at one site that was not matched at the other site. If a difference was detected and E.L.F. cumulative ground field exposure was linked to the difference, this would support the results from the R.I.A. test for summer insect mass. E.L.F. cumulative ground field exposures replaced years in these tests. Regression coefficients (R^2) for the sites appear in Figure 4.34. Standard partial regression coefficients appear in Figure 4.35 (FEX) and Figure 4.36 (FCD).

Figure 4.34 shows that much more of the variation in summer insect mass can be accounted at FCD! Another unexpected result was that even with increasing years, the physical attributes we selected to explain the variation did not increase the R^2 values! Possibly, biotic interactions and/or other underlying physical factors would explain more of the variance as time accrued; for example, changes in substrate particle sizes over time and/or competition for space within the substrates.

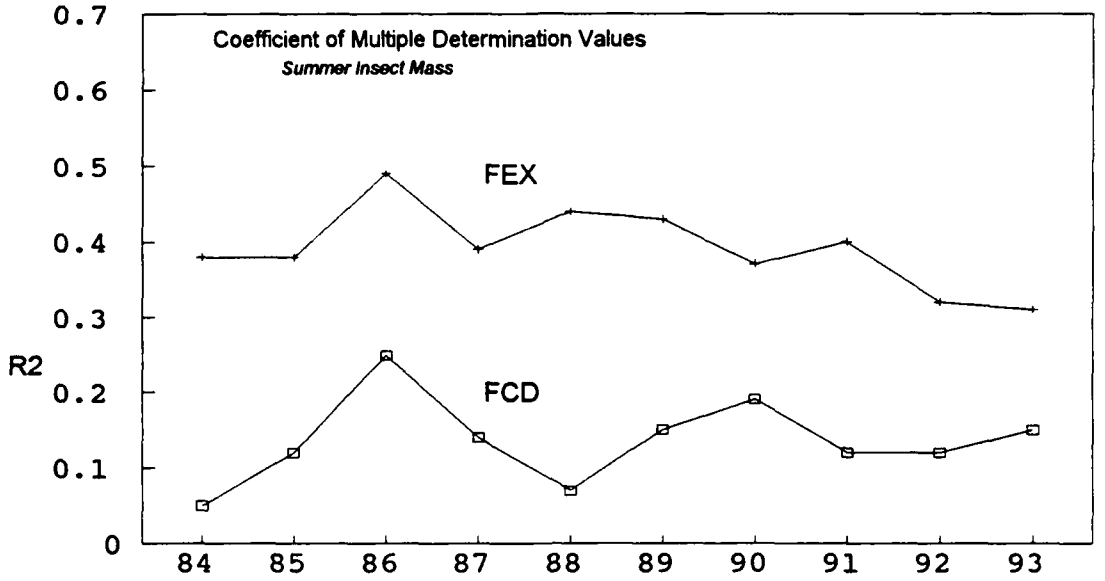

Figure 4.34. Coefficient of multiple determination values for summer insect mass vs. ELF cumulative groundfield exposure, discharge, and cumulative degree days. A successive year was added for each run, from 1984 through 1993.

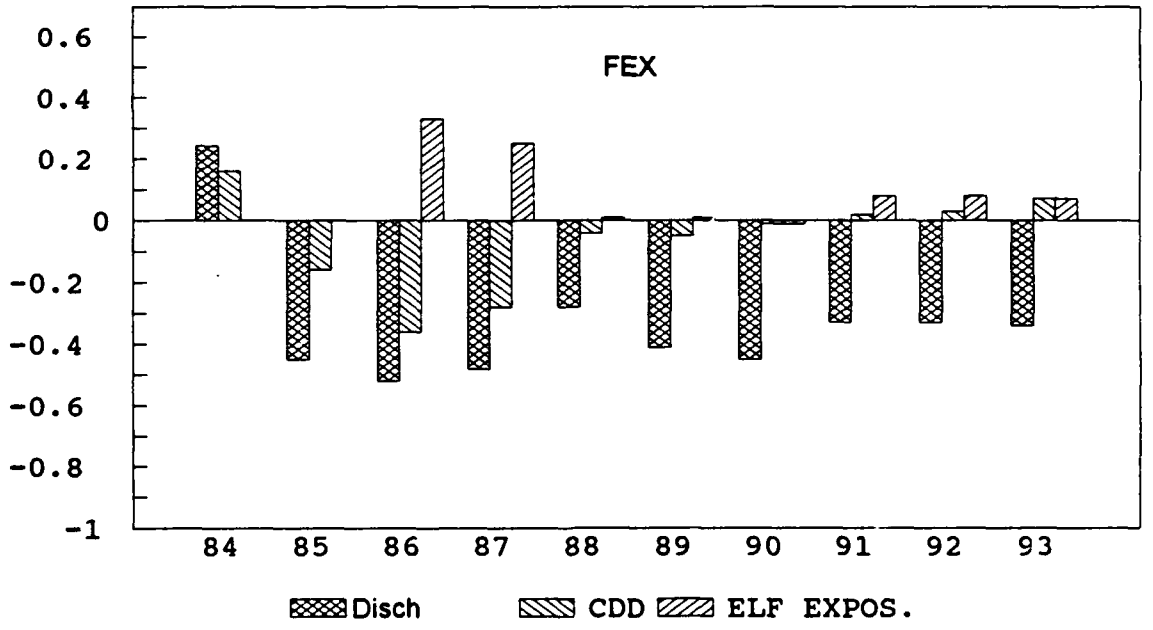

Figure 4.35 **FEX**. Standard partial regression coefficients for summer insect mass versus physical factors. Years are cumulative

Figure 4.35 shows that discharge was consistently the most important factor at the experimental site. E.L.F. field exposures explained virtually none of the variation in summer insect mass. On the other hand, all three dependent

factors contributed to explaining that variation in summer insect mass at the reference site (Figure 4.36). Even though the R^2 values at FEX are low (Figure 4.34), discharge rather than E.L.F. fields explains more of that variation. As suggested earlier, factors other than E.L.F. activation may account for the variation in insect mass during the summer months.

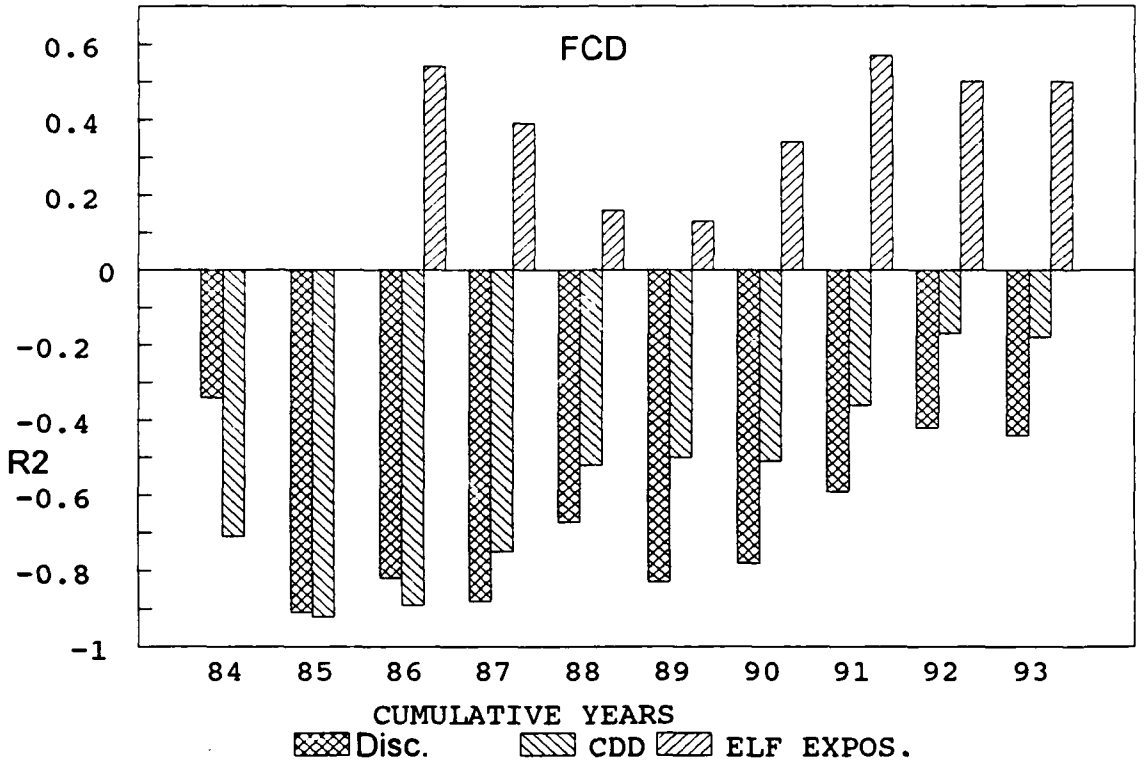

Figure 4.36. **FCD.** Standard partial regression coefficients for summer insect mass versus physical factors. Years are cumuolative.

Changes in Mean Dry Weights Per Individual:

Six taxa 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 the family Chironomidae. Samples were collected mid-month each year within five days of each other for each month. 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. Data for changes in MDW/IND of P. mollis versus cumulative degrees were grouped for ANCOVA analyses to reflect three levels of E.L.F. intensity: Before = July 1984 - June, 1986; Intermediate intensity = July, 1987 - June, 1989; and Full Power = July,

1989 - June, 1992. The physiological independent parameter, cumulative degree days (rather than the chronological parameter, months) incorporates the yearly differences in water temperatures (Figures 4.29A and B). In past Annual Reports, this species has been shown to achieve its largest size each year after 500 to 600 °C have accumulated in the stream (Figure 4.25B, 1991 Annual Report). In the following figures, changes in MDW/IND values are plotted against cumulative degree days, with physiological T = 0 in July each year and T_{final} = June of the following year. Figure 4.37A presents Before Impact data at FEX and 4.37B presents Before Impact data for FCD.

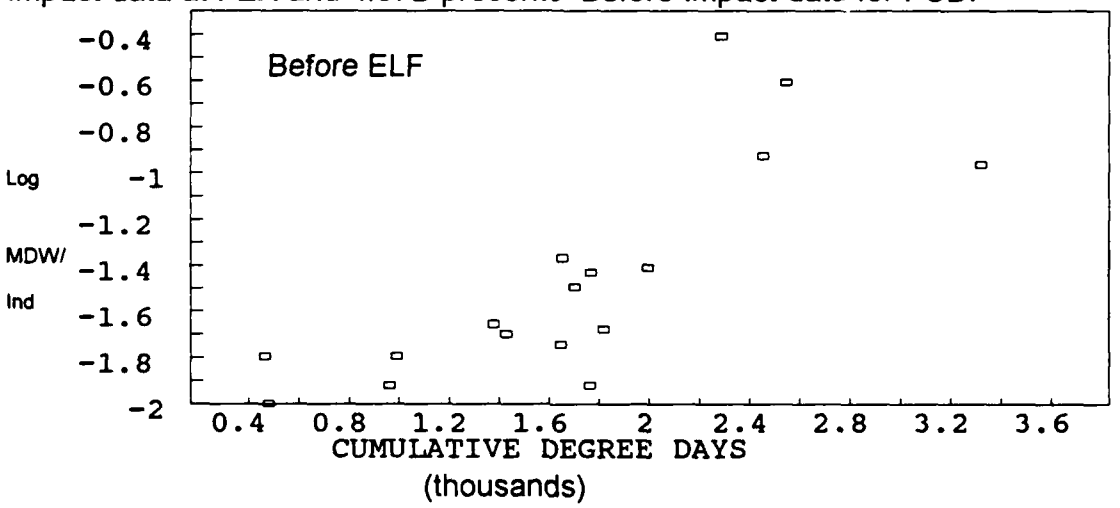

Figure 4.37A. **FEX.** Changes in MDW/ IND values for *P. mollis* versus cumulative degree days. BEFORE IMPACT: July 1984 - June 1986.

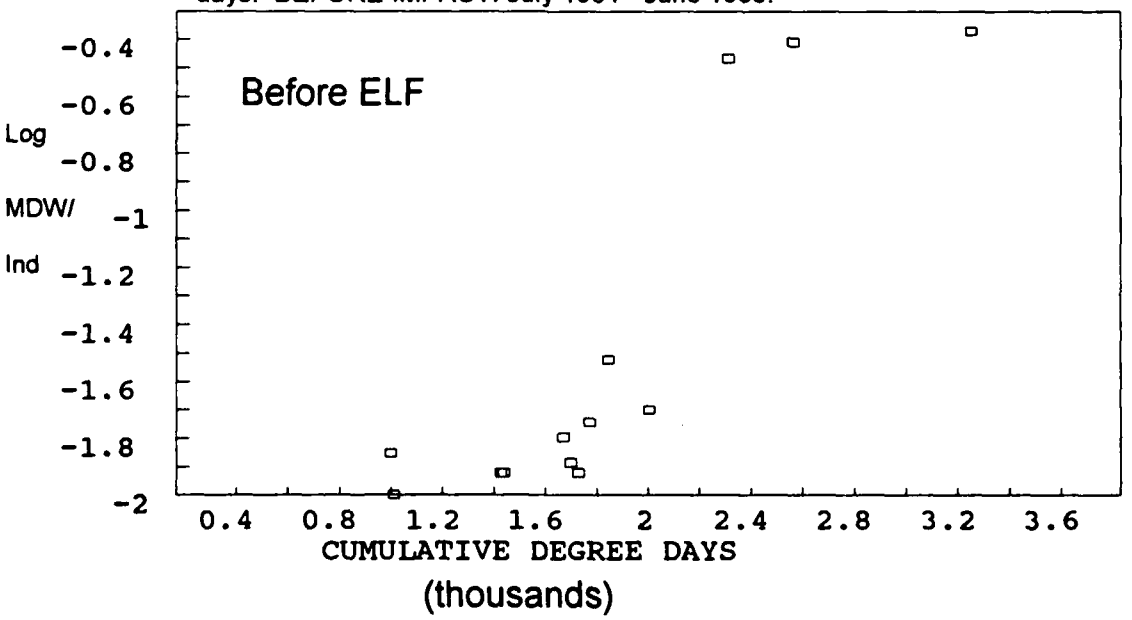

Figure 4.37B. **FCD.** Changes in MDW/IND values for *P. mollis* versus cumulative degree days. BEFORE IMPACT: July 1984 - June 1986.

Figures 4.37C and 4.37D present graphical results for P. mollis during the transitional phase of E.L.F. operation, July 1986 - June 1989.

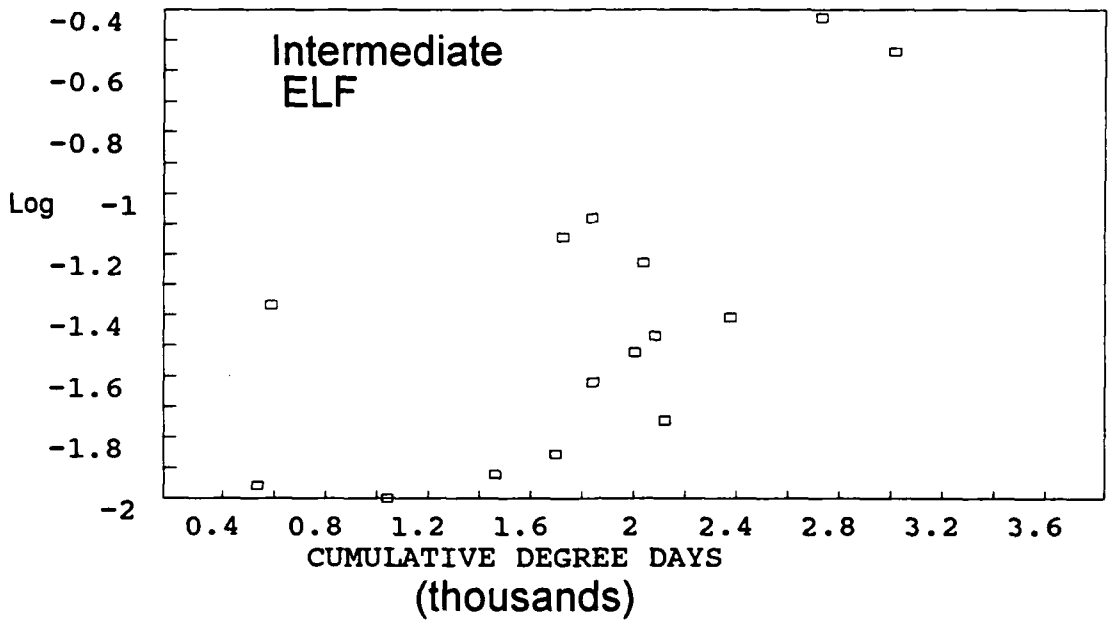

Figure 4.37C. **FEX**. Changes in MDW/IND values for *P. mollis* versus cumulative degree days. TRANSITION PERIOD: July 1986 - June 1989.

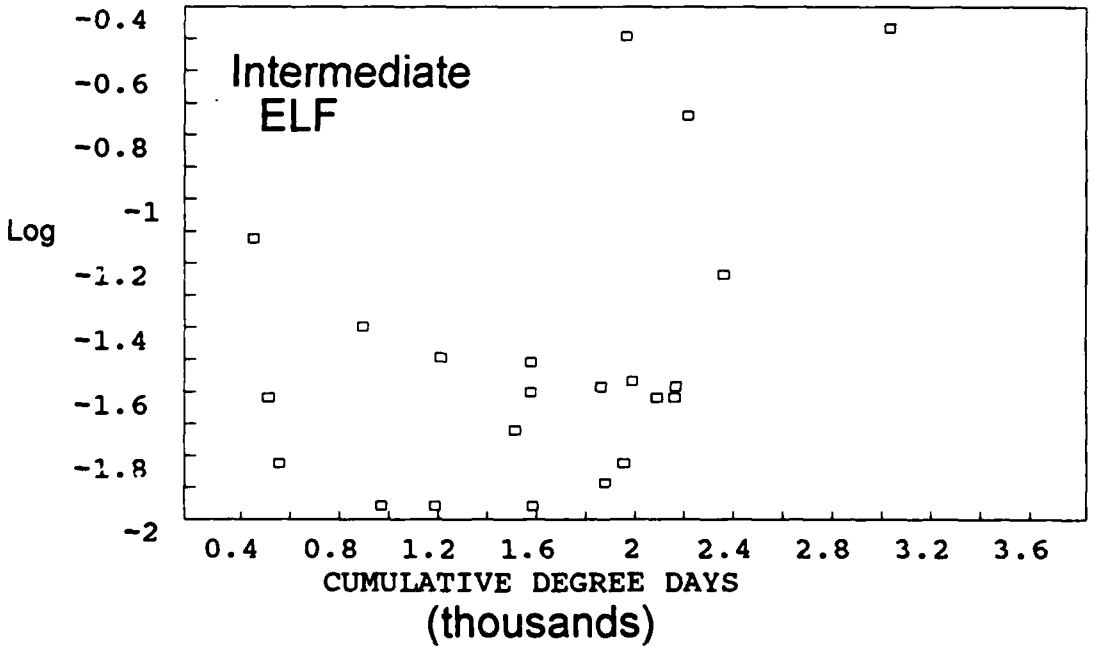

Figure 4.37D. **FCD**. Changes in MDW/IND values for *P. mollis* versus cumulative degree days. TRANSITION PERIOD: July 1986 - June 1989.

Figures 4.38A and 4.38B present the After Impact data, which extends from July, 1989 to June, 1993.

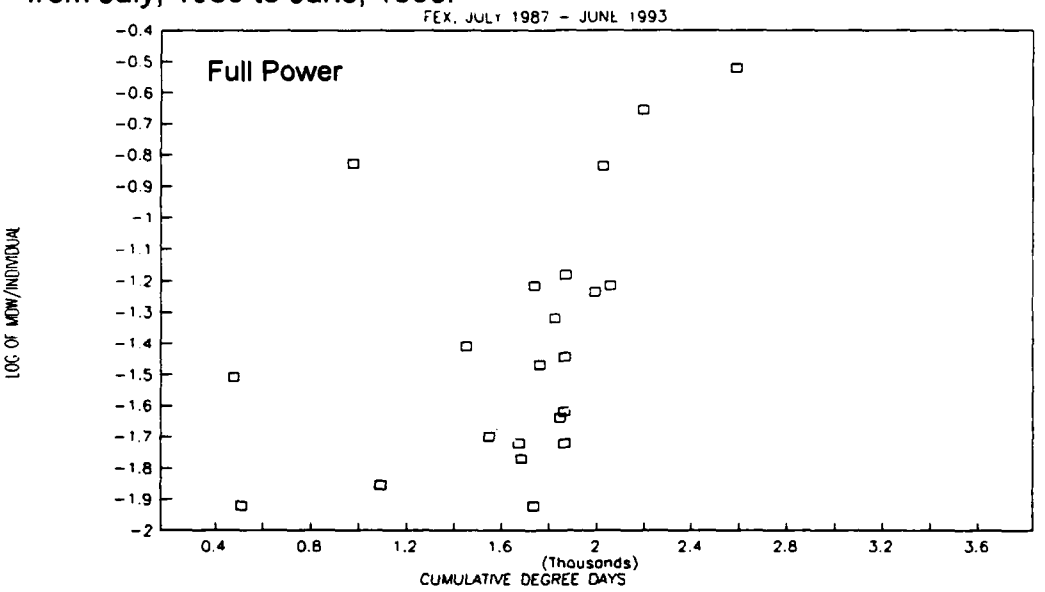

Figure 4.38A. FEX Changes in MDW/IND values for *P. mollis* versus cumulative degree days. AFTER IMPACT: July 1989 - June 1993.

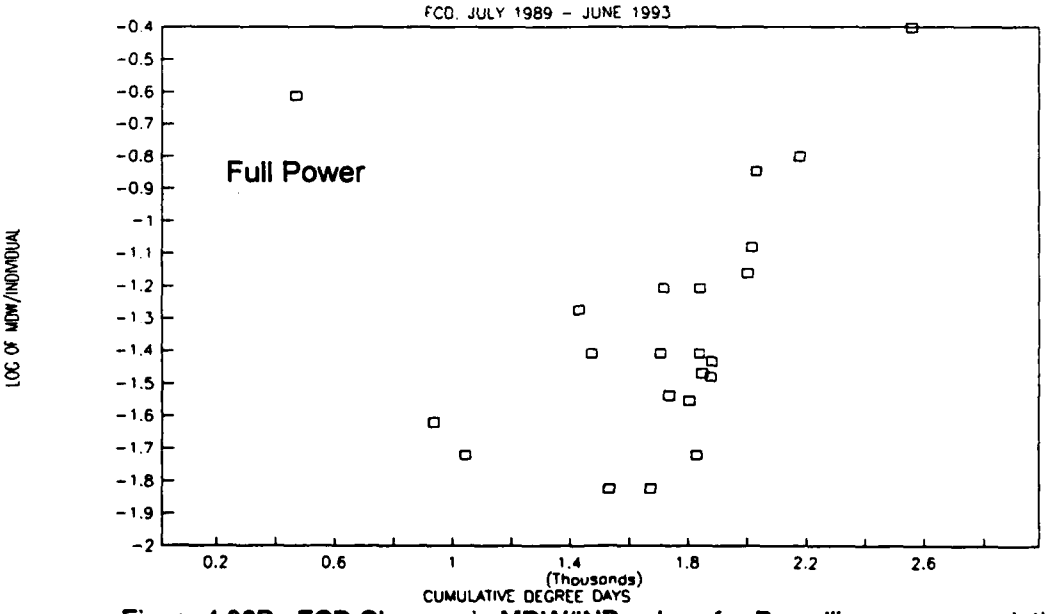

Figure 4.38B. FCD Changes in MDW/IND values for *P. mollis* versus cumulative degree days. AFTER IMPACT: July 1989 - June 1993.

Differences in adjusted mean differences and/or differences between slopes for FEX versus FCD were run on the three time periods, Table 4.10.

TABLE 4.10
ANCOVAS for Changes in MDW/IND for P. mollis vs. Cumulative Degree Days **FEX** versus **FCD**: Before, Transitional, and After Impact for E.L.F. Fields

Time Period	Adj. Means: $F_{d.f.}$ and Significance	Slopes; $F_{d.f.}$ and Significance
BEFORE E.L.F.	$F_{1,30} = 1.640$, $P > .10$	$F_{1,29} = 1.876$, $P > .10$
TRANSITIONAL	$F_{1,45} = 0.296$, $P > .50$	$F_{1,44} = 0.245$, $P > .50$
AFTER E.L.F.	$F_{1,60} = 0.013$, $P > .75$	$F_{1,59} = 0.003$, $P > .75$

There were no significant differences for growth rates of P. mollis versus physiological time between FEX and FCD for any E.L.F. activity periods. This species is univoltine and occurs in high numbers at both sites. Usage of all the data show that over the years, there was no significant change in its growth rates before E.L.F. activity, transitional ups and downs of the operating system, and finally, full power. For the reader's benefit and for comparison with data for other species, Figure 4.39 is a presentation of the chronological changes in MDW/IND.

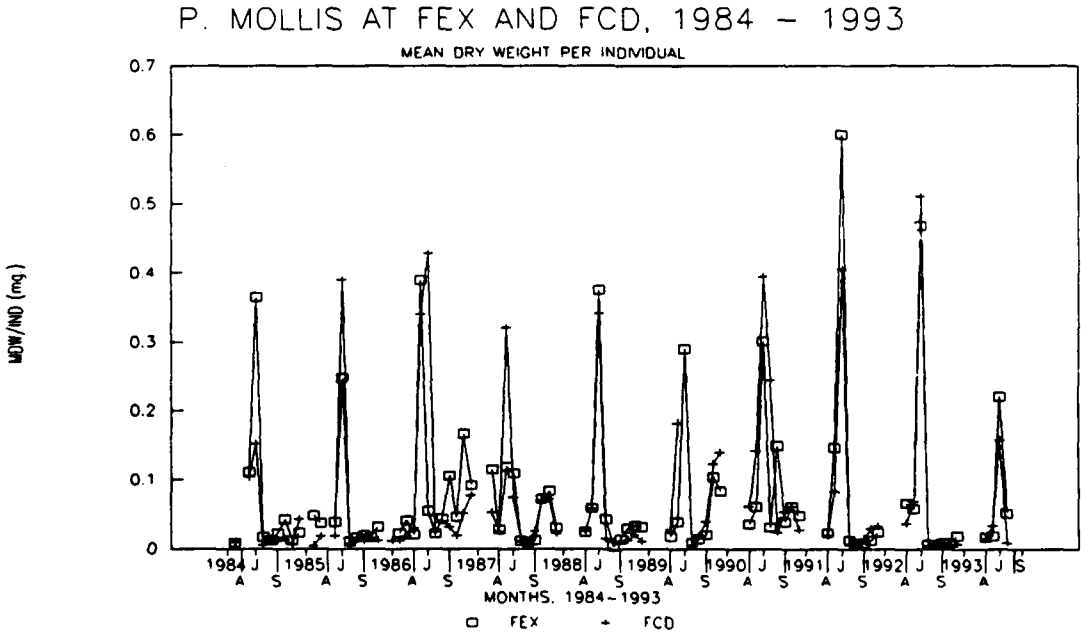

Figure 4.39. Changes in MDW/IND values for *P. mollis* at FEX (squares) and FCD (pluses) from July 1983 through July 1993.

Figure 4.40 shows changes in MDW/IND for E. invaria and E. subvaria.

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 grows to only about half the size of its sister species, E. subvaria. We collected samples once a month, and we collected the final instars of E. invaria at FEX in May of 1987 through May of 1993. We often did not collect final instars of E. invaria at FCD (Figure 4.40). Had we collected samples at FCD a few days later those years, we may have collected fully mature nymphs there as well. Although the two sites are somewhat similar in flow and water temperatures, waters at FCD tend to be cooler in the summer and warmer in the fall than FEX. This is probably owing to springs flowing into the river near the FCD site. Substrates at FCD are more sandy (although the sites appear to becoming more similar to one another). These and other subtle biotic or physical factors probably account for the perceived lag in development at FCD. Graphical analysis (Figure 4.40) does not reveal differences between the two sites 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.) Statistical analysis will be performed in the future for Ephemerella invaria in the same way as we analyzed data for Paraleptophlebia mollis.

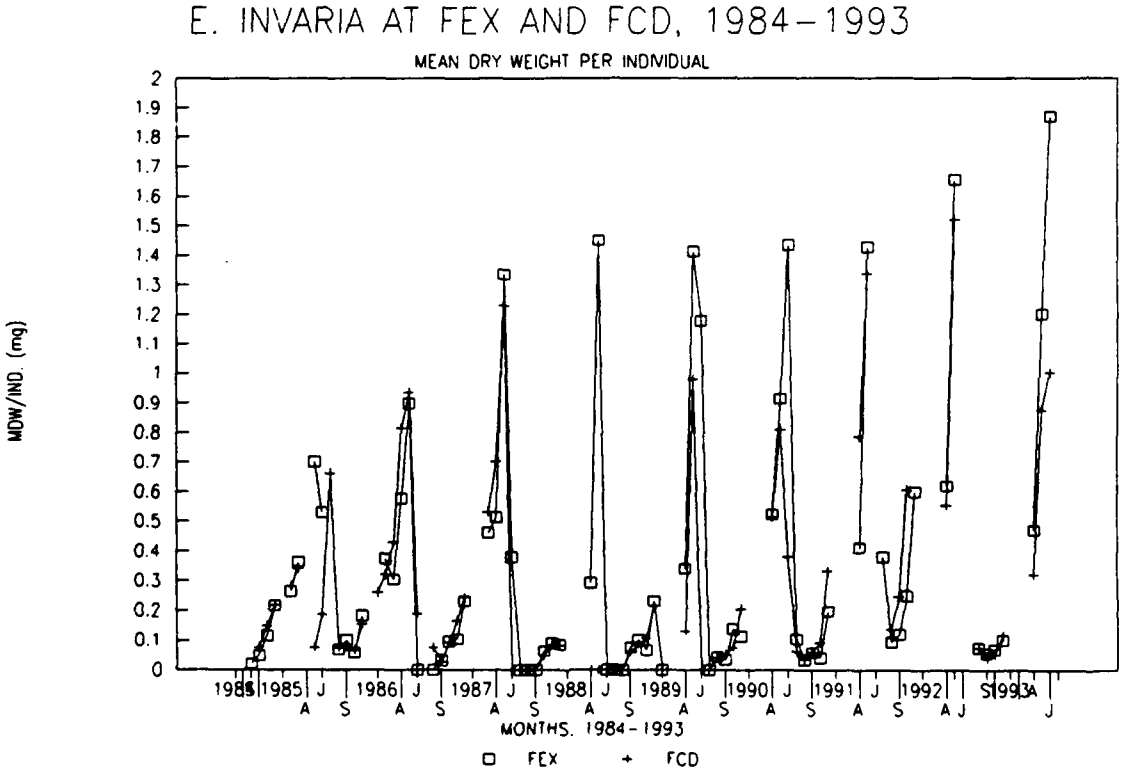

Figure 4.40. changes in MDW/IND values for *Ephemerella invaria* at FEX (squares) and FCD (pluses). June 1984 - July 1993.

Ephemerella subvaria is less common than E. invaria, and therefore, there are more data gaps in Figure 4.41. However, it is possible to see the major emergence periods for this univoltine species. Final instars were collected in June of 1988 and in June of 1990 through 1993. As for E. invaria, more final instars were found at FEX than at FCD through the years. We plan on publishing a paper on the target species we have monitored for changes in size classes.

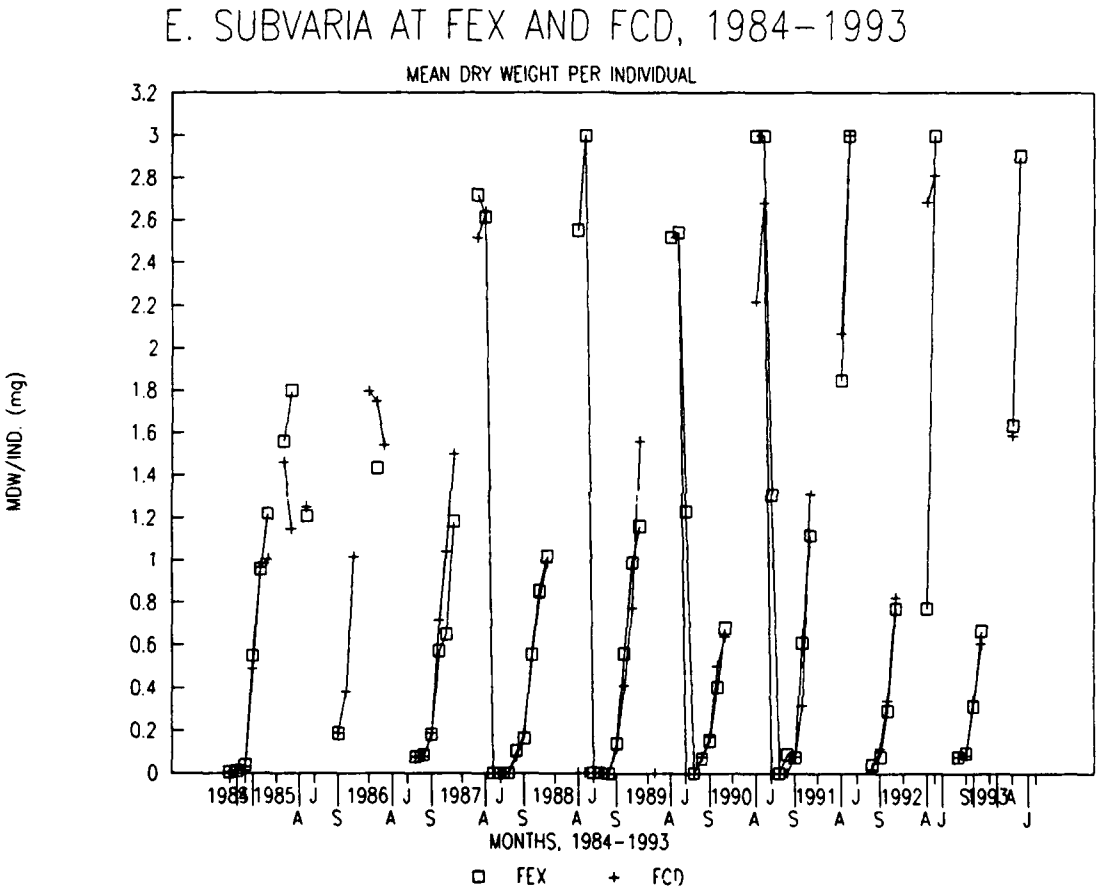

Figure 4.41. Changes in MDW/IND values for *Ephemerella subvaria* at FEX (squares) and FCD (pluses). June 1984 - July 1993.

The young of Protoptila sp. are most common during the mid-summer just after mid-May emergences(Figure 4.42). In 1989, there were heavy rains in late May and June, which we feel contributed to the low numbers of individuals and the 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 in 1985, 1989, and 1992; therefore, analyses of changes in MDW/IND values may be impossible.

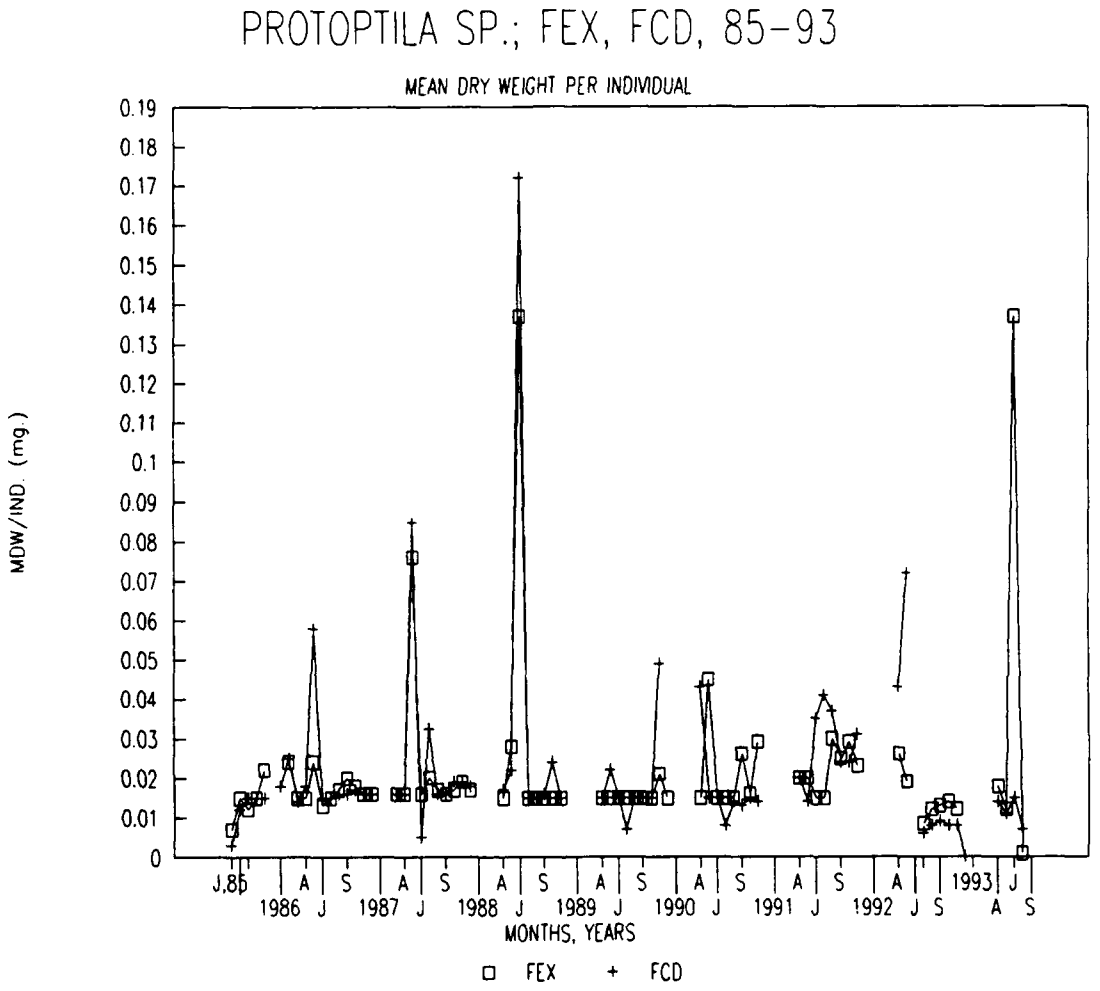

Figure 4.42. Changes in MDW/IND for *Protoptila* sp. FEX (squares) and FCD (pluses). May 1985 - July 1993.

Glossosoma nigrior, which is in the same family as Protoptila and is a collector-grazer, is most abundant at FEX (Figure 4.23A, 1990 Annual Report, p. 234). Peak size occurs in May of each year (Figure 4.43, this report). We have found fewer numbers of individuals of this species at the two sites than of Protoptila sp. Analyses similar to those for that species will be attempted for G. nigrior in the Final Report. Glossosoma nigrior will continue to be monitored because studies for Element 3 on grazers in the Ford River have used this species and it may be useful for those researching that Element.

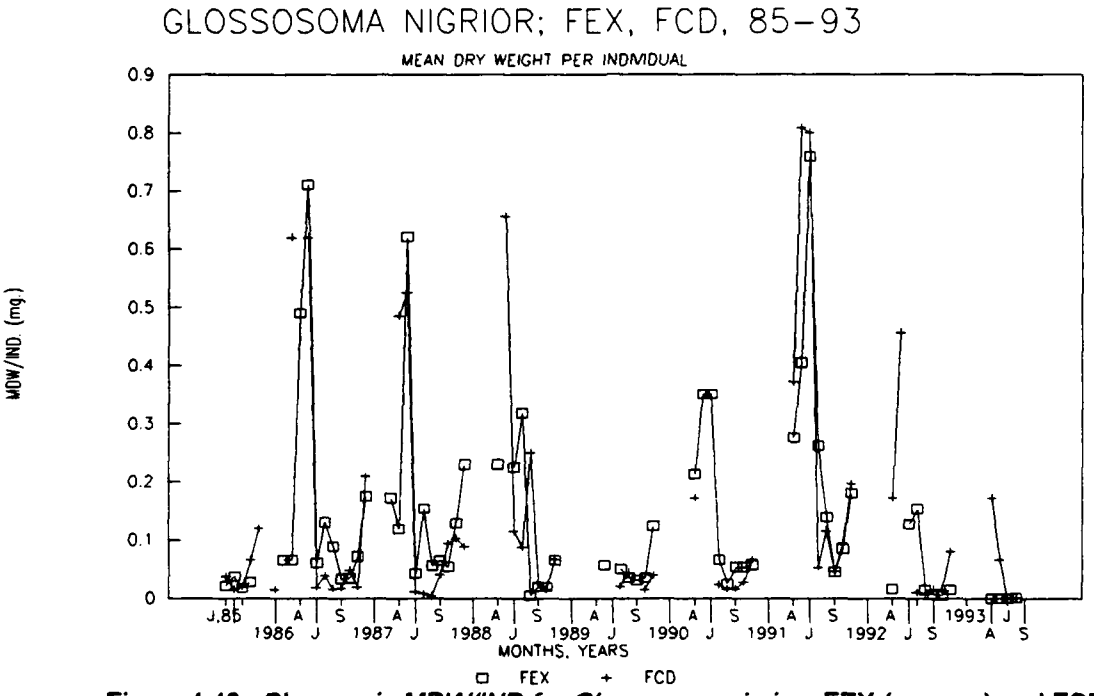

Figure 4.43. Changes in MDW/IND for *Glossosoma nigrior*. FEX (squares) and FCD (pluses). May 1985 - July 1993.

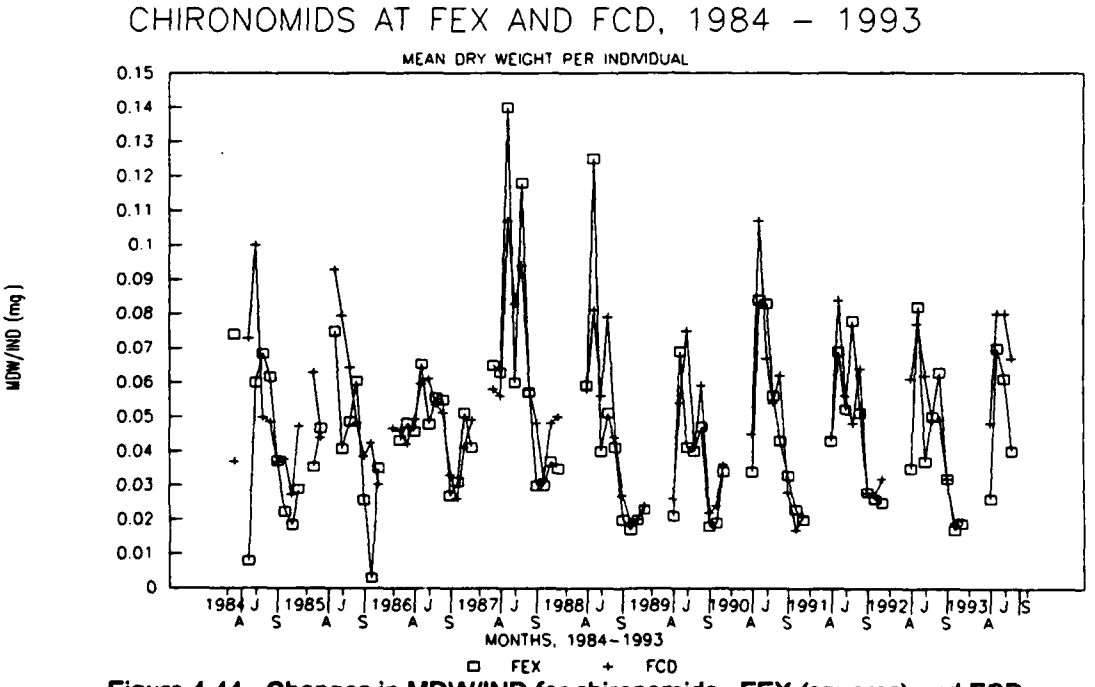

Figure 4.44. Changes in MDW/IND for chironomids. FEX (squares) and FCD (pluses). May 1985 - July 1993.

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 4.44). 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 could reflect a number of phenomena: replacements of summer emerging with fall growing species, differences in maximum size classes of different species through the year, both phenomena, and/or additional phenomena. If person power and money were no object, she/he could select a few species that do not require head capsule preparation for identification, and then follow numbers and growth patterns of the species through the seasons. We have retained all samples, and so if a masochistic graduate student wished, the field-collected data would be available for many months or years of intensive labor.

Future Plans for This Element

The same design and accumulation of data continued until September of 1993. Data from FEX.LINE have been graphed and some statistics were done on them. Overall, those data do not appear similar to data from FEX. Because FEX and FEX.LINE differ, one cannot assume that the biotic community at FEX.LINE was similar to the community at FEX before ELF activation. But more importantly, we have no before impact data to see whether changes occurred as a result of ELF activation. The after impact data span only four summers, three fall seasons, and lack April data for 1991 and 1993.

The three principle investigators for the Aquatics Task Group will continue to discuss their choices for breakpoints in the data relative to ELF activation in hopes of using the same time periods. B.A.C.I. tests and R.I.A. tests may be modified with the help of Dr. Abdul El Shaarowi, as described earlier in the text. It is hoped that residuals among samples rather than sample means can be used in the analyses to 1) account for sample variance, and 2) to utilize all the data rather than only the means.

A draft for a paper on five of the biotic parameters for this Element is complete. It will be submitted to *Hydrobiologia* in the spring of 1994. An outline for another paper on evaluation of techniques for monitoring streams has been completed. Work will continue on that paper. A last paper on growth rates of aquatic insects has been outlined and is fifty percent completed. That

paper will include data from Element 6 as well. We plan on having all three papers accepted by the August, 1994 Annual Meetings.

The taxa identified through 1993 appear in Appendix I of this Report.

Summary

Data were grouped according to season for statistical analyses after looking at coefficient of variation values: **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. Coefficient of variation values were highest during those seasons. Seasonal data were first analyzed, using 2-Way ANOVAS. Data from each site were regressed against years, ELF cumulative exposure, discharge, and water cumulative degree days to determine which physical factors were more important in accounting for the biotic variance. Usually discharge was most correlated in the spring. Discharge and/or cumulative degrees was most important in the summer. There were mixed results with regard to the fall season data.

B.A.C.I. tests and R.I.A. tests were used to look for significant before versus after ELF activation associations. One biotic parameter in the R.I.A. tests showed significant before versus after differences; namely, total insect mass in the summer stable period. Multiple regressions showed that discharge and water temperature were correlated with insect mass, and so those parameters were graphically analyzed to determine whether there were clusters of points for years before E.L.F. activation versus after E.L.F. activation, the hypothesis being that, by chance alone, other physical factors had changed in a manner similar to E.L.F. field intensities and durations. There were no sequential pattern in the graphs. Sequential multiple regressions, using E.L.F. cumulative ground field exposure rather than years were performed to see if E.L.F. exposure was related to summer insect mass changes. Each statistical run incorporated an additional year. Discharge was shown to be more important than E.L.F. exposure or cumulative degree days over the years at FEX. All three variables at FCD contributed to the R^2 values. Evenso, discharge generally was the most important physical factor. These results suggest to us that E.L.F. exposure did not directly affect changes in insect mass at the experimental site. Variation in discharge and water temperature is much greater in the spring and fall seasons, and it was much easier to detect differences attributable to those physical factors in the spring and fall than in the summer. Total insect mass showed no significant before versus after differences in the spring and fall.

R.I.A. tests showed significant differences for number of individuals (without chironomids) in the summer and fall, and significant differences for percent chironomid dominance in the fall. Numbers of individuals is the most highly variable parameter we have. Only means are used in the B.A.C.I. and R.I.A. analyses so the tests do not take extreme variability into consideration. Both biotic parameters were similar at FEX and FCD after E.L.F. full power, but were higher at FEX before E.L.F. activation. We hypothesize that the substrate at FEX became more sandy over the years, owing to higher beaver activity just upstream of the FEX site. (At FCD, beaver activity did occur, but it occurred below the FCD site).

Discharge and water temperatures were highly correlated with taxon richness, with insect mass, and with periphyton density. The linear relationship was very pronounced in May each year, with the highest R^2 value being for taxon richness versus water temperature (R^2= 0.85).

ANCOVAS showed no differences between sites with respect to mean dry weight values per individual and physiological time (cumulative degree days for water temperatures) for the collector-gatherer mayfly, Paraleptophlebia mollis. Five other prominent taxa were monitored at the sites. Graphical analyses revealed no obvious differences between the sites for those species.

A summary table (4.11) gives statistical results for comparisons of the biotic parameters. (See Tables 4.1B and 4.5B for 2-way ANOVAS comparing FEX, FCD, and FEX.LINE.)

TABLE 4.11
Summary of Statistics for Structural and Functional Community Parameters
2-Way ANOVAS and Multiple Regressions: 1986-1993
B.A.C.I. and R.I.A.: Before: April 1984 - May, 1986
After = June 1989 - May, 1993

PARAMETER, SEASON	***2-WAY ANOVA: Signif. factors (FEX vs. FCD)***	***MULT.REG.: For Vars. with R^2 > .29***	***BACI TEST S***	***RIA Tests***
DIVERSITY				
Spring	Friedman: none	N/A	N/A	n.s.
Summer	Site, Year, S*Y	FEX: Disch,CDD	n.s.	
Fall	Site, Year	FEX: Disch	n.s.	
EVENNESS				
Spring	Friedman: none	N/A	N/A	n.s.
Summer	Site, Year, S*Y	FEX: Disch,CDD	n.s.	
Fall	Site, Year		n.s	

RICHNESS				
Spring	Site, Year,S*Y	FEX: Disch	n.s.	
Summer	Site, Year	FEX: Disch FCD: Disch	n.s.	
Fall	Site, Year, S*Y		n.s.	
NO. INDIVIDUALS				
Spring	Site, Year, S*Y	FEX: Disch FCD: Disch	n.s.	
Summer	Site, Year, S*Y	FCD: Disch	N/A	***
Fall	Site, Year, S*Y	FEX: Disch, CDD	N/A	***
CHIRO. # DOM.				
Spring	Site, Year, S*Y		**	
Summer	Friedman: Site		n.s	
Fall	Site, Year	FEX: Yr, CDD	N/A	***
TOTAL INSECT MASS				
Spring	Year, S*Y	FEX: Disch	n.s.	
Summer	Site, Year, S*Y	FEX: Disch FCD: Disch, CDD, ELF fields	N/A	***
Fall	Site, Year, S*Y		n.s.	
CHIRO. MASS DOMINANCE				
Spring	Year		n.s.	
Summer	Site, Year		n.s.	
Fall	Friedman: Site		n.s.	
COLL.GATH. MASS DOM.				
Spring	Site, Year		n.s.	
Summer	Site, Year		n.s.	
Fall	Site, Year		n.s.	
PRED./PREY RATIO				
Spring	Year		n.s.	
Summer	Site, Year, S*Y		n.s.	
Fall	Site, Year		n.s.	

N/A = Not appropriate or failed Tukey's Test

Disch = Discharge
CDD = Cumulative Degree Days
Yr = Year

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APPENDIX I

List of Aquatic Insect Taxa from the FEX and FCD sites in the Ford River

EPHEMEROPTERA

Tricorythodes
Caenis sp.
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.
Siphlonorus rapidus
Paraleptophlebia mollis
Paraleptophlebia debilis
Leptophlebia cupida
L. nebulosa
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

Allocapnia
Paracapnia
Phasganophora capitata
Capnia
Haploperla
Alloperla
Suwallia
Acroneuria lycorias
A. abnormis
Paragnetina media
Isogenoides
I. olivaceous
Isoperla transmarina
I. slossonae
Amphinemura
Paranemoura
Pteronarcys
Taeniopteryx nivalis
Leuctra sp.
Ostrocerca sp.
Oemopteryx glacialis
Prostoia sp.

HEMIPTERA

Belostoma flumineum
Lethocerus

TRICHOPTERA

Brachycentrus numerosus
Glossosoma intermedium
G. nigrior
Protoptila tenebrosa
Anabolia

Hydatophylax argus
Platycentropus
Pycnopsyche subfasciata
Neophylax nacatus
Ceratopsyche morona (= Symphitopsyche morona)
C. sparna (= Symphitopsyche sparna)
Cheumatopsyche analis
Hydropsyche sp.
Ochrotrichia sp.
Potamyia
Hydroptila
Leucotrichia pictipes
Neotrichia
Oxyethira
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
Mayatrichia sp.
Micrasema sp.
Polycentropus sp.
Ceratopsyche bifida (= Symphitopsyche bifida)

COLEOPTERA
Ancyronyx variegata
Optioservus
O. fastiditus
O. trivittatus
Macronychus glabratus
Dubiraphia
Helichus lithophilus
Gyrinus
Celina

Dytiscus harrisi
Laccophilus
Paracymus subcupreus
Stenelmis sp.

MEGALOPTERA
Nigronia sp.
Sialis sp.

DIPTERA

DOLICHOPODIDAE
Rhaphium sp.

EMPIDIDAE
Hemerodromia sp.
Clinocera sp.
Chelifera sp.

BLEPHARICERIDAE
Blepharicera sp.

TABANIDAE
Tabanus sp.
Chrysops sp.

TIPULIDAE
Antocha sp.
Tipula sp.
T. abdominalis
Hexatoma spinosa
Dicranota sp.
Hesperoconopa sp.
Ormosia sp.
Limnophila sp.

PSYCHODIDAE
Pericoma sp.

CERATOPOGONIIDAE
Probezzia sp
Culicoides sp.
Bezzia sp.
Atrichopogon sp.

CHIRONOMIDAE

Tanytarus sp.
Rheotanytarsus sp.
Microspectra sp.
Stempellinella sp.
Stempellina sp.
Ablabesymia sp.
Pentaneura sp.
Thienemannimyia sp.
Labrundina sp.
Procladius sp.
Procladius cf. sublettei
Nilotanypus sp.
Brillia flavifrons
Parametriocnemus sp.
Corynoneura sp.
Eukiefferiella sp.
E. devonica sp.
E. claripennis sp.
Rheocricotopus sp.
Cricotopus sp.
Thienemanniella sp.
Synorthocladius sp.
Orthocladius sp.
Tventenia bavarica group
T. discoloripes sp.
Diplocladius sp.
Lopescladius sp.
Nannocladius sp.
Chaetocladius sp.
Symposiocladius sp.
Heterotrissocladius marcidus
Xylotopus par
Polypedilum lonvictum
P. scalaenum
P. halterale
P. aviceps
Robackia sp.
R. demeijerei sp.
Microtendipes sp.
Stenochironomus sp.
Cryptochironomus sp.
Saetheria sp.
Parachironomus sp.
Chironomus sp.

Cryptotendipes sp.
Xenochironomus sp.
Paraleuterborniella sp.
Potthastia sp.
Pagastia sp.

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

DIXIDAE
Dixella sp.

Element 5 - Movement Patterns of Dragonfly Naiads

The work for Element 5 was completed in 1989 and was published in the December, 1992 issue of the Journal of Freshwater Ecology. The paper, entitled "Responses to extremely low frequency electromagnetic fields by a dragonfly naiad (*Ophiogomphus colubrinus*) in a northern Michigan stream: a five year study", appeared in last year's Annual Report but is not included in the 1993 Annual Report.

Element 6 - Summary for Leaf Litter Processing

There were no differences between FEX and FCD for leaf processing rates. Leaf processing rates at the new site, FEX.LINE were usually slower than the processing rates at FEX or FCD. The addition of this new site may have come too late in our monitoring program, even though ground field E.L.F. exposures are higher there than at the original test site, FEX.

Coefficient of variation values for structural and community parameters of the insect community colonizing leaves were low after the leaves had been in the river four weeks. They were higher for earlier collections (Day 7, 14, and 21) and higher again for later collections (Day 50, 80). Therefore, we concentrated our statistical analyses the four week incubation period. Two-way ANOVAS showed significant year differences for each of the six biotic parameters. Leafpack experiments were initiated earlier in the season in 1987 through 1992. This change in procedure probably contributed to the significant year differences. The insect community colonizing leaves at FEX appears to be more diverse, but the higher diversity cannot be attributable to ELF fields. There were no significant site differences for evenness, richness, numbers of individuals, chironomid dominance, or total insect mass (adjusted for leaf mass). Evenness decreased over the years until 1991 and 1992. Numbers of individuals increased over the years. Chironomid dominance and insect mass/leaf mass ratios increased over the years until 1991 and 1992.

Graphical analyses did not show that year differences were associated with E.L.F. activation in 1986 nor from 1989 throught 1992 (when the fields were at full power). Multiple linear regressions, using mean discharge and cumulative degree days as the independent variables, showed that cumulative degree days accounted for more of the variability than discharge for the six biotic parameters. Coefficient of multiple determination values were always higher at FCD than at FEX for the two tests for each biotic parameters. The higher r^2 values at FCD may be related to the fact that that site is more sandy and contains fewer larger particles which can act as refugia during spating. The animals at that site may be more vulnerable to discharge events.

ANCOVAS showed that mean sizes of three species, *Ephemerella subvaria, Ephemerella invaria,* and *Isoperla transmarina,* were similar at FEX and FCD each year. There were three years, however, when there were significant slope differences between the two sites (individuals of *E. subvaria* only). Because the sites oscillated over time with respect to slope differences, it is improbable that ELF activation is related. We compared results from the new site, FEX.LINE with those from our original site, FEX. There were significant

and FEX.LINE in 1990 and 1991. There were significant slope differences for the other two species in 1991. The new site, separate from its value of having a 10-fold difference in ELF exposure with respect to the control site, appears to be distinctly different from either the original test or control site. Our preliminary data support that biological viewpoint.

A summary of results of statistical analyses for this Element appears in two tables. Table A contains eight biotic parameters and four types of analyses. Leaf processing coefficients (-k/day) for each year from 1984 through 1992 were compared, using a two-tailed Student t-test. The remaining seven parameters include data for one collection period: Four weeks' incubation data from 1984 through 1992. Significant main effects and interactions are presented in the Two-Way ANOVA column. Within site multiple regression analyses, using discharge, and cumulative degree days as independent variables appear in Table A as well. The highest standard regression coefficients were listed when the r^2 values were greater than 0.30.

TABLE A

Summary of Statistics for Element 6

PARAMETER	T TEST	2-WAY ANOVA	MULT. REG.
-K/DAY	n.s.		
After 4 Weeks			
Leaf losses		Site,Yr,Interact.	FEX: Discharge
Diversity		Site,Yr,Interact.	FEX&FCD: Cum.Deg. Days
Evenness		Years	FEX&FCD: Cum.Deg. Days
Richness		Yr, Interact.	N/A
No. Individuals		Years	FCD: Cum. Deg. Days
Midge Dominance		Years	FCD: Cum. Deg. Days
Insect Mass		Years	FEX&FCD: Cum. Deg. Days

N/A: Not appropriate

Table B gives a summary of year by year ANCOVA comparisons between FEX and FCD with respect to changes in mean dry weight per individual (MDW/IND) for three insect taxa. When there were no significant differences between FEX and FCD, that was noted with a zero (0); when FEX was higher than FCD, it was noted with a plus (+); and when FEX was lower than FCD, it was noted

with a minus (-). Comparisons between FEX and FEX.LINE were also made for 1990 through 1992 data. The same notation as above was used.

TABLE B

ANCOVAS for Testing Differences Between sites for Changes in MDW/IND of Three Insect Species

A. FEX vs. FCD

Year	Ephemerella subvaria	Ephemerella invaria	Isoperla transmarina
1984	0	0	0
1985	0	0	0
1986	-	0	0
1987	0	0	0
1988	0	0	N/A
1989	+	0	0
1990	-	0	0
1991	0	0	0
1992	-	0	N/A

B. FEX vs. FEX.LINE

Year	E. subvaria	E. invaria	I. transmarina
1990	-	0	0
1991	+	+	+
1992	0	0	N/A

N/A = not enough individuals for the analysis

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. Autumn abscissed leaf study was deleted after 1990.

Objectives

1) To quantify leaf processing rates for fresh 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 if E.L.F. fields alter structural and functional community values of the insect communities that colonized tag alder leaves; 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. fields affect 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.

A number of anthropogenic factors can 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 commerical 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 under field conditions is the most pragmatic approach for detecting any E.L.F. effects.

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 abscissed leafpacks would have similar numbers of leaves and similar initial dry weights. Because initial dry weights could not be taken for fresh green leaves, care was given in the weighing of leafpacks so that initial fresh weights would be as similar to each other as possible. Low variance in initial fresh weights minimized variability in final dry weights. Picked leaves were also gently mixed prior to the construction and weighing of the leafpacks in order to reduce selection bias for any site.

After leafpacks were weighed, they were taken to the field, lashed to bricks using rubber bands with replicate identification numbers, and then placed in riffles at FEX and FCD. Seven replicates per collection date were placed in a riffle at each site. In 1990 FEX.LINE was included in the fresh leaf studies after field testing for ELF intensities showed that the new site experienced higher intensities than did the original FEX experimental site.

From 1984 through 1986, fresh leaves were placed in the stream in mid- to late September along with autumn-abscissed tag alder leafpacks. After

1986, the previous year's autumn leaves were used to allow us to begin studies in mid-August. Only fresh leaves were used after 1990. The autumn-abscissed leaves were deleted, with permission, for three reasons. First, we had a more complete dataset for fresh leaves; second, the addition of a new study site would increase our work efforts; and third, allocation of funds for this project were reduced in 1992 and so work effort had to be reallocated.

Leafpacks were collected from the sites six times over a three to four month period. The critical incubation period was found to be four weeks. Coefficient of variation values for leaf losses and for most of the structural and functional insect community parameters were at their lowest at four weeks. Variability for all parameters was very high after 80 days' incubation and so we changed our collection schedule after 1986 to more carefully bracket the critical period. Collection days were changed from 3, 9, 24, 50, 90 and 120 days to 7, 14, 21, 28, 50 and 80 days, weather and travel permitting. On collection days, each leafpack was removed carefully from its brick and placed in a plastic box and the portion of the brick touching the leafpack was carefully washed over the box. After returning to the laboratory, each leafpack and container 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 -$\underline{k}$/day after Petersen and Cummins (1974). Then, two-way ANOVAs were performed on leaf losses for leaves that had been in the stream four weeks to determine whether there were site, year or site-year interaction differences. Processing rate values were regressed against year, cumulative degree days, and discharge values using multiple regression analyses. B.A.C.I. tests could not be performed on these data as only one value was generated each year. B.A.C.I. tests also could not be used for comparing leaf losses from each collection period, as leaf losses represent serial data and are fixed to a particular Time 0 each year when leaves were put in the stream. Paired t-tests were used to test for for differences in -$\underline{k}$/day values between sites over the years.

B. Colonization of Insects on Leaves

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). Taxon diversity (H'), evenness (J'), richness (S') numbers of individuals, and percent numerical

dominance of chironomids, which often comprise over 50 percent of the total number of individuals, were computed for each sample. Total insect mass, adjusted for leaf mass values were also computed. An attempt to analyze the mass of an important functional feeding group for leaf processing; namely, shredders, failed because the data were too variable.

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 ±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', J', numbers of individuals, percent numerical dominance of chironomids, and total insect biomass adjusted to leaf biomass occurred between 24 and 28 days over the years. (See the 1988 Annual Report.) Although there were six collection periods, data analyses efforts were concentrated on datasets from one period in this Annual Report for the reason given above. The variables were analyzed with 2-Way ANOVA tests to determine whether there were site, year, or site x year differences. Multiple linear regression analyses for linear data were performed to see how much mean discharge and cumulative degree days accounted for the variation in the biotic parameters at each site.

Mean dry biomass per individual (MDW/IND) values were determined for three species: Ephemerella subvaria, E. invaria, and Isoperla transmarina. The data were analyzed for differences in growth rates (MDW/IND) between sites and among years. These species have their major growth periods in the late fall through spring. Quickly changing water temperatures in the fall and spring are related to their growth rates so physiological time (cumulative degree days) was used as the independent variable in the graphical analyses and in the ANCOVA tests.

Results and Discussion

Leaf Processing

1. Processing rates within and among sites

Processing rates (-k/day) at FEX were similar before full power of E.L.F. fields as compared with after full power (Figures 6.1A, 6.1B; Table 6.1). Only

in 1985 were leaves processed fast as compared with other years. (Note that the Y-axes differ, giving an apparent greater slope for Figure 6.1A). The mean processing rate for all years at FEX was 0.0137/day.

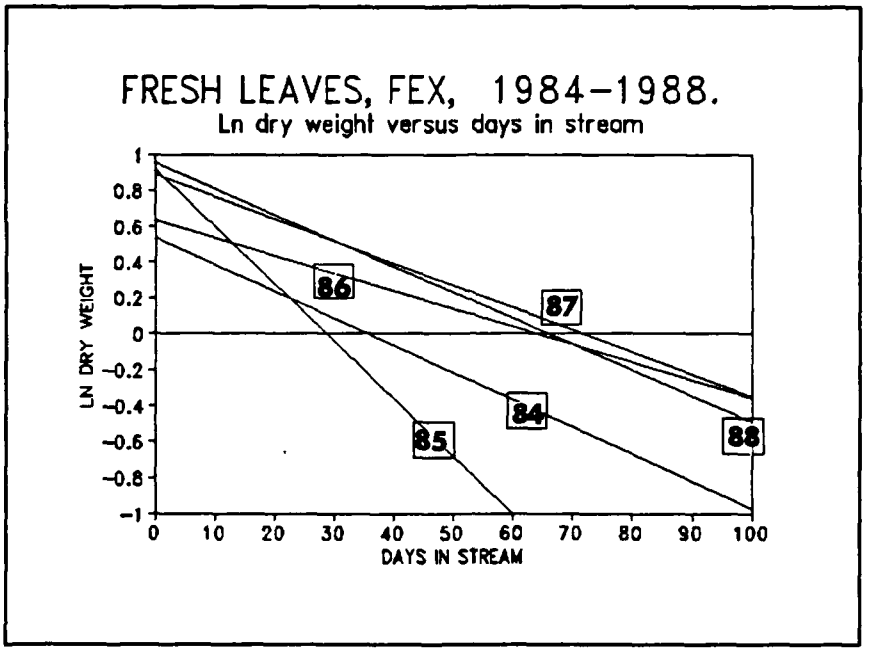

Figure 6.1A. Leaf processing rates for fresh leaves at FEX prior to full power of E.L.F. fields, 1984 - 1988.

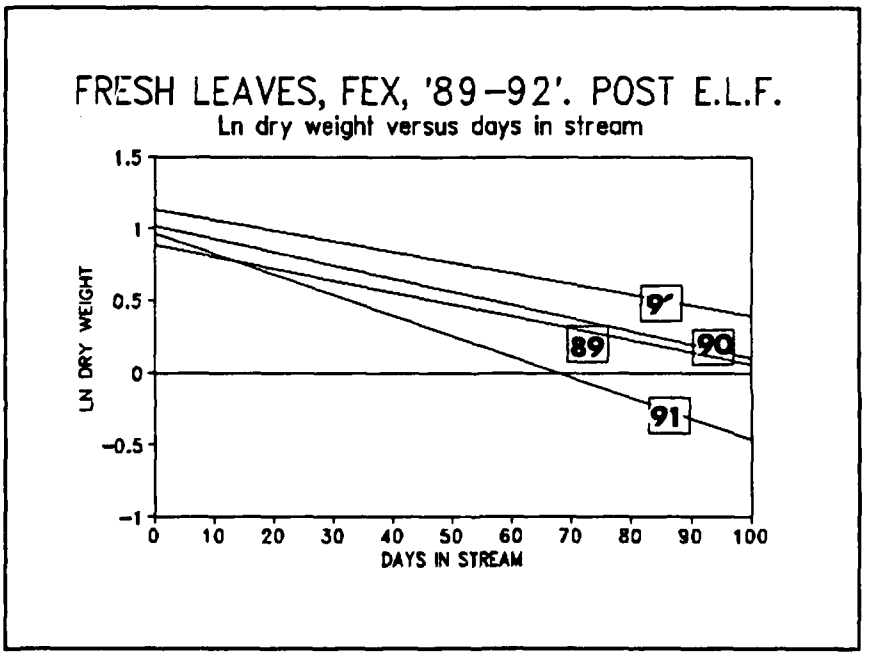

Figure 6.1B. Leaf processing rates for fresh leaves at FEX after full power of E.L.F. fields, 1989 - 1992.

Year to year variation in leaf processing rates at the reference site, FCD, was lower (Figures 6.2A, 6.2B; Table 6.1).

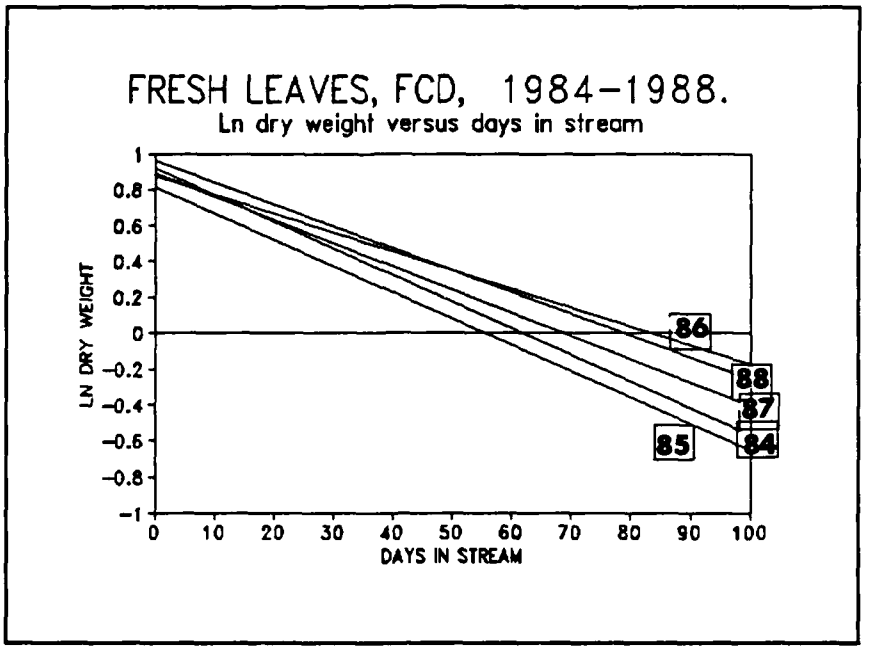

Figure 6.2A. Processing rates for fresh leaves at FCD before full power of E.L.F. fields, 1984 - 1988.

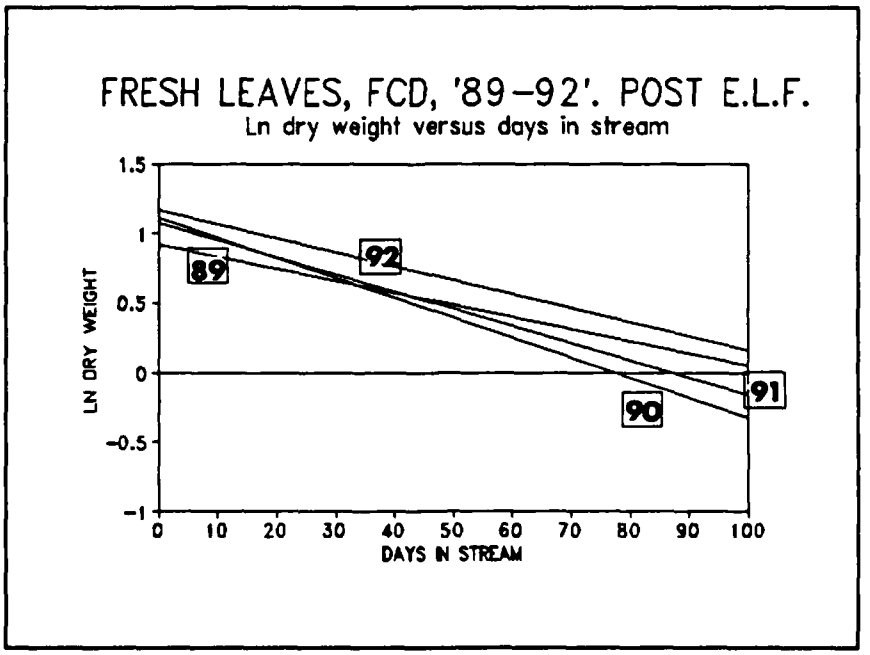

Figure 6.2B. Processing rates for fresh leaves at FCD after full power of E.L.F. fields, 1989 - 1992.

Data from 1990 through 1992 for processing rates of leaves at the FEX.LINE site show that in the cool fall of 1992, -k/day was slow as compared with other years (Table 6.1)

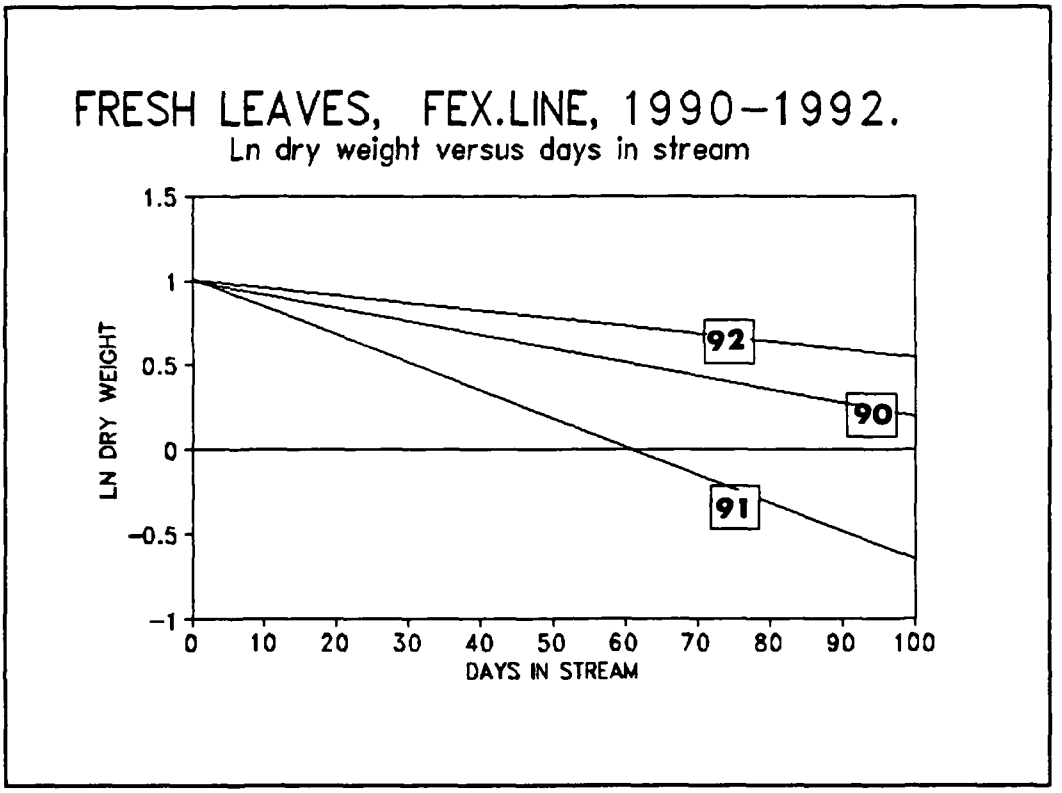

Figure 6.3. Processing rates for fresh leaves at FEX.LINE after full activation of E.L.F. fields, 1990 - 1992.

Student T-tests showed that there were no significant differences between FEX and FCD with respect to processing rates over the years (T_{16} = 0.530, $p > 0.30$). [A Fisher Exact Test showed no significant difference between FEX and FEX.LINE (T_4 = 0.12) and between FCD and FEX.LINE (T_4 = 0.66).] Only in 1985 and in 1990 did -k/day values strongly deviate between FEX and FCD (Figure 6.4A, 6.4B). In the pre-operational year of 1985 the rate was faster at FEX and in the post-operational year the rate was faster at FCD. Figure 6.4A shows the mean values for processing rates over the years at the two sites, and Figure 6.4B shows the differences between FEX and FCD for the entire study as well as differences for FEX, FCD, and FEX.LINE from 1990 through 1992. FEX and FEX.LINE data have been more similar than has FCD and FEX.LINE. More years would be needed to detect any trend in differences among FEX.LINE and the other two sites. Certainly, data from 1984 through 1992 for FEX and FCD show oscillations over the years (Figures 6.4A, 6.4B).

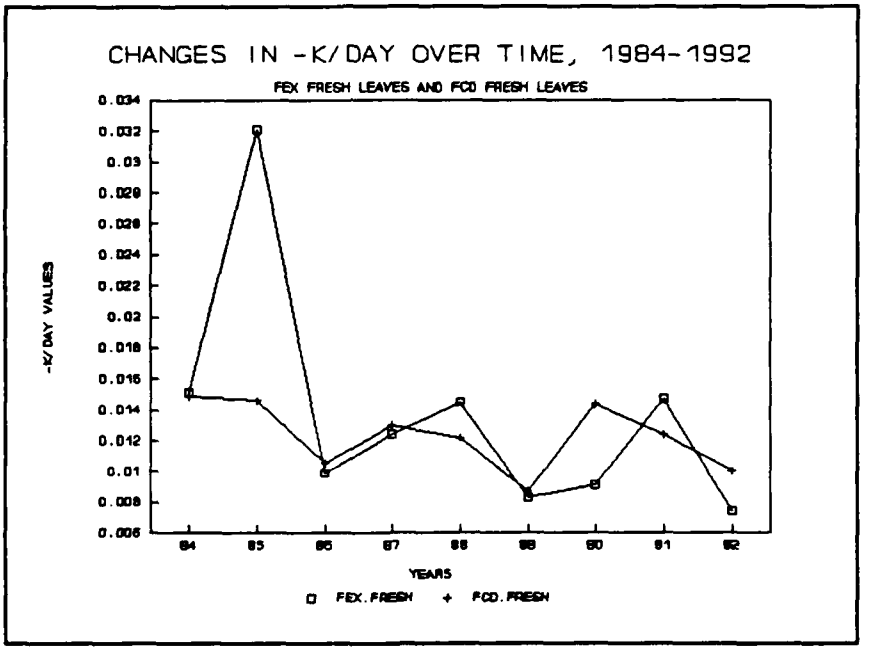

Figure 6.4A. Mean values for processing rates of fresh leaves at FEX (squares) and FCD (pluses) from 1984 through 1991.

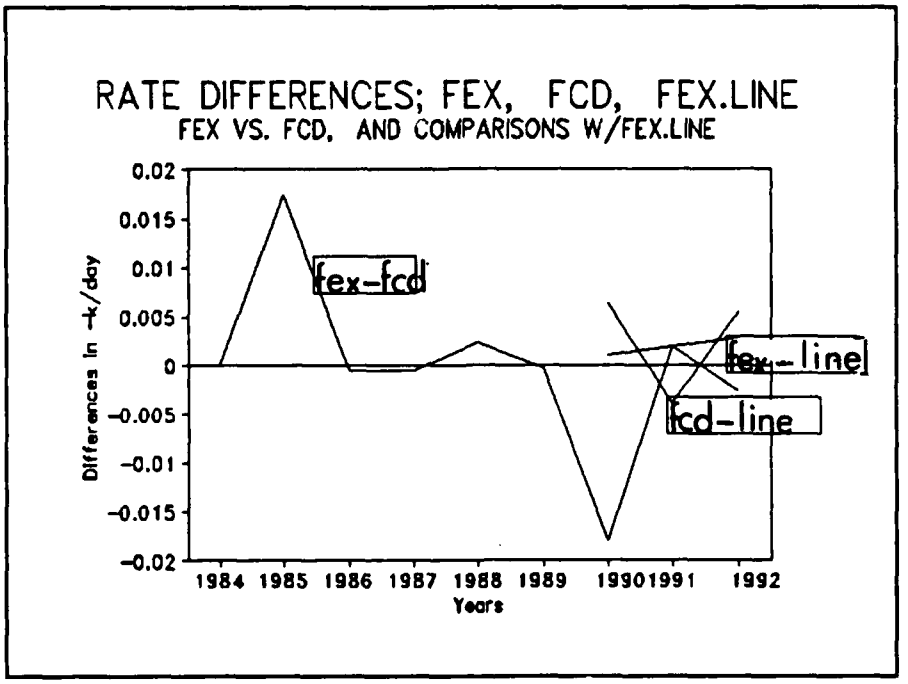

Figure 6.4B. Differences between fresh leaf processing rates from 1984 through 1992, FEX minus FCD. 1990 - 1992: FEX minus FEX.LINE, and FCD minus FEX.LINE.

Table 6.1 shows that fresh leaves at the sites were processed fast, a designation given by Petersen and Cummins (1974) for leaves processed faster than -0.0099/day. Variation was higher at FEX over the years than at FCD; evenso, there were no statistically significant differences between the two sites for processing rates. Regression coefficient values were usually high over the years as well.

TABLE 6.1
Processing Coefficients (-k/day) and Regression Coefficients for the slopes. Fresh Leaves at FEX, FCD, and FEX.LINE, 1984 - 1991

Year	FEX, -k/day	FEX, r^2	FCD, -k/day	FCD, r^2	FEXLINE -k/day	FEX.LINE r^2
1984	.0151	.78	.0149	.83		
1985	.0321	.62	1.016	.47		
1986	.0099	.69	.0105	.68		
1987	.0124	.80	.0130	.74		
1988	.0145	.70	.0122	.57		
1989	.0102	.84	.0087	.74		
1990	.0091	.78	.0144	.78	.0081	.62
1991	.0147	.49	.0126	.75	.0166	.68
1992	.0074	.46	.0100	.54	.0046	.45
Mean	**.0137**		**.0123**		**.0098**	
S.D.	**.0075**		**.0022**		**.0062**	

One should expect yearly processing rates to differ, as leaves were placed in the river from mid-August to mid-September over the years and water temperatures ranged a great deal in August through November each year (See Figures 4.30A and 4.30B, this Report). In any year, however, leaves were treated the same way and were placed at the sites on the same day. Any differences of interest, therefore, would be site differences before as compared with after E.L.F. activation.

2. Leaf losses after four weeks' incubation

The lowest coefficient of variation values for leaf loss over the years occurred during the first month the leaves were in the water. Variation in mass remaining values remained low through Day 28; thenafter, they rose sharply. For that reason and for the fact that biotic parameters for the insect community showed the least variation at 28 day's incubation of the leaves, analyses were confined to that period, both for leaf losses and for insect colonization patterns.

Coefficient of variation values (CV) were low at FCD for leaf dry weights after four weeks' incubation in the stream, but they were usually higher at FEX over the years (Figure 6.5).

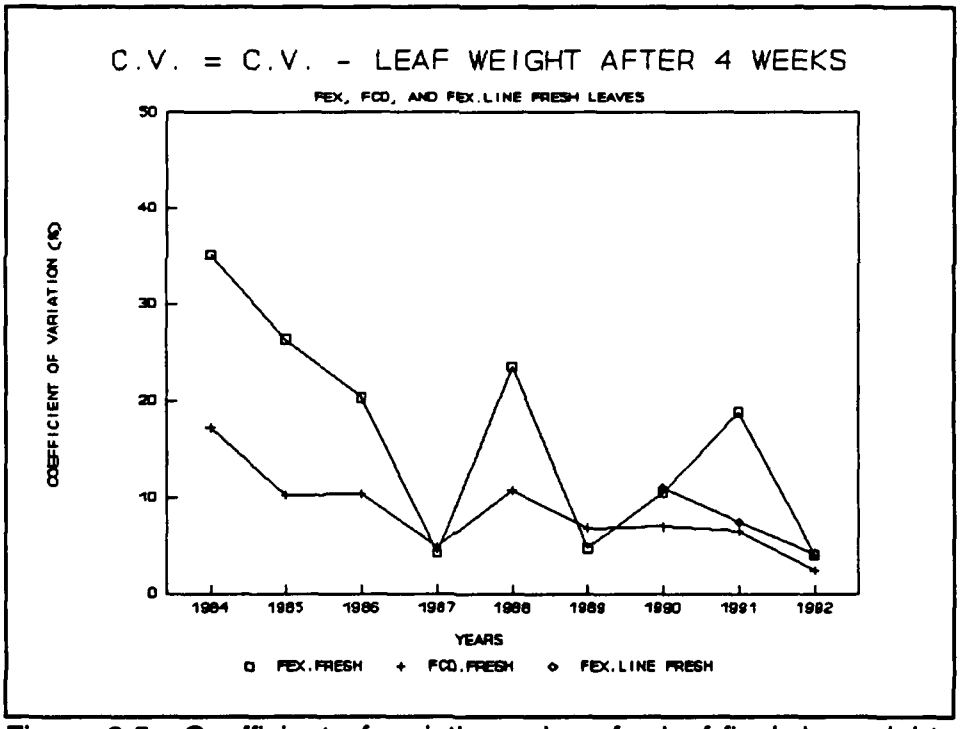

Figure 6.5. Coefficient of variation values for leaf final dry weights after 4 weeks' incubation. FEX (squares), FCD (pluses), FEX.LINE (diamonds). 1984 - 1992.

A 2-Way ANOVA was performed on ln leaf dry mass after four weeks' incubation each year (Table 6.2). There were significant site ($p < .001$), year ($p < .001$) and site by year ($p < .001$) differences. In 1984, 1986, and 1987 more leaf material was lost at FEX than at FCD, resulting in the significant site

differences after the 24 - 28 day period. When all collection dates were used for the computation of -k/day values, however, there were no significant differences between sites.

TABLE 6.2
Two-Way ANOVA Tests for Ln Leaf Losses on Fresh Leaves
After 24 to 28 Days at FEX versus FCD, 1984 - 1992

Source	*d.f.*	*SS*	*MSS*	*F; Signif.*
Site	*1*	*0.514*	*.514*	*33.61****
Years	*8*	*2.463*	*.308*	*20.124****
Years, Site	*8*	*1.129*	*.141*	*9.222****
Error	*108*	*1.724*	*.015*	

There were differences in discharge and in water temperatures from year to year. As those variables can affect leaf losses, they have to be considered. Figure 6.6A shows mean discharge values at FEX and FCD over the years when the leaves had been in the river for four weeks. Figure 6.6B is a plot for the amount of cumulative degrees the leaves had experienced after four weeks in the river each year.

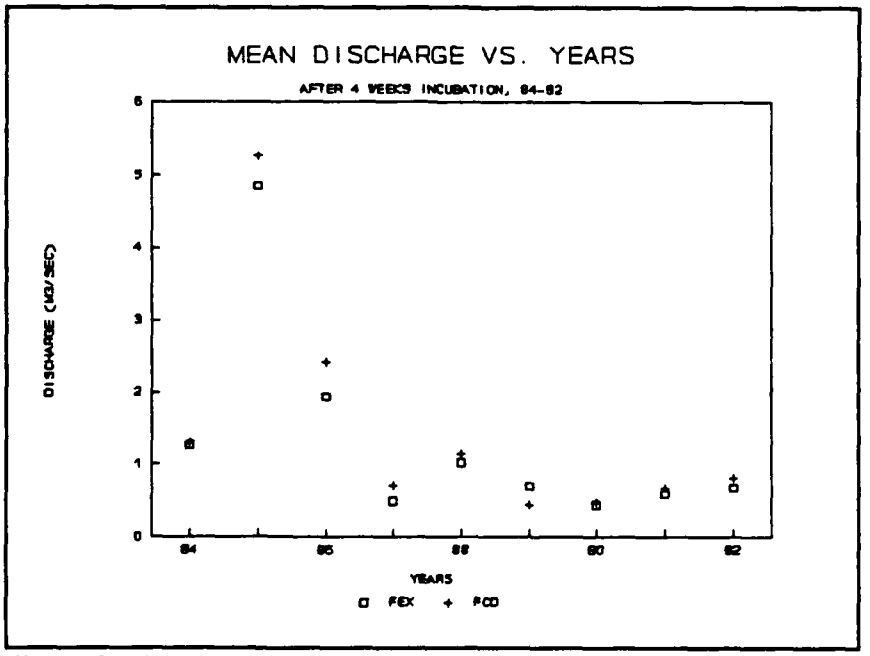

Figure6.6A. Average discharge at FEX (squares) and FCD (pluses) during a four week incubation period for fresh leaves each year. 1984 - 1992.

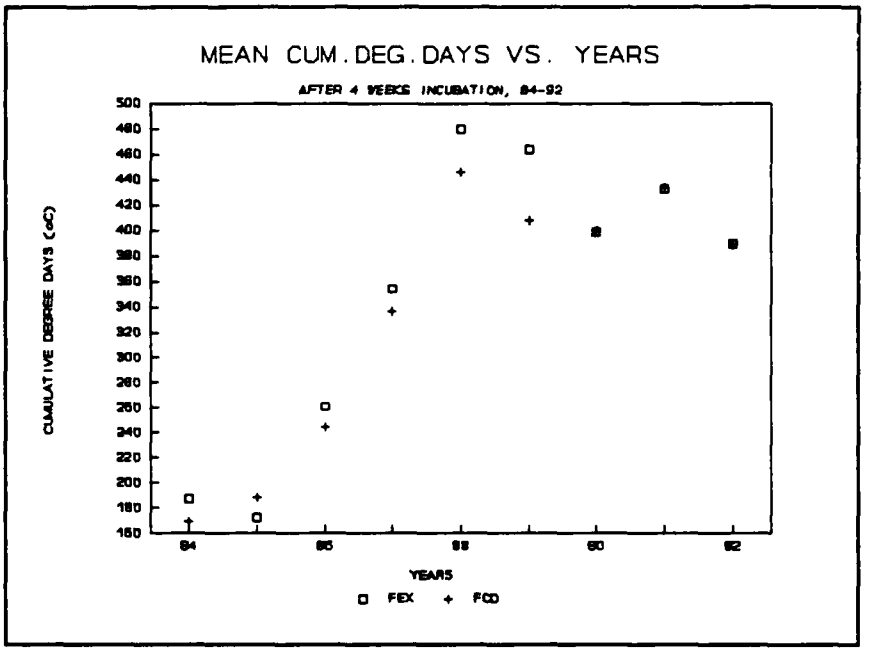

Figure 6.6B. Cumulative degree days at FEX (squares) and FCD (pluses) during a four week incubation period for fresh leaves each year. 1984 - 1992.

Cumulative degree day and mean discharge values were computed by taking the time from Day 0 when the leaves were put in the stream each year and accumulating degree day water temperatures to the fourth week, and determining the mean discharge value during that period. These values were used for multiple regression analyses for leaf losses (Table 6.3) as well as for ANCOVAS for insect colonization data.

TABLE 6.3
Multiple Regression Values for Fresh Leaf Processing Rates
from 1984 through 1992 at FEX and FCD

1. FEX Fresh Leaves

Variable	Reg.Coeff.	Std.Err	T(df=5)	P	Partial
Year	-.00036	.0009	-.401	.705	.0311
Cum.Deg.Day	.0000109	.00002	.445	.675	.0381
Discharge	.0049	.0017	3.184	.024	.6697

Std.Err.Est.: .0043 r^2: .790

Table 6.3, continued

2. FCD Fresh Leaves

Variable	Reg.Coeff.	Std.Err	T(df=5)	P	Partial
Year	-.0024	.0006	-.402	.704	.0313
Cum.Deg.Day	.00004	.00002	-.209	.842	.0087
Discharge	.00006	.0007	.083	.937	.0014

Std.Err.Est.: .0024 r^2: .236

Table 6.3 shows that the partial regression for discharge at FEX was very high. The partial regression value for years was not 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. The location for the leafpacks at FCD may have been less subject to abrasion, activities of the insects less pronounced, or more years of data may be required before any effects of discharge can be detected.

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. Graphs of mean values and of C.V. values for the structural community parameters for samples collected after four weeks' incubation each year are presented first; then statistical analyses follow.

Taxon diversity (H') declined from 1984 through 1990 and then increased in 1991 and 1992. (Figure 6.7A), but coefficient of variation values have remained rather steady and below 20 percent, except at FEX in 1985 (Figure 6.7B).

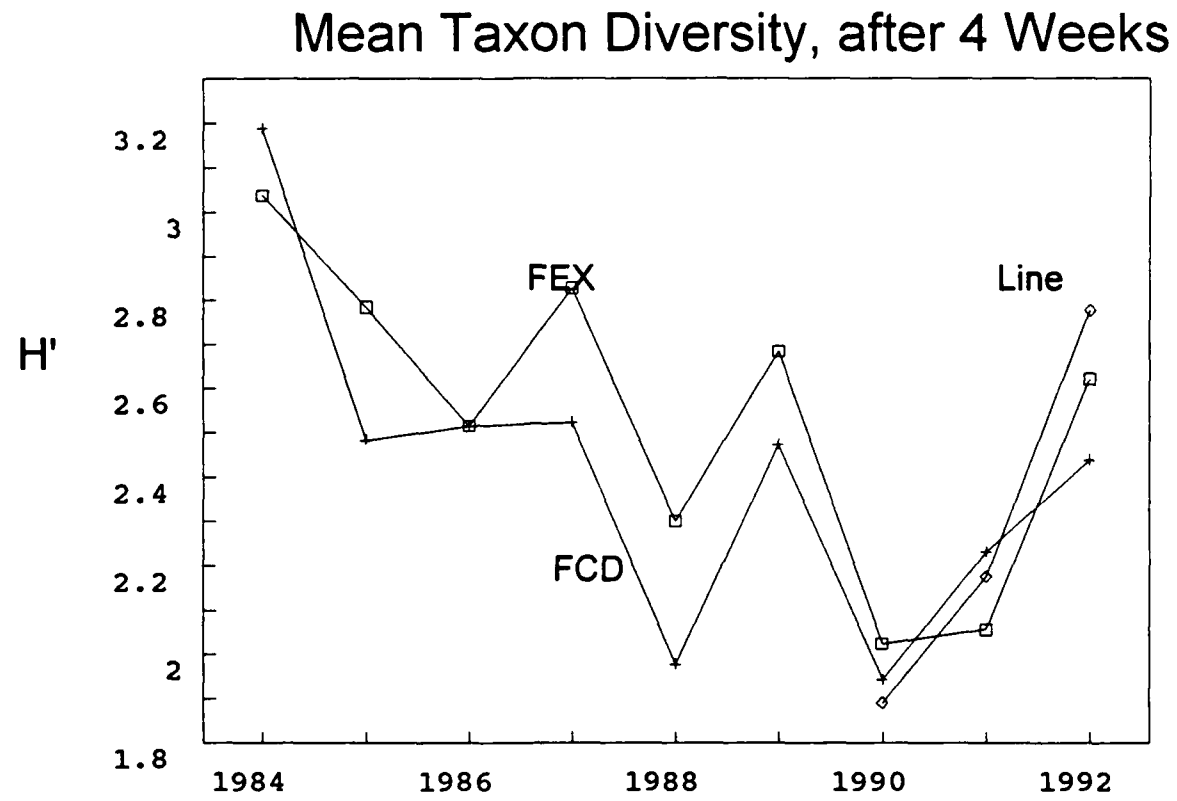

Figure 6.7A. Mean taxon diversity on fresh leaves, 1984 - 1992.

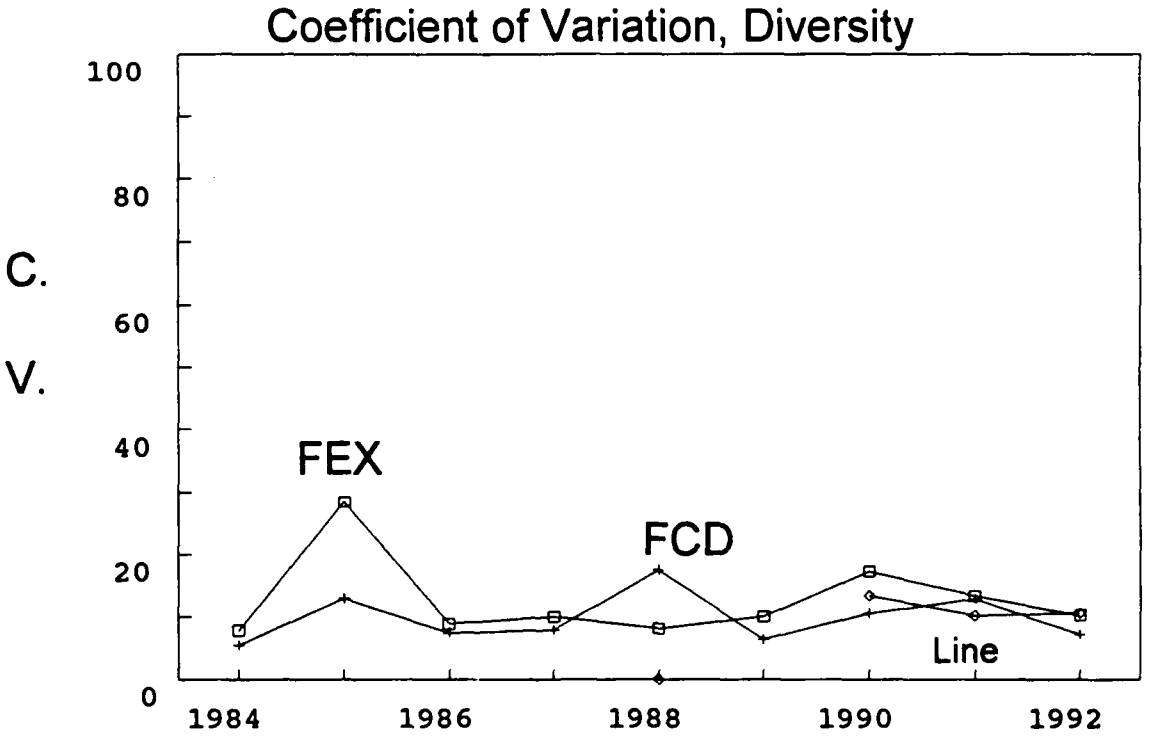

Figure 6.7B. Coefficient of variation values for mean taxon diversity on fresh leaves, 1984 - 1992.

A Two-Way ANOVA for taxon diversity (H') showed significant site, year, and interaction differences (Table 6.4). Figure 6.7A shows that H' was higher at FCD than at FEX only in 1985 and 1991. These reversals in the usual pattern resulted in a significant interaction term. E.L.F. fields were activated in the summer of 1986 and were fully operational in the fall of 1989. The pattern between FEX and FCD during that time was similar.

Taxon diversity at FEX.LINE was similar to H' at FEX and FCD in the two years since the new site was added, Figure 6.7A.

TABLE 6.4
Two-Way ANOVA Tests for H' for Insects on Fresh
After 24 - 28 Days
1984 - 1991

Source	*d.f.*	*SS*	*MSS*	*F value*
FRESH				
Site	*1*	*0.528*	*0.538*	*9.938***
Years	*8*	*13.096*	*1.637*	*30.829****
Interaction	*8*	*0.895*	*0.112*	*2.107**
Error	*108*	*6.093*	*0.053*	

B.A.C.I. tests cannot be run on these data to see whether there is a before versus after effect because there is only one mean value per year. B.A.C.I. tests are not very powerful; moreover, they do not incorporate variation in the data. Variation may be more important than mean values for these studies. For example, ELF exposure may have some threshold effect that increases variance around a similar mean value. Multiple linear regressions were performed for each site's data for H', J', numbers of individuals, and then chironomid numerical dominance versus mean discharge and cumulative degree days, Table 6.5. (Richness was not included as the data were not linear.) Because leaves were put in the river at differing times in August and September, water temperatures and season may have affected taxon diversity, which could be partially factored out by using cumulative degree days (See Figure 6.6B).

Table 6.5 shows that both discharge and cumulative degree days were negatively related to taxon diversity. In addition, much of the variation in H' could be attributed by the two physical factors at FCD (R^2 = .673). Overall, cumulative degree days accounted for more of the variation than did mean discharge.

TABLE 6.5

Multiple Linear Regressions for H', J', Numbers of Individuals, and Chironomid Numerical Dominance *versus* Mean Discharge and Cumulative Degree Days, 1984 - 1992

Sites, Description	Diversity	Evenness	# Individuals	Chiro. Dom.
FEX				
R^2	0.380	0.467	0.187	0.247
Discharge	-.177	-.319	-.181	.406
Cum.D.D.	-.726	-.864	.287	.683
FCD				
R^2	0.673	0.760	0.547	0.705
Discharge	-.592	-.310	-.303	.295
Cum.D.D.	-1.094	-1.050	.500	1.010

Taxon evenness (Figure 4.8A, Figure 4.8B) had patterns similar to those for taxon diversity (Figure 4.7A, Figure 4.7B).

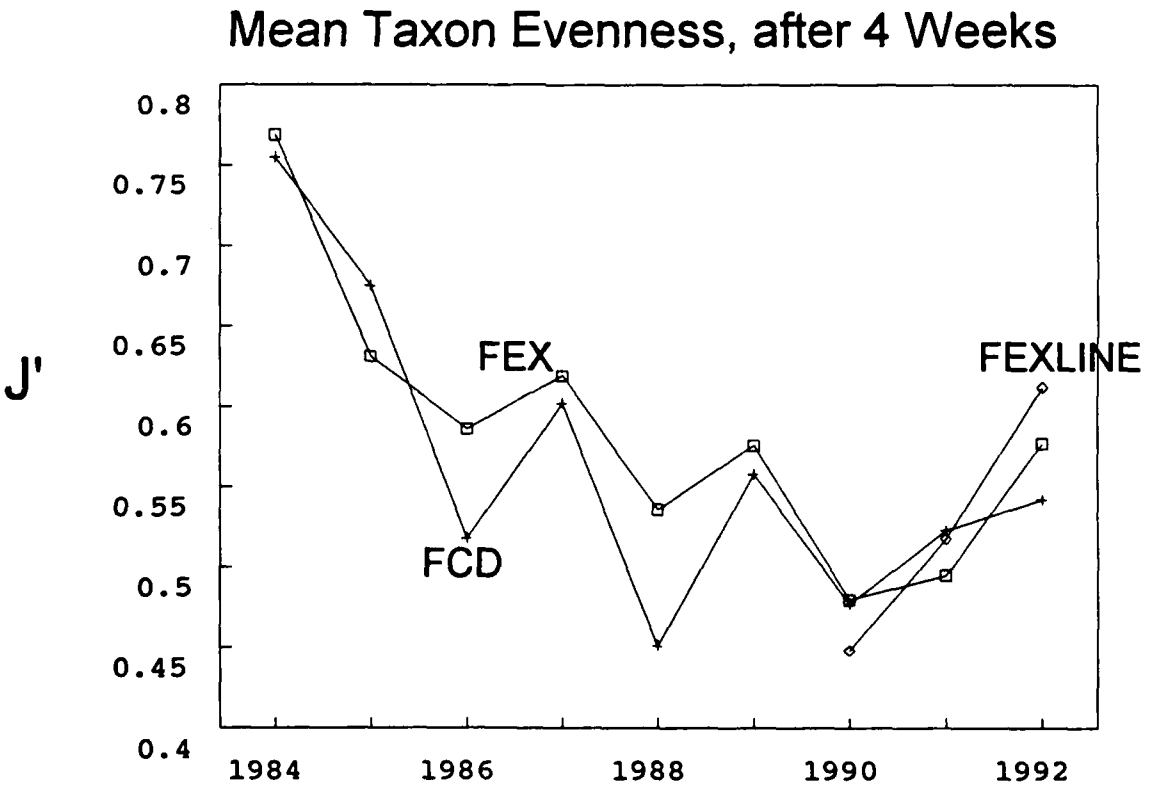

Figure 6.8A. Taxon evenness (J') on fresh leaves after 4 weeks in FEX, FCD, and FEXLINE. 1984 - 1992.

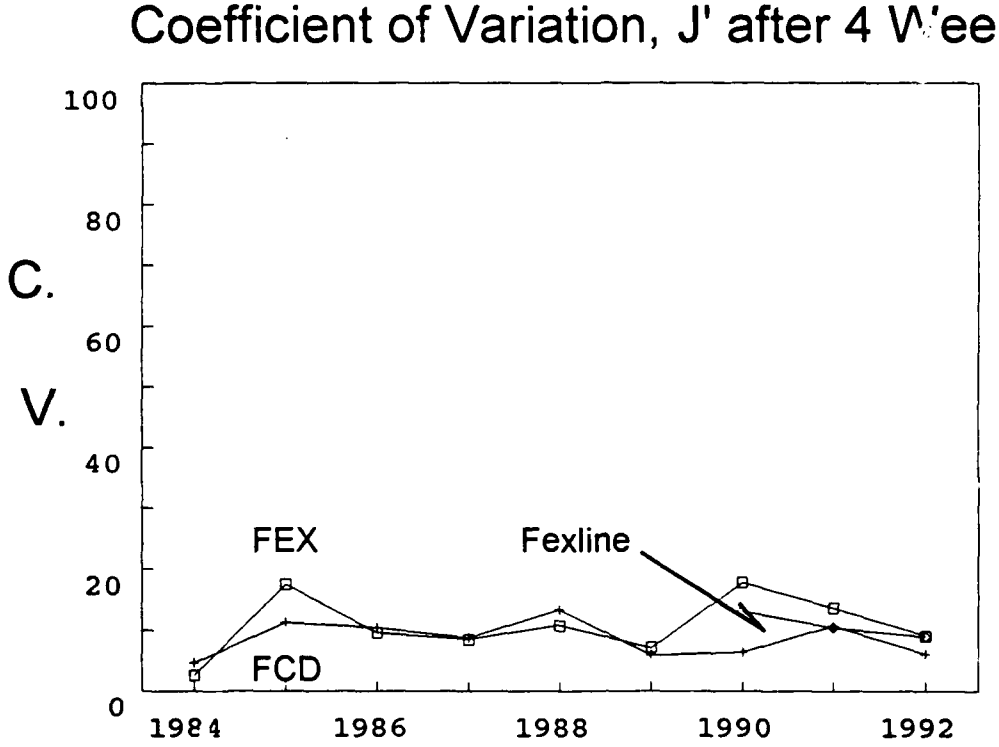

Figure 6.8B. Coefficient of variation values for taxon evenness after 4 weeks in stream. 1984 - 1992.

Table 6.6 presents a Two-Way ANOVA table testing for differences between the sites and years for taxon evenness.

TABLE 6.6
Two-Way ANOVA Tests for J' (Arc Sine Transform) for Insects on Fresh Leaves After 24 to 28 Days, 1984 - 1992

Source	*d.f.*	*SS*	*MSS*	*F value*
Site	*1*	*21.24*	*21.24*	*2.02 , p >.25*
Years	*8*	*3118.76*	*389.84*	*37.15 ****
Interaction	*8*	*107.62*	*13.45*	*1.28 , p >.25*
Error	*108*	*1190.56*	*10.49*	

Fresh leaves showed no significant site differences or a significant interaction term. There were highly significant year differences, as one would suspect, given the days each year that the leafpack experiments were initiated. Figure 6.8A shows that evenness declined over the years until 1990 and then increased in 1991 and 1992. Table 6.5 shows results from multiple linear regression tests for J' at each site, with mean discharge and cumulative degree days as independent variables. Much of the variation in J' at each site was explained by cumulative degree days. Evenness was higher in 1984 and 1985

when leafpacks were placed in the stream in late September. Other years, they were put in the streams in mid-August to early September. The higher cumulative degree day values were in 1986 through 1992, with the highest values being in 1988, the year of extreme heat and low rainfall. Clearly, cumulative degree days accounted for most of the variation in J' at each of the sites.

Taxon richness did not show a steady decline over the years (Figure 6.9A). In fact, richness on fresh leaves at the two sites did not track each other until 1988, afterwhich time, the two sites showed some similarity. Taxon richness at FEX.LINE was similar to that for FEX in 1990 through 1992. As taxon richness showed no linear pattern and there was a significant interaction between years and sites (Table 6.7), no multiple linear regressions were performed on these data.

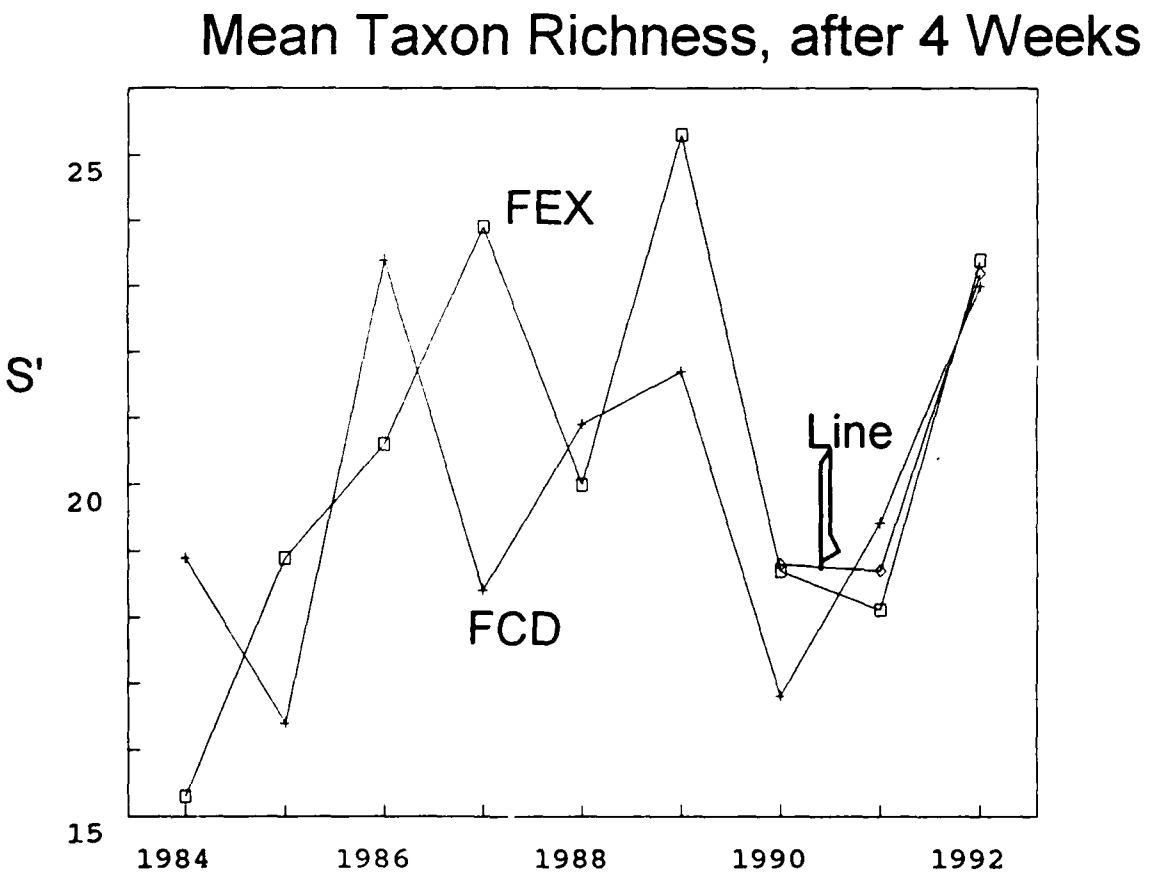

Figure 6.9A. Mean taxon richness (S') on fresh leaves after 4 weeks in FEX, FCD, and FEXLINE, 1984 - 1992.

Coefficient of variation values were high at FEX in 1985 (Figure 6.9B), for reasons described earlier. From 1987 through 1992, C.V. values were below 20 percent.

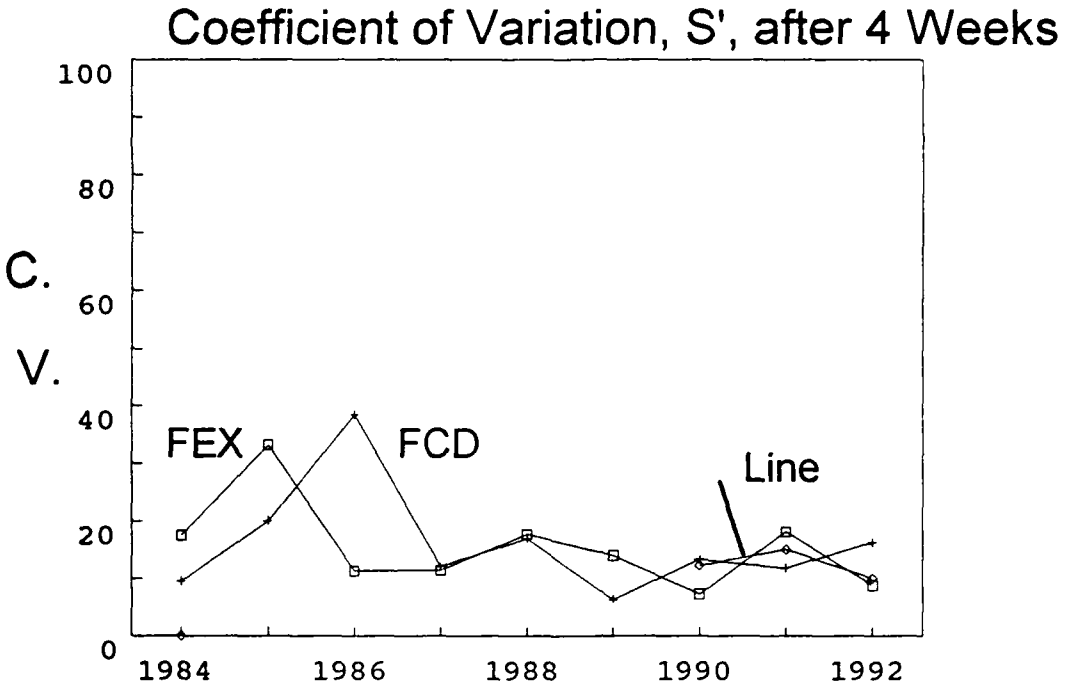

Figure 6.9B. Coefficient of variation values for taxon richness (S') on fresh leaves after four weeks at FEX, FCD, and FEXLINE. 1984 - 1992.

Table 6.7 shows that there were no significant site differences but there were significant year differences and significant interaction between years and site. Figure 6.9A shows that FEX and FCD alternated in having the highest numbers of taxa for most years in the study.

TABLE 6.7
Two-Way ANOVA Tests, Taxon Richness for Insects on Fresh Leaves After 24 to 28 Days, 1984 - 1992

Source	*d.f.*	*SS*	*MSS*	*F value*
(A) FRESH				
Site	*1*	*12.70*	*12.70*	*1.939 n.s.*
Years	*8*	*653.00*	*81.62*	*12.463 ****
Interaction	*8*	*252.87*	*31.61*	*4.826****
Error	*108*	*676.86*	*6.55*	

Numbers of individuals on the leaves generally increased through time (Figure 6.10A). Numbers were higher on fresh leaves at FEX some years and were higher on fresh leaves at FCD other years. FEX.LINE had values similar to those at FEX and FCD. Coefficient of variation values were high in 1985,

1988, and 1990 at FEX. On the other hand, C.V. values remained steady at FCD over the years (Figure 6.10B). FEX.LINE had values similar to those at FCD.

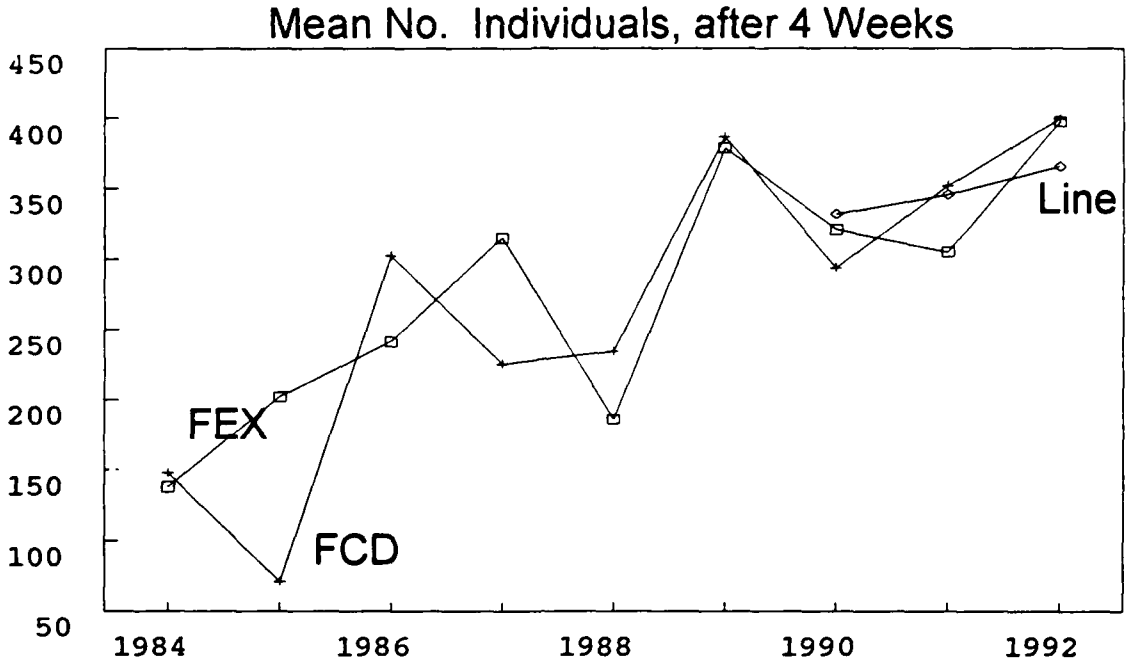

Figure 6.10A. Mean numbers of individuals on fresh leaves after 4 weeks in FEX, FCD, and FEX.LINE, 1984 - 1992.

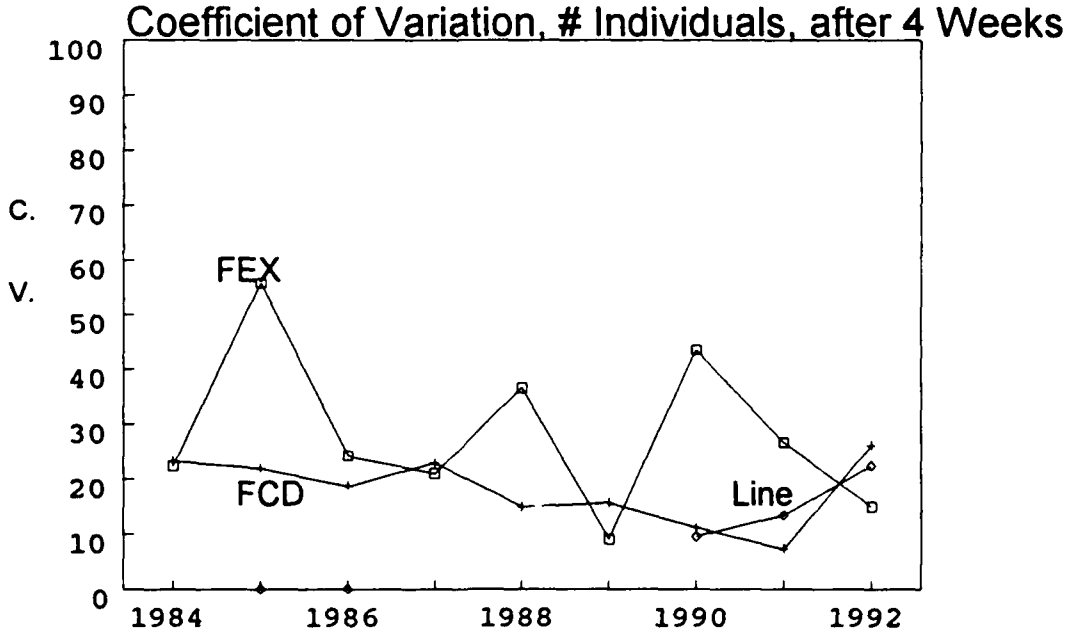

Figure 6.10B. Coefficient of variation values for numbers of individuals on fresh leaves after 4 weeks in FEX, FCD, and FEX.LINE, 1984 - 1992.

Table 6.8 presents results for a 2-Way ANOVA for numbers of individuals on fresh and autumn leaves over the years.

TABLE 6.8
Two-Way ANOVA Tests, Numbers of Insects on Fresh and for Leaves After 24 to 28 Days, 1984 - 1991

Source	*d.f.*	*SS*	*MSS*	*F value*
Site	*1*	*73201*	*73201*	*1.345 n.s.*
Years	*8*	*1677083*	*209635*	*3.500***
Interaction	*8*	*644281*	*80535*	*1.222 n.s.*
Error	*108*	*6490664*	*59894*	

Numbers of individuals showed no significant site differences nor a significant interaction term between site and year differences. Figure 6.10A shows that numbers of individuals gradually increased over the years on fresh leaves.

Multiple linear regressions were performed for numbers of individuals at FEX and then FCD versus mean discharge and cumulative degree days, Table 6.5. Discharge was negatively related to numbers of individuals, which makes logical sense. Numbers were positively related to cumulative degree days, suggesting that when the leaves were placed in the river later in the season (1984 and 1985), the leaves attracted more insects after four weeks incubation than if the leaves were placed in the stream in mid-August to early September (1986-1992). Much more of the variability in numbers of individuals was explained by the two independent variables at FCD than at FEX. However, the pattern of having this biotic parameter being negatively related to discharge and positively related to cumulative degree days was similar at both sites.

Many chironomids colonize leaf inputs in the Ford River, and our introduced leafpacks are no exception. They dominate many of our samples. Because they are very common, include several functional feeding groups, and show patterns of dominance over the 'life' of each leafpack season as well as among the years of our leafpack studies, we analyzed their dominance for this Report. Figure 6.11A shows mean dominance and Figure 6.11B, CV values for that family.

Chironomid dominance increased over the years for samples taken after four weeks' incubation each year (Figure 6.11A). Figure 6.11B shows that C.V. values were very high in 1985 at both sites, but they decreased to less than 20 percent after 1986. Table 6.9 shows the relationships between years and sites for this biotic parameter.

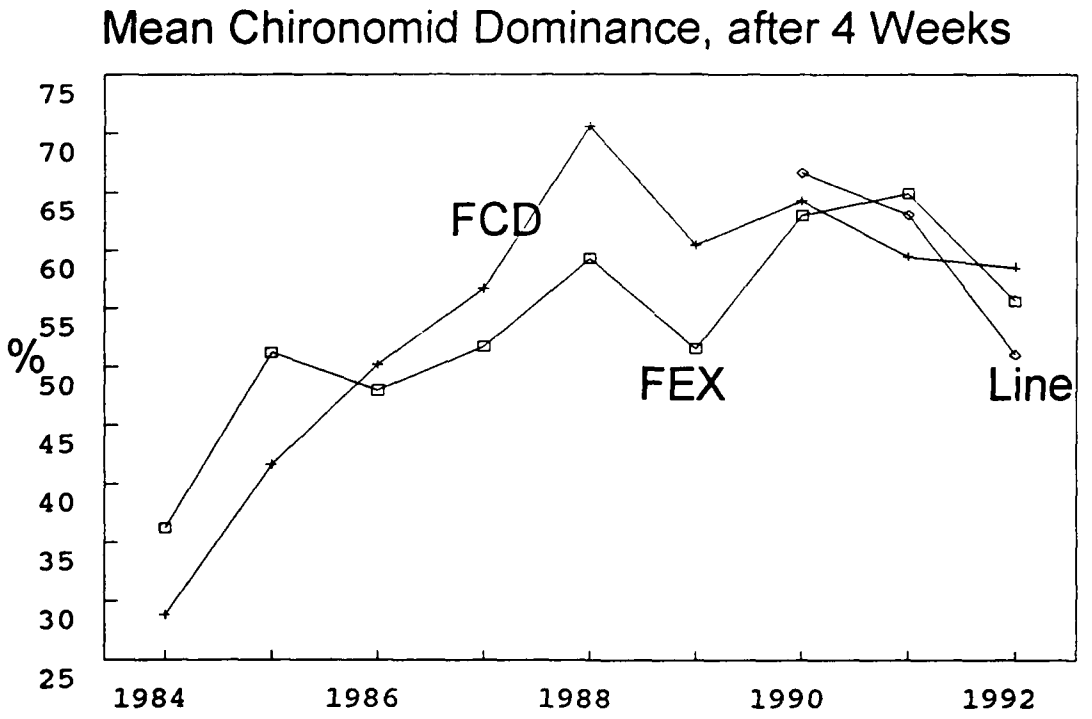

Figure 6.11A. Mean numerical chironomid dominance on leaves after 4 weeks at FEX, FCD, and FEX.LINE. 1984 - 1992.

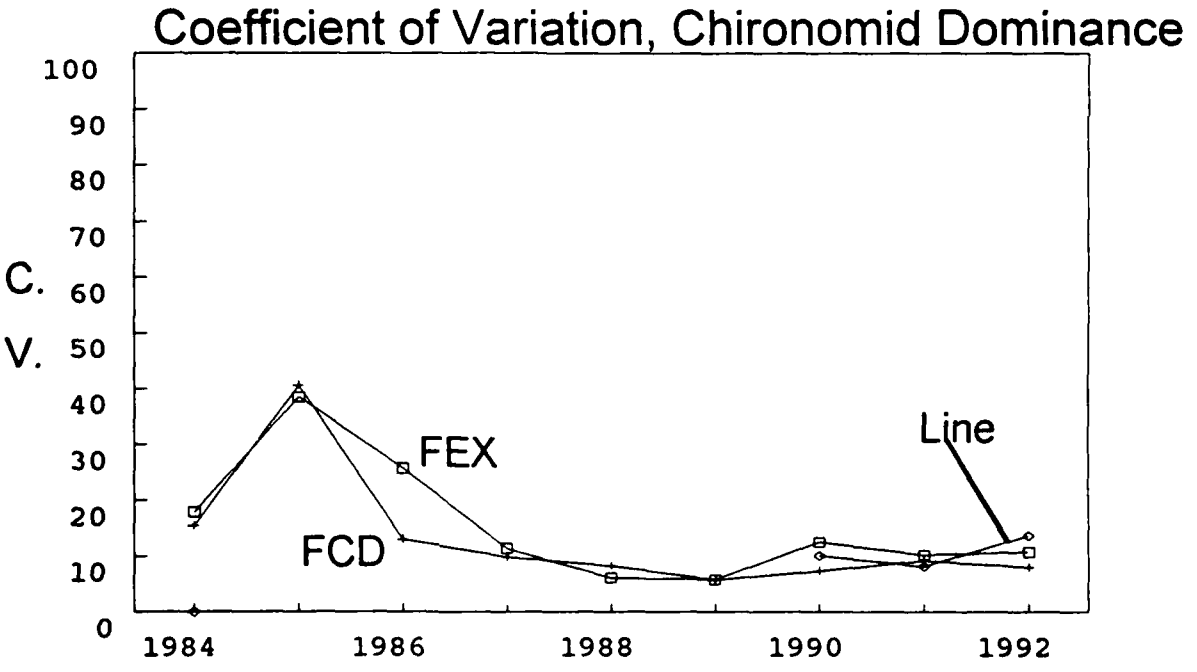

Figure 6.11B. Coefficient of varation vales for chironomid numerical dominance on fresh leaves after 4 weks at FEX, FCD, and FEX.LINE. 1984 - 1992.

TABLE 6.9
Two-Way ANOVA Tests, Chironomid Numerical Dominance on Fresh Leaves After 24 to 28 Days, 1984 - 1992

Source	d.f.	SS	MSS	F value
Site	1	6.12	6.12	0.204 n.s.
Years	8	3404.50	425.56	14.183***
Interaction	8	480.95	60.12	2.004 n.s.
Error	108	2517.21	30.00	

Chironomid dominance on fresh leaves showed no significant site or site by year interaction differences. Dominance continued to increase over the years (Figure 6.11A). In summary, 2-way ANOVA tests for five structural community parameters showed distinct patterns: none showed significant site differences except for H'; all showed highly significant year differences, and only two parameters showed significant interaction terms (H' and S'). One would expect significant year differences, given yearly variability in weather and our placing leafpacks in the river in mid-August rather than mid-September after 1985.

Because chironomid numerical dominance was linear over time, multiple linear regressions were performed on data from FEX and FCD, with mean discharge and cumulative degree days being the independent variables, Table 6.5. Chironomid numerical dominance was positively related to both mean discharge and to cumulative degree days. More of the variation in chironomid dominance was explained by cumulative degree days than by discharge. When the leaves were put into the river in mid-August or when the August and September were unusually warm (1988), we found proportionately more chironomids than other taxa. A great deal of the variation at FCD for this biotic parameter was explained by the two physical variables (coefficient of multiple determination = .705). In summary, coefficient of multiple determination values in the multiple linear regression analyses were always higher at FCD than at FEX for the two tests of each biotic parameter. Finally, cumulative degree days always explained more of the variation in a given biotic parameter than mean discharge.

Functional Community Parameters

1. Total Insect Mass

The last biotic parameter is a functional community pararneter; namely, total insect mass, adjusted for leaf mass after four week's incubation. Figure 6.12A

shows the mean values for this parameter over time. The means show similar values over time until 1989 when they very high at both sites. In 1991, total insect mass/leaf mass was exceedingly high at FEX, primarily owing to some very large individuals of the stonefly *Acroneuria lycorias* on two of the seven leafpacks. Coefficient of variation values were very high (Figure 6.12B), owing to a few very large animals relative to many smaller animals. There were years when C.V. values were less than 20 percent. The probability of detecting any ELFeffect on the mass of insects, adjusted for leaf mass is very small indeed.

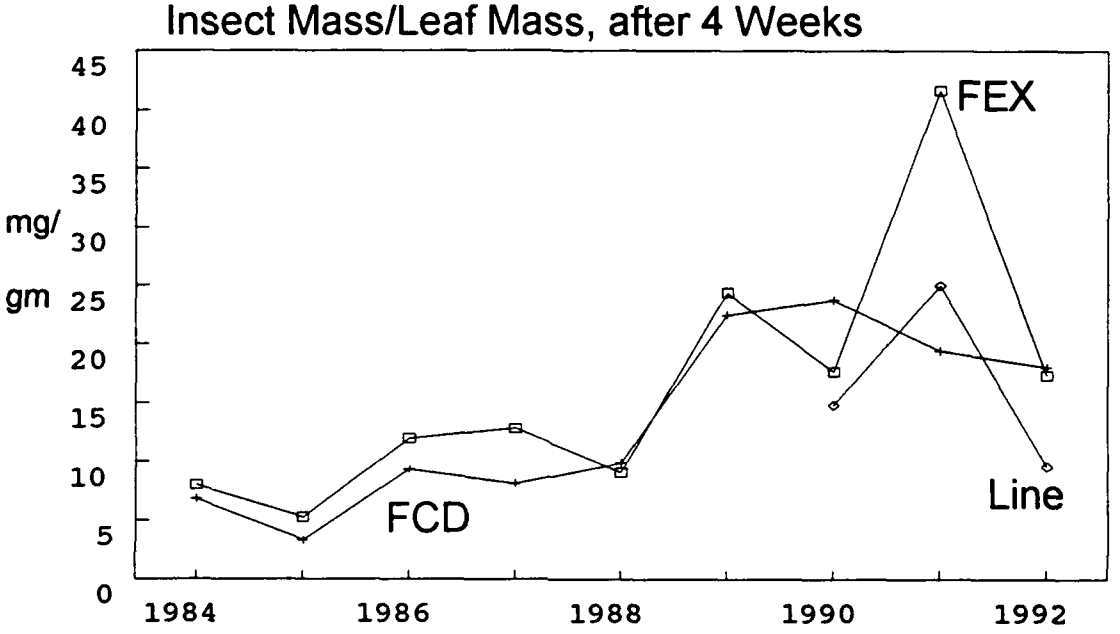

Figure 6.12A. Mean total insect mass/leaf mass (mg./gm.) after 4 weeks at FEX, FCD and FEXLINE. 1984 - 1992.

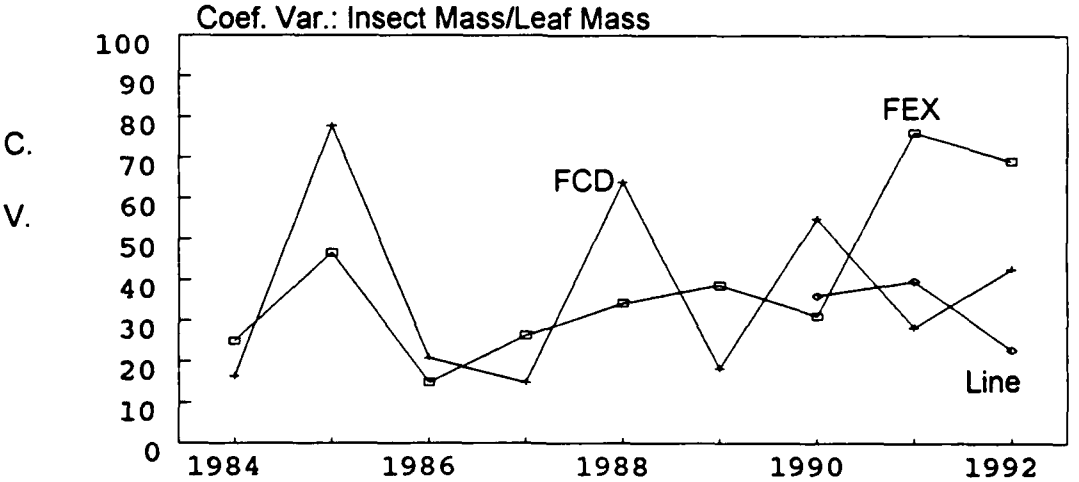

Figure 6.12B. Coefficient of variation values for total insect mass/leaf mass (mg./gm.) after 4 weeks at FEX, FCD and FEXLINE. 1984 - 1992.

Two-way ANOVAS were run for this parameter. Table 6.10 shows that there were significant year differences between the two sites but no significant site differences nor a significant interaction term. Although insect mass adjusted for leaf mass increased over the years, the increases were similar at the sites.

TABLE 6.10
Two-Way ANOVA Tests, Total Insect Mass/Leaf Mass for
Fresh Leaves After 24 to 28 Days
1984 - 1992

Source	*d.f.*	*SS*	*MSS*	*F value*
Site	*1*	*33.12*	*33.11*	*0.856 n.s.*
Years	*8*	*5596.76*	*699.60*	*18.09****
Interaction	*8*	*357.92*	*44.74*	*1.16 n.s.*
Error	*108*	*3548.67*	*38.68*	

Multiple linear regressions were performed to determine the relationship between insect mass *versus* mean discharge and cumulative degree days from 1984 through 1992, Table 6.11.

TABLE 6.11
Multiple Linear Regressions for Mean Insect Mass/Leaf Mass
versus Mean Discharge and Cumulative Degree Days
1984 - 1992

Site, Description	**Insect Mass/ Leaf Mass**
FEX	
R^2	0.310
Discharge	-.317
Cumulative Degree Days	.288
FCD	
R^2	0.418
Discharge	-.273
Cumulative Degree Days	.430

Insect mass, adjusted for leaf mass was negatively related to discharge but positively related to cumulative degree days. The same pattern was true for numbers of individuals (Table 6.5). In warmer years or in those years when leaves were put into the river in mid-August (1986-1992), both mass of insects and numbers of individuals colonizing leafpacks were higher. Because the variation in insect mass/leaf mass is so high, however, it may be that this parameter is too variable and cannot be used to detect any biological effect for E.L.F. fields.

2. Changes in Mean Dry Weight per Individual (MDW/IND) for Three Species

Individuals of species found in sufficient numbers on leafpacks that grew during the autumn and winter seasons were monitored for possible changes in yearly growth rates at FEX, FCD, and at FEX.LINE. Three species fulfilled those criteria: *Ephemerella subvaria, Ephemerella invaria* (mayfly collector-gatherers), and *Isoperla transmarina* (a predatory stonefly). Changes in MDW/IND values for each species were plotted against physiological time, cumulative degree days. As growth was related to reductions in daily water temperatures, cumulative degree days were used to show that these species grew faster when water temperatures decreased rapidly in the fall and winter months (Figures 6.13A,B through 6.15A,B). The fastest growth rates occurred when the fewest number of degree days accumulated between sampling dates. By late October through November, the waters had cooled and the leaf inputs were high for these collector-gatherers and predators. The species emerge in the late spring-early summer (See Element 4). They had not attained their peak growth by the end of the leafpack experiments, but their accelerated rates of growth were obvious during the leafpack studies. If ELF exposure alters growth rates, one would expect the effects to be apparent in rate changes and/or in maximum size at emergence. This Element and Element 4 are designed to identify any significant changes.

Table 6.12 presents results for ANCOVAS for growth of *E. subvaria.* The covariate is chronological time.

TABLE 6.12

ANCOVAS for MDW/IND Changes for *Ephemerella subvaria* on Fresh Leaves, FEX vs FCD and FEX vs. FEX.LINE. 1984 - 1992

F VALUES, SIGNIF.

FEX VS.FCD	*ADJ. MEANS*	*SLOPES*	***FEX vs.Line***	*ADJ MEANS*	*SLOPES*
1984	*0.688*	*.001*			
1985	*1.951*	*.066*			
1986	*1.610*	*5.978**			
1987	*1.761*	*2.299*			
1988	*1.797*	*1.555*			
1989	*2.169*	*12.356****			
1990	*2.115*	*16.567****	*1990*	*4.330**	*34.465****
1991	*0.069*	*0.892*	*1991*	*0.483*	*4.230**
1992	*2.398*	*14.831****	*1992*	*0.180*	*0.092*

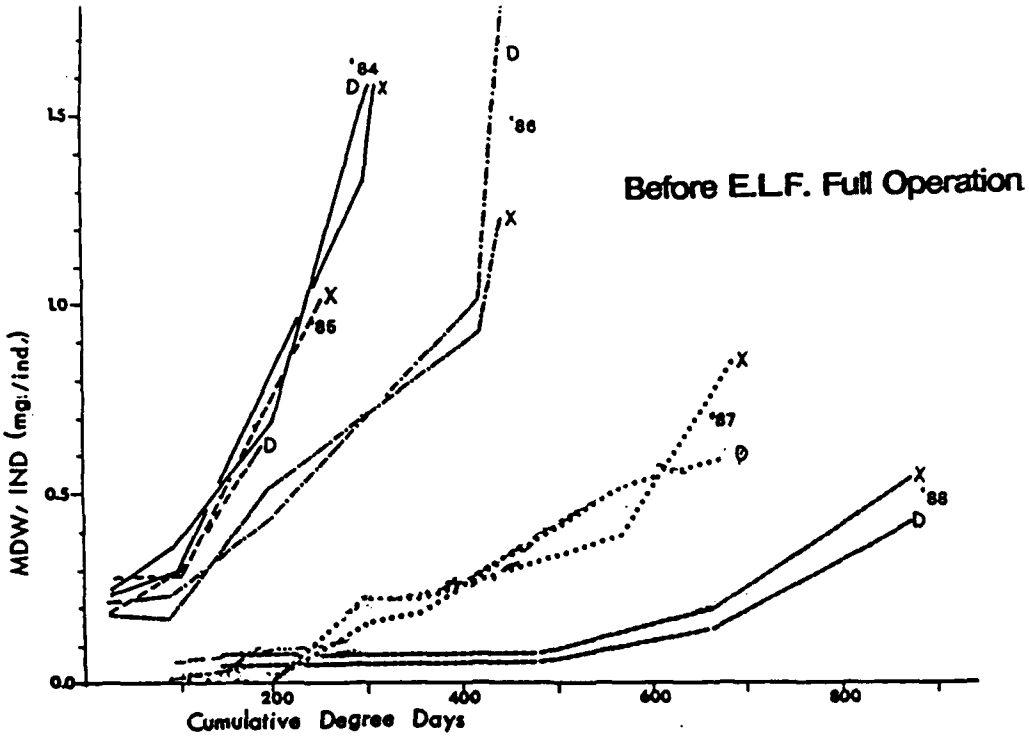

Figure 6.13A. *Ephemerella subvaria* on fresh leaves. Changes in MDW/IND vs. cum. degree days. **Before E.L.F. Full Operation.** FEX, FCD: 1984-1988.

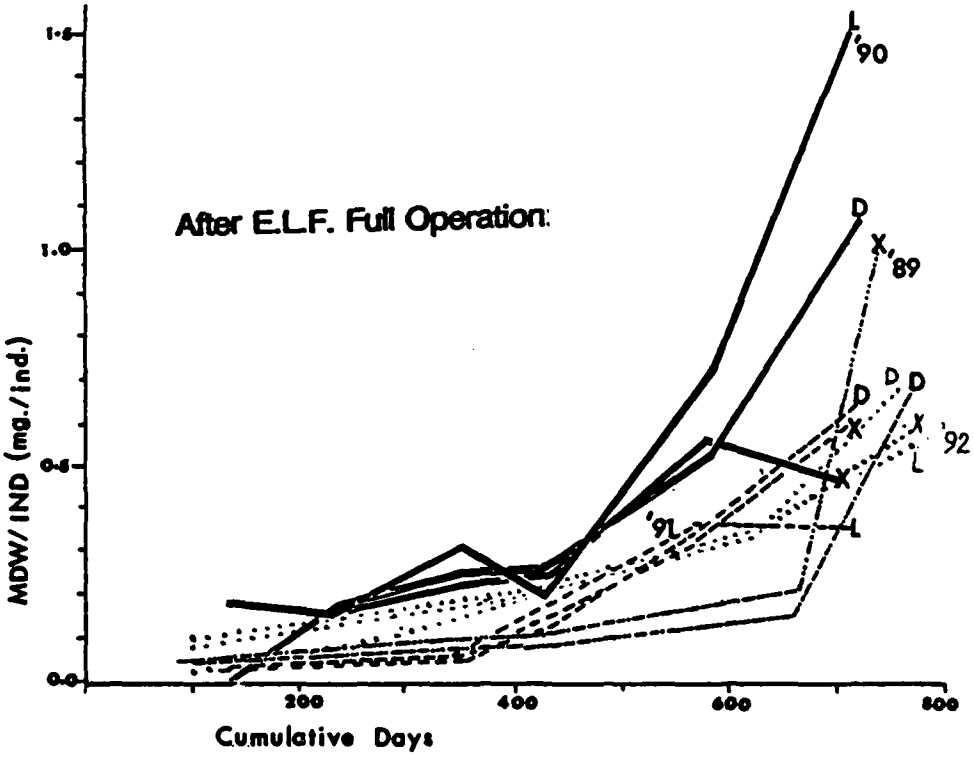

Figure 6.13B. *Ephemerella subvaria* on fresh leaves. Changes in MDW/IND vs. cum. degree days. **After E.L.F. Full Operation:** FEX, FCD:1989-1992; FEX.LINE: 1990, 1992.

There were no significant differences in adjusted mean values for *E. subvaria* on fresh leaves at FEX versus FCD each year. However, slopes differences were significant in 1986, 1990, and 1992. The slopes of the MDW/IND values were higher at FCD in 1986 and 1992 (Figure 6.13A, 6.13B); in 1989, they were higher at FEX (Figure 6.13B). There were significant differences between FEX and FEX.LINE with respect to adjusted means in 1990 and with respect to slopes in 1990 and 1991. In 1990 animals were larger at FEX.LINE and in 1991 they were larger at FEX Figure 6.13B). The new site had high primary productivity in 1990 (See Element 2 of this Report). We found in 1991 more collector-gatherers in substrates at the new site.

Table 6.13 showed that there were no significant adjusted mean value or slope differences for *Ephemerella invaria* at FEX and FCD. Figure 6.14A graphically illustrates the ANCOVAS. There were differences between FEX and FEX.LINE in 1991; slopes were higher at FEX (Figure 6.14B; Table 6.16).

TABLE 6.13
ANCOVAS for MDW/IND Changes for *Ephemerella invaria*, FEX vs FCD and FEX vs. FEX.LINE. Fresh Leaves, 1984 - 1992

F VALUES, SIGNIFICANCE

FEX VS. FCD	*ADJ. MEANS*	*SLOPES*
1984	*0.503*	*0.460*
1985	*1.605*	*0.434*
1986	*2.332*	*0.034*
1987	*1.400*	*0.008*
1988	*1.332*	*0.691*
1989	*1.413*	*0.048*
1990	*0.420*	*0.116*
1991	*0.008*	*0.399*
1992	*1.033*	*3.572*

FEX VS. FEX.LINE		
1990	*0.215*	*0.106*
1991	*0.246*	*4.349**
1992	*0.180*	*0.092*

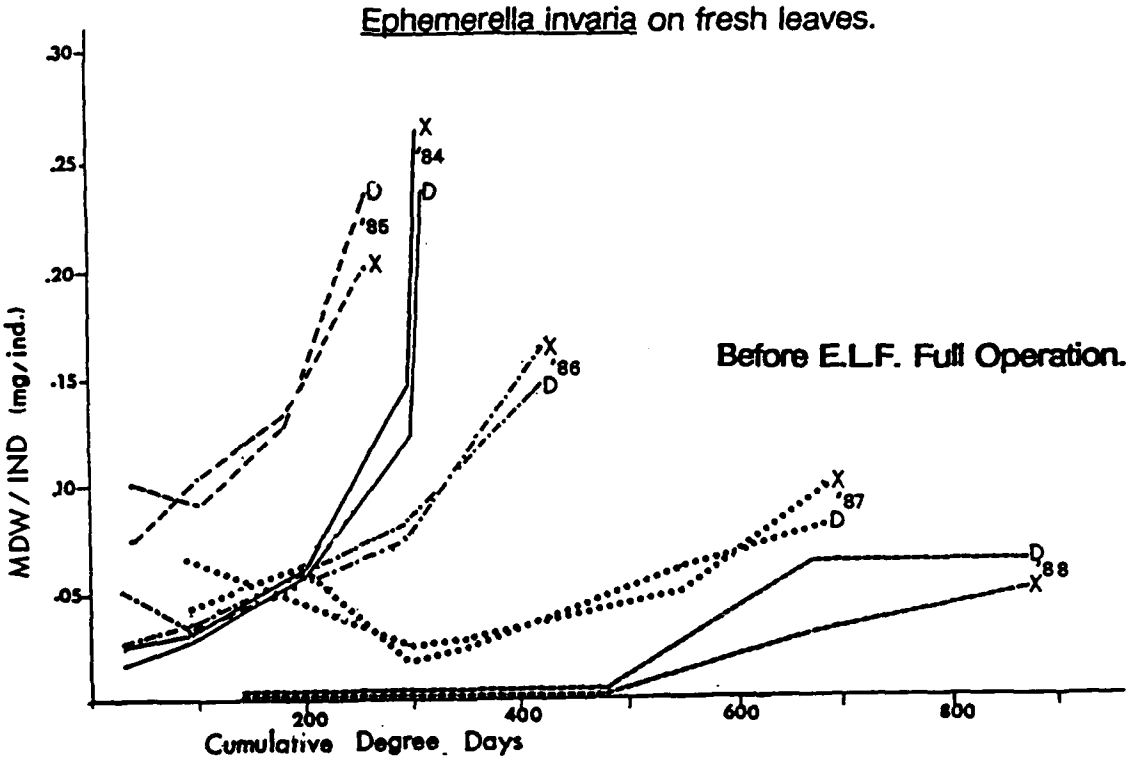

Figure 6.14A. *Ephemerella invaria* on fresh leaves. Changes in MDW/IND vs. cum. degree days. **Before E.L.F. Full Operation.** FEX, FCD: 1984-1988.

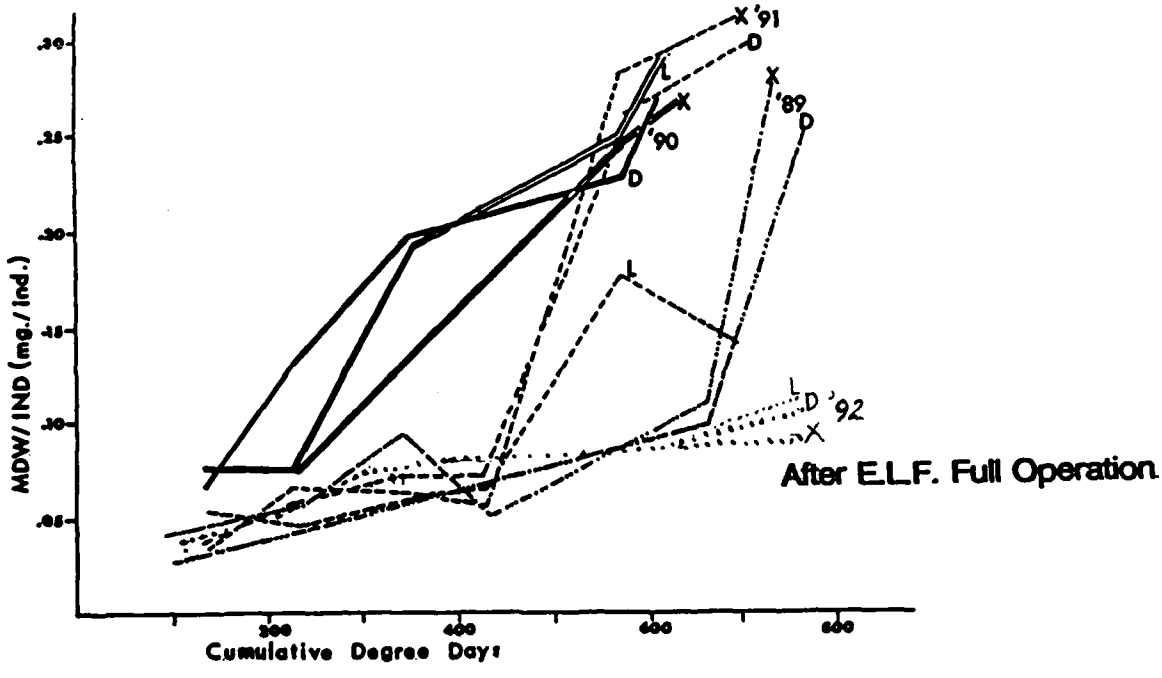

Figure 6.14B. *Ephemerella invaria* on fresh leaves. Changes in MDW/IND vs. cum. degree days. **After E.L.F. Full Operation.** FEX,FCD: 1989-1992; FEX.LINE: 1990, 1992.

It would take several years to determine whether the higher E.L.F. fields at FEX.LINE had an impact on growth of *E. invaria*. The data for FEX and FCD span nine years and those data give a good view as to changes in size classes for the three species we are monitoring. We have three years of data from FEX.LINE for making comparisons with FEX.

A predatory stonefly, *Isoperla transmarina* on fresh leaves, showed significant differences between FEX and FCD only once. That was in 1984 when the adjusted mean value for MDW/IND was higher at FCD, Table 6.14; Figure 6.15A. There were no significant differences between FEX and FCD **after** full operation of E.L.F. lines in the fall of 1989, which suggests that E.L.F. fields did not affect growth rates of this species. There were significant slope differences between FEX and FEX.LINE in 1991 (Figure 6.15B). The sizes of the animals increased much faster at FEX. It appears that FEX.LINE cannot be considered as a matched site for FEX. If E.L.F. fields affect biotic parameters at FEX.LINE more than at the original test site, we will not know this for several years, as we have no 'before' data by which to obtain baseline information.

TABLE 6.14
ANCOVAS for MDW/IND Changes for *Isoperla transmarina*, FEX vs FCD and FEX vs. FEX.LINE on Fresh Leaves, 1984 - 1992

F VALUES, SIGNIF.

FEX vs. FCD	*ADJ. MEANS*	*SLOPES*
1984	*4.329**	*1.963*
1985	*2.310*	*1.674*
1986	*0.452*	*3.172*
1987	*0.002*	*0.380*
1988	*Too few*	*data*
1989	*0.003*	*2.183*
1990	*0.282*	*0.374*
1991	*1.024*	*1.223*
1992	*Too few*	*data*

FEX vs. FEX.LINE	*ADJ. MEANS*	*SLOPES*
1990	*0.343*	*0.011*
1991	*2.284*	*12.215***
1992	*Too few*	*data*

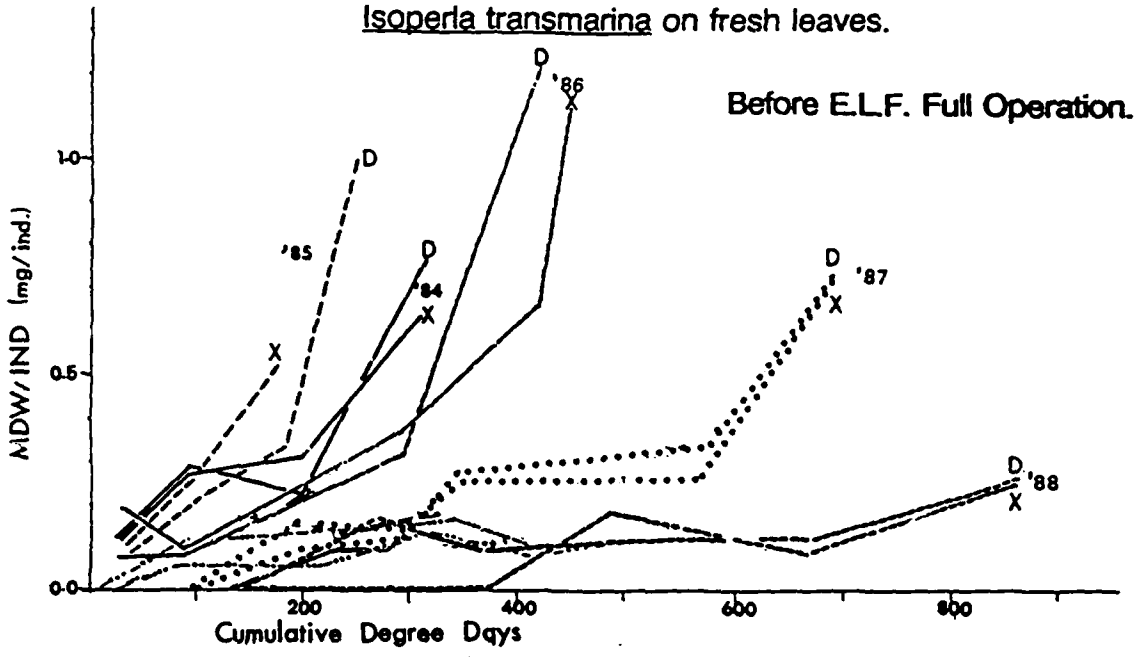

Figure 6.15A. *Isoperla transmarina* on fresh leaves. Changes in MDW/IND vs. cum. degree days. **Before E.L.F. Full Operation.** FEX, FCD: 1984-1988.

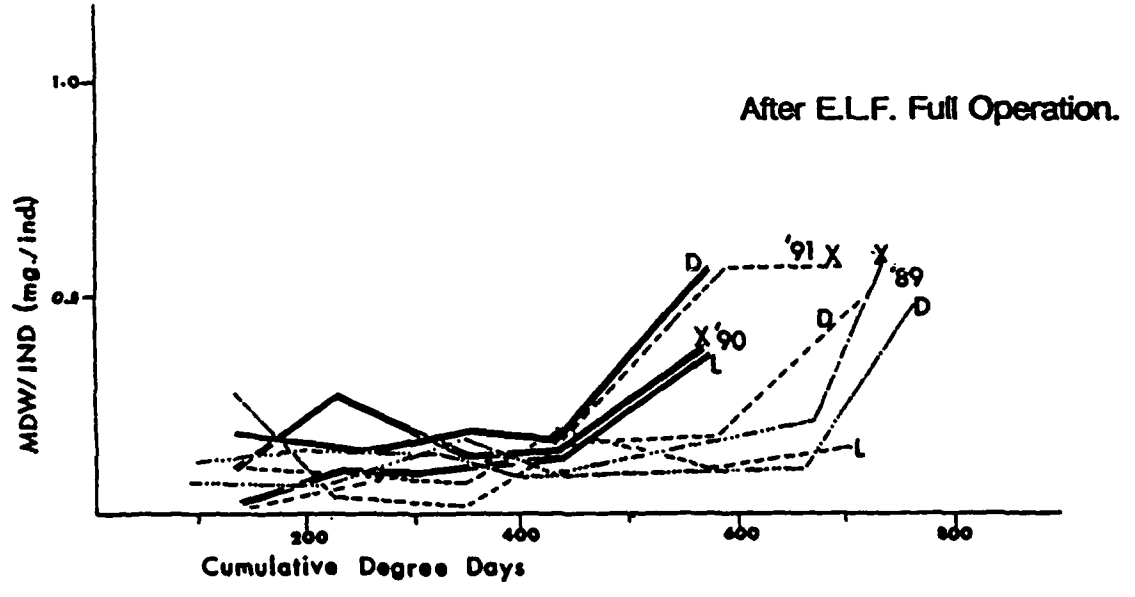

Figure 6.15B. *Isoperla transmarina* on fresh leaves. Changes in MDW/IND vs. cum.degree days. **After E.L.F. Full Operation.** FEX,FCD: 1989-1991; FEX.LINE: 1990, 1991.

Summary

There were no differences between FEX and FCD for leaf processing rates. Leaf processing rates at the new site, FEX.LINE were usually slower than the processing rates at FEX or FCD. The addition of this new site may have come too late in our monitoring program, even though ground field E.L.F. exposures are higher there than at the original test site, FEX.

Coefficient of variation values for structural and community parameters of the insect community colonizing leaves were low after the leaves had been in the river four weeks. They were higher for earlier collections (Day 7, 14, and 21) and higher again for later collections (Day 50, 80). Therefore, we concentrated our statistical analyses on data from the four week incubation period. Two-way ANOVAS showed significant year differences for each of the six biotic parameters. Leafpack experiments were initiated earlier in the season in 1987 through 1992. This change in procedure probably contributed to the significant differences in years. The insect community colonizing leaves at FEX appears to be more diverse, but the higher diversity cannot be attributable to ELF fields. There were no significant site differences for evenness, richness, numbers of individuals, chironomid dominance, or total insect mass (adjusted for leaf mass). Evenness decreased over the years until 1991 and 1992. Numbers of individuals increased over the years. Chironomid dominance and insect mass/leaf mass ratios increased over the years until 1991 and 1992.

Graphical analyses did not show that year differences were associated with E.L.F. activation in 1986 nor from 1989 through 1992 (when the fields were at full power). Multiple linear regressions, using mean discharge and cumulative degree days as the independent variables, showed that cumulative degree days accounted for more of the variability than discharge for the six biotic parameters. Coefficient of multiple determination values were always higher at FCD than at FEX for each biotic parameter. The higher r^2 values at FCD may be related to the fact that that site is more sandy and contains fewer larger particles which can act as refugia during spating. The animals at that site may be more susceptable to discharge events.

ANCOVAS showed that mean sizes of three species, *Ephemerella subvaria, Ephemerella invaria,* and *Isoperla transmarina,* were similar at FEX and FCD each year. There were three years, however, when there were significant slope differences between the two sites (individuals of *E. subvaria* only). Because the sites oscillated over time with respect to slope differences, it is improbable that ELF activation is related. We compared results from the new site, FEX.LINE with those from our original site, FEX. There were significant

differences in slopes and/or in adjusted mean values for *E. subvaria* at FEX and FEX.LINE in 1990 and 1991. There were significant slope differences for the other two species in 1991. The new site, separate from its value of having a 10-fold difference in ELF exposure with respect to the control site, appears to be distinctly different from either the original test or control site. Our preliminary data support that biological viewpoint.

A summary of results of statistical analyses for this Element appears in two tables. Table 6.15 contains eight biotic parameters and four types of analyses. Leaf processing coefficients (-k/day) for each year from 1984 through 1992 were compared, using a two-tailed Student t-test. The remaining seven parameters include data for one collection period: Four weeks' incubation data from 1984 through 1992. Significant main effects and interactions are presented in the Two-Way ANOVA column. Within site multiple regression analyses, using discharge, and cumulative degree days as independent variables appear in Table 6.15 as well. The highest standard regression coefficients were listed when the r^2 values were greater than 0.30.

TABLE 6.15

Summary of Statistics for Element 6

PARAMETER	T TEST	2-WAY ANOVA	MULT. REG.
-K/DAY	n.s.		
After 4 Weeks			
Leaf losses		Site,Yr,Interact.	FEX: Discharge
Diversity		Site,Yr,Interact.	FEX&FCD: Cum.Deg. Days
Evenness		Years	FEX&FCD: Cum.Deg. Days
Richness		Yr, Interact.	N/A
No. Individuals		Years	FCD: Cum. Deg. Days
Midge Dominance		Years	FCD: Cum. Deg. Days
Insect Mass		Years	FEX&FCD: Cum. Deg. Days

N/A: Not appropriate

Table 6.16 gives a summary of year by year ANCOVA comparisons between FEX and FCD with respect to changes in mean dry weight per individual (MDW/IND) for three insect taxa. When there were no significant differences between FEX and FCD, that was noted with a zero (0); when FEX was higher than FCD, it was noted with a plus (+); and when FEX was lower than FCD, it was noted

with a minus (-). Comparisons between FEX and FEX.LINE were also made for 1990 through 1992 data. The same notation as above was used.

TABLE 6.16

ANCOVAS for Testing Differences Between sites for Changes in MDW/IND of Three Insect Species

A. FEX vs. FCD

Year	Ephemerella subvaria	Ephemerella invaria	Isoperla transmarina
1984	0	0	0
1985	0	0	0
1986	-	0	0
1987	0	0	0
1988	0	0	N/A
1989	+	0	0
1990	-	0	0
1991	0	0	0
1992	-	0	N/A

B. FEX vs. FEX.LINE

Year	E. subvaria	E. invaria	I. transmarina
1990	-	0	0
1991	+	+	+
1992	0	0	N/A

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Element 7 = Fish Community and Abundance

Changes from workplan: Data analysis design structured in this manner: pre-operational years (1983-1985), transitional years (1986-1988), and fully-operational years (1989-1993). Before 1992, 1989 was analyzed as a transitional year. We have treated 1989 as an operational year after discussion with IITRI engineers. The primary analyses presented in this report compare pre-operational years with transitional and fully-operational years.

Fishing at the wire mesh weir sites FCU and TM was discontinued in 1992. The fyke net site FEN, added in 1990 400m upstream of FEX, was again fished in 1993.

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 FEN, 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 FEN, FEX, and FCD. Nets were fished continuously from May 14 to July 9; however, on several occasions discharge levels were above gear and personnel capabilities to fish. High water inhibited net fishing for 5 days in late May and for a total of 13 days in June. When catch rates were low (< 1 fish/day) from July 4 through August 21, 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 at FEX and FCD is reported in Figure 7.1. Net days at FEN totaled 55.

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.

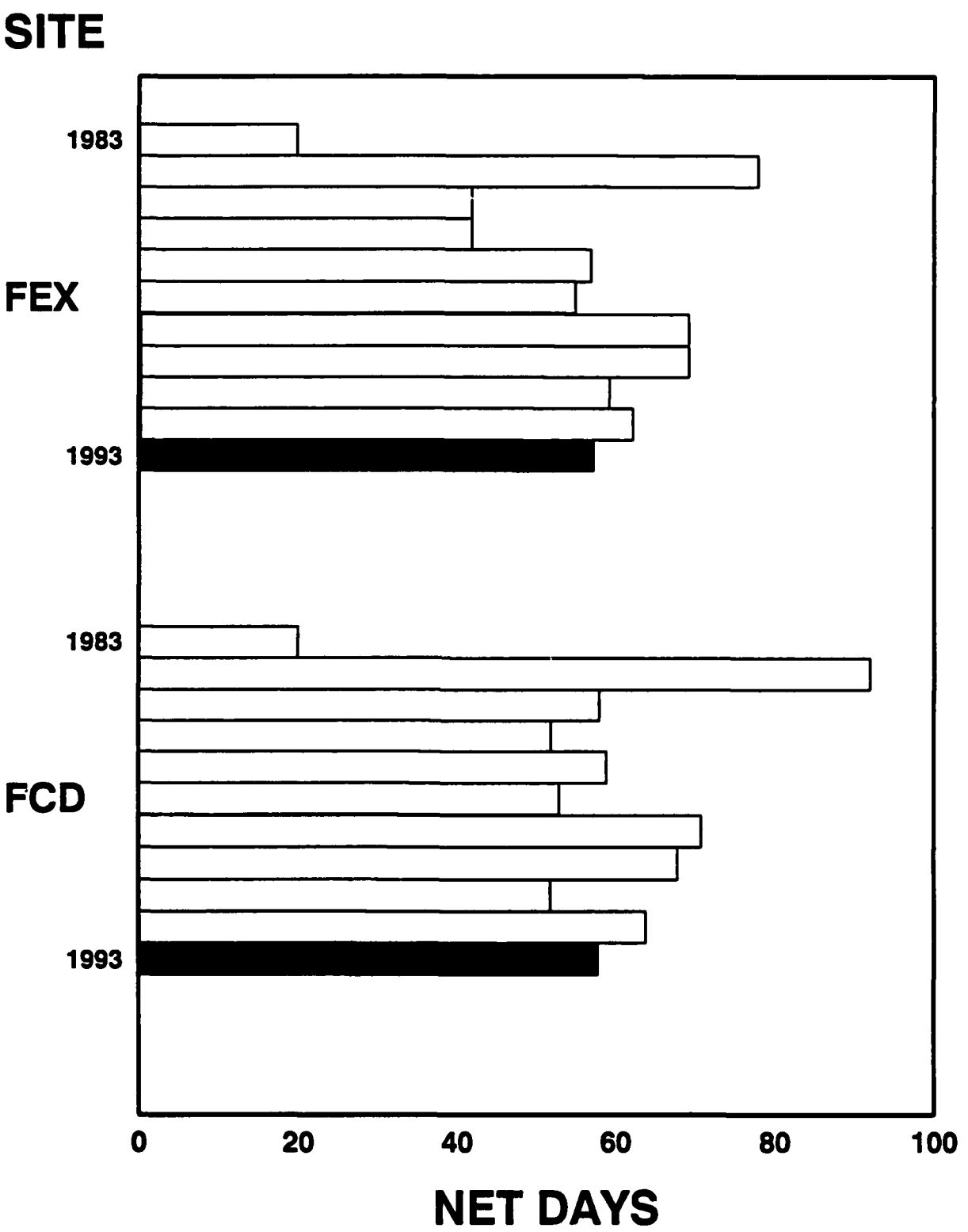

Figure 7.1. Net days at ELF study sites from 1983-1993.

B. Fish Community Mobility

Movement patterns for the most abundant species in the Ford River were monitored by observing the frequency of recapture of marked fish in our gear. Fish recaptured at a site other than the original marking site were measured for total length, weighed, and given an additional fin clip specific to the recapture site.

Results and Discussion

A. Species Composition

Fourteen species from six orders and ten families were collected at FEX in 1993 (Table 7.1). One new species, the brook stickleback (Culaea inconstans), was observed. Variation between years in the overall species composition at FEX can be attributed to changes in the catch of rare species.

The catch at FCD in 1993 consisted of thirteen species from four orders and nine families (Table 7.2). The johnny darter (Etheostoma nigrum) was the only new species recorded. Observed changes in the species composition at FCD also resulted from the capture of rare species.

In contrast to past years, species richness was slightly lower at FCD than at FEX, a difference attributable to infrequently captured species. The two sites continued to be similar in composition of the most abundant species and catches were consistent within each 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). White suckers were most abundant comprising 24.1% of the numeric catch but were below the overall mean for previous years (34.1%). Common shiners made-up 22.2% of the catch, also well below the combined mean (34.9%) for previous years. Creek chubs, 20.7%, were as numerous as in past years (20.8%) and the abundance of brook trout, 17.6%, increased from the mean of previous years (10.9%). Burbot were found in 3.2% of the catch, below the combined mean of previous years (11.1%). Creek chubs and brook trout were the only species that showed an increase in percent of the numeric catch at FEX compared to 1992. White suckers, common shiners, and burbot all decreased in abundance.

Catch by number percentages were different at FCD, where common shiners dominated the catch at 37.0%, although their abundance was below the combined mean for previous

Table 7.1. Fish species collected at FEX from May 1983 through September 1993 using 1/2" mesh fyke nets. Scientific names are from Robins et al. 1991.

Scientific Name	Common Name	FEX										
		1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Cypriniformes												
Catastomidae												
Catastomus commersoni (Lacepede)	White sucker	x	x	x	x	x	x	x	x	x	x	x
Hypentelium nigricans (Lesueur)	Northern hog sucker			x					x			
Cyprinidae												
Luxilus cornutus (Mitchill)	Common shiner	x	x	x	x	x	x	x	x	x	x	x
Margariscus margarita (Cope)	Pearl dace	x	x		x	x	x	x	x	x		x
Rhinichthys atratulus (Hermann)	Blacknose dace	x	x		x	x	x	x	x	x	x	x
Rhinichthys cataractae (Valenciennes)	Longnose dace	x	x	x	x	x	x	x	x	x	x	x
Semotilus atromaculatus (Mitchill)	Creek chub	x	x	x	x	x	x	x	x	x	x	x
Gasterosteiformes												
Gasterosteidae												
Culaea inconstans (Kirtland)	Brook stickleback											x
Gadiformes												
Gadidae												
Lota lota (Linnaeus)	Burbot	x	x	x	x	x	x	x	x	x	x	x
Perciformes												
Centrarchidae												
Ambloplites rupestris (Rafinesque)	Rock bass		x	x	x	x	x	x	x	x	x	x
Lepomis gibbosus (Linnaeus)	Pumpkinseed					x						
Micropterus dolomieu (Lacepede)	Smallmouth bass		x			x	x				x	
Micropterus salmoides (Lacepede)	Largemouth bass		x		x	x	x			x		
Cottidae												
Cottus bairdi (Girard)	Mottled sculpin	x	x	x	x	x	x	x	x	x	x	x
Percidae												
Etheostoma nigrum (Rafinesque)	Johnny darter										x	x
Percina maculata (Girard)	Blackside darter	x	x	x	x		x	x	x	x	x	

Table 7.1 continued

Scientific Name	Common Name	FEX										
		1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Petromyzontiformes												
Petromyzontidae												
Ichthymyzon fossor (Reighard and Cummins)	Northern brook lamprey			x								
Petromyzon marinus (Linnaeus)	Sea lamprey		x	x	x		x			x	x	
Salmoniformes												
Esocidae												
Esox lucius (Linnaeus)	Northern pike	x	x	x	x	x	x	x	x	x	x	
Salmonidae												
Oncorhynchus kisutch (Walbaum)	Coho salmon						x			x	x	
Oncorhynchus mykiss (Walbaum)	Rainbow trout					x				x		
Salvelinus fontinalis (Mitchill)	Brook trout	x	x	x	x	x	x	x	x	x	x	x
Umbridae												
Umbra limi (Kirtland)	Central mudminnow	x	x	x	x	x	x	x	x	x		x
Siluriformes												
Ictaluridae												
Ameirus nebulosus (Lesueur)	Brown bullhead						x	x			x	x

Table 7.2. Fish species collected at FCD from May 1983 through September 1993 using 1/2" mesh fyke nets. Scientific names are from Robins et al. 1991.

Scientific Name	Common Name	FCD										
		1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
Clupeiformes												
Clupeidae												
Alosa pseudoharengus (Wilson)	Alewife	x							x			
Cypriniformes												
Catostomidae												
Catostomus commersoni (Lacepede)	White sucker	x	x	x	x	x	x	x	x	x	x	x
Hypentelium nigricans (Lesueur)	Northern hog sucker			x				x	x		x	
Cyprinidae												
Cyprinus carpio (Linnaeus)	Carp							x	x	x	x	
Luxilus cornutus (Mitchill)	Common shiner	x	x	x	x	x	x	x	x	x	x	x
Margariscus margarita (Cope)	Pearl dace	x	x	x	x	x	x	x	x	x		
Nocomis biguttatus (Kirtland)	Hornyhead chub							x	x			
Notemigonus crysoleucas (Mitchill)	Golden shiner						x		x			
Phoxinus eos (Cope)	Northern redbelly dace	x								x		
Pimephales promelas (Rafinesque)	Fathead minnow				x							
Rhinichthys atratulus (Hermann)	Blacknose dace		x	x	x	x	x	x	x	x	x	x
Rhinichthys cataractae (Valenciennes)	Longnose dace	x	x	x	x	x	x	x	x	x	x	x
Semotilus atromaculatus (Mitchill)	Creek chub	x	x	x	x	x	x	x	x	x	x	x
Gadiformes												
Gadidae												
Lota lota (Linnaeus)	Burbot	x	x	x	x	x	x	x	x	x	x	x
Perciformes												
Centrarchidae												
Ambloplites rupestris (Rafinesque)	Rock bass	x	x	x	x	x	x	x	x	x	x	x
Lepomis gibbosus (Linnaeus)	Pumpkinseed		x	x						x		
Lepomis macrochirus (Rafinesque)	Bluegill						x	x				
Micropterus dolomieu (Lacepede)	Smallmouth bass		x			x	x					
Micropterus salmoides (Lacepede)	Largemouth bass		x		x	x	x	x	x	x	x	
Cottidae												
Cottus bairdi (Girard)	Mottled sculpin	x	x	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	1990	1991	1992	1993
Percidae												
Etheostoma nigrum (Rafinesque)	Johnny darter											x
Percina maculata (Girard)	Blackside darter	x	x	x	x		x	x	x	x	x	x
Petromyzontiformes												
Petromyzontidae												
Petromyzon marinus (Linnaeus)	Sea lamprey	x	x	x	x		x	x		x	x	
Salmoniformes												
Esocidae												
Esox lucius (Linnaeus)	Northern pike	x	x	x	x	x	x	x	x	x		x
Salmonidae												
Oncorhynchus kisutch (Walbaum)	Coho salmon						x				x	
Oncorhynchus mykiss (Walbaum)	Rainbow trout						x			x		
Salvelinus fontinalis (Mitchill)	Brook trout	x	x	x	x	x	x	x	x	x	x	x
Umbridae												
Umbra limi (Kirtland)	Central mudminnow		x	x	x	x	x	x	x	x	x	x
Siluriformes												
Ictaluridae												
Ameiurus nebulosus (Lesueur)	Brown bullhead			x			x	x	x		x	

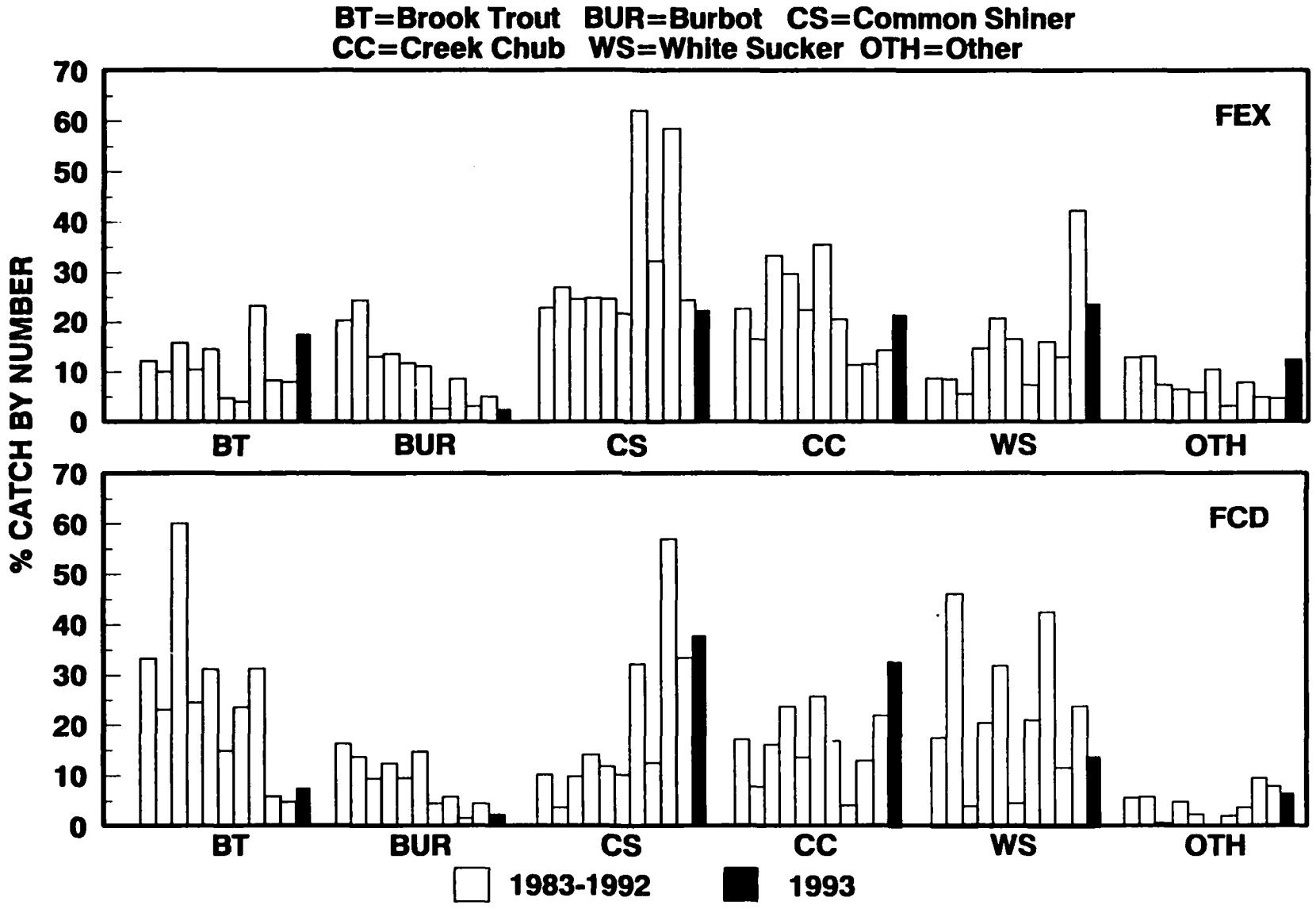

Figure 7.2. Percent catch by number at FEX and FCD from 1983 through 1993.

years (43.9%). Creek chubs were represented in 32.0% of the catch, above the past mean (23.0%). White suckers, 15.7%, were slightly above the mean of previous years (13.1%) and brook trout, 7.1%, were almost as abundant as in the past (7.6%). Burbot, 1.7%, were below the mean of previous years (5.2%). Common shiners, creek chubs, and brook trout all displayed an increase in abundance relative to 1992. As at FEX, white suckers and burbot both decreased in percent of catch at FCD.

To analyze the total catch by numbers by year, the data for each species were weighted by the number of net days per site per year. There were no significant differences in the distribution of numeric catch among species (adjusted for the number of net days) between FEX and FCD (Chi-square, $p<0.05$; 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, 1986, 1989, and 1991 (Table 7.4). The numeric catch in 1983, 1984, 1985, 1987, 1988, 1990, 1992 and 1993 were not correlated. To examine the correlation results for all 11 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 ($X^2=47.34$, df=22, $p<0.05$).

Furthermore, a BACI one-way ANOVA of the log transformed abundance data was used to test for differences among periods for each species (Table 7.5). There was no evidence of any difference in numeric catch among the three periods for any of the 5 most abundant species. Overall, there were no significant between site differences or among period differences in catch by number over all years of the study despite species showing variable abundance from year to year.

Although the weighing scales were field calibrated, they appear to have been in error in 1993. Consequently, the computation and analysis of percent catch by biomass in 1993 should be regarded with caution though we still present it for inspection. Percent catch by biomass differed from percent catch by number in 1993, more so than in 1992. White suckers were greatest at 38.1%, above the combined mean of previous years (27.0%). Brook trout, 30.2%, were also above the previous mean (28.1%). However, common shiners (10.7%), creek chubs (14.0%), and burbot (3.6%) were all below the respective means for past years (15.6%, 18.0%, and 12.4%)

Biomass caught at FCD in 1993 was partitioned similarly to that at FEX (Figure 7.3). White suckers made up 32.4% of the catch by biomass, above the mean for previous years

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 1993.

YEAR	X^2 VALUE	YEAR	X^2 VALUE	YEAR	X^2 VALUE
1983	3.98	1986	1.44	1989	1.18
1984	4.30	1987	5.96	1990	4.06
1985	1.30	1988	6.04	1991	0.69
				1992	2.19
				1993	2.50

$X^2_{5,0.05}=11.1$ 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 1993.

YEAR	CORRELATION COEFFICIENT	PROBABILITY[1]
1983	0.543	0.532
1984	0.200	0.950
1985	0.886*	0.038
1986	0.886*	0.038
1987	0.828	0.082
1988	0.828	0.082
1989	0.943*	0.010
1990	0.486	0.658
1991	0.886*	0.038
1992	0.771	0.144
1993	0.829	0.100

* INDICATES SIGNIFICANT CORRELATION EXISTS

[1] Used in Sokal and Rohlf (1969) X^2 test to examine correlation results over the 8-year period, where:

X^2_{calc} = -2Sum(ln P) = 47.34; df=2*(number of tests)=22
$X^2_{22,0.05}$ = 30.8, (1-sided alternative), and P = the probability associated with the correlation coefficient.

Table 7.5. BACI one-way ANOVA on log transformed abundance data to test for differences among periods for each species.

SPECIES	$F_{2,8}$	Probability
Burbot	2.21	0.172
Brook Trout	1.11	0.374
Creek Chub	2.25	0.168
Common Shiner	1.42	0.297
White Sucker	0.89	0.447

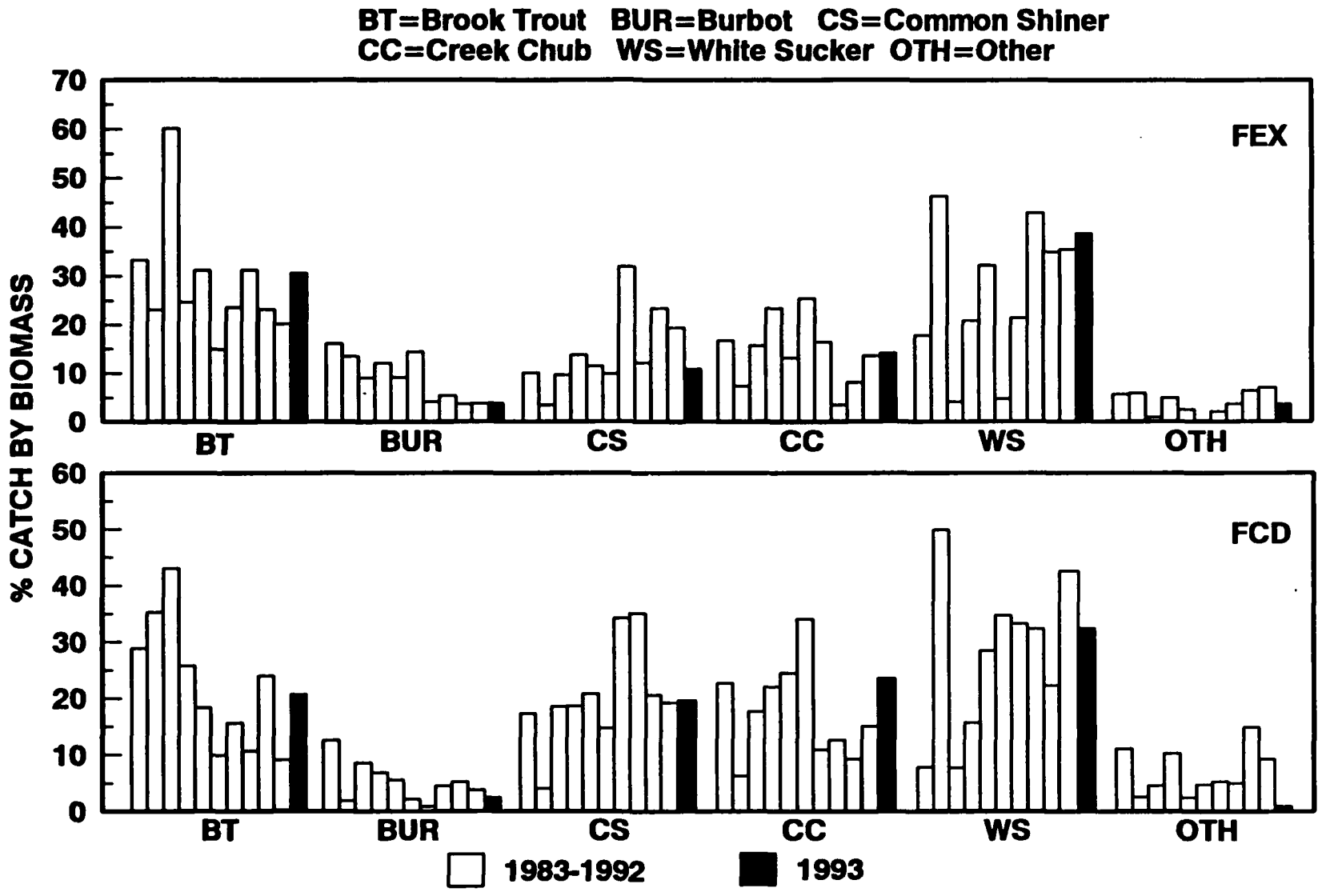

Figure 7.3. Percent catch by biomass at FEX and FCD from 1983 through 1993.

(27.1%). Brook trout, 21.2%, and common shiners, 19.7%, were slightly below the respective means of previous years (22.2% and 20.8%). Creek chubs were above the mean (23.0%, mean: 16.5%). Burbot biomass (2.3%) was below the overall mean of past years (5.5%).

To analyze the species biomass data, biomass estimates were adjusted for the number of net days. 1993 will not be included in the analysis at this time as a result of biased biomass data. FEX and FCD displayed similar patterns for the distribution of catch by biomass among species (adjusted for the number of net days) in 5 of the 10 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 10-year period of the study FEX and FCD had similar catch-by-biomass patterns ($X^2=55.93$, $df=20$, $p>0.05$). Additionally, a BACI one-way ANOVA was used to test for differences in log transformed biomass data among periods for each species. Only one species, burbot, showed a significant period effect (Table 7.7). Overall, there were no consistent significant between site differences or among period differences in catch by biomass over all years of the study despite species showing variable biomass from year to year.

Shannon-Weaver diversity values for 1993 remained low at both FEX and FCD relative to previous years (Table 7.8). Values increased from 1992 at FEX but decreased at FCD; in 1992, diversity values were the lowest recorded during the study. A Spearman Rank Correlation test ($r_s=0.87$, $p<0.05$) indicated a similar pattern in the Shannon-Weaver index for FCD and FEX from 1983-1993. A BACI one-way ANOVA of the log transformed index data was used to test for differences among periods. No difference was detected among periods ($F_{2,8}=0.44$, $P>0.05$).

Diversity values have decreased in a fairly linear fashion over the course of the study according to the following relationships:

FEX: Index = 12.15 - 0.119 (Year) $r^2 = 0.81$
FCD: Index = 10.27 - 0.098 (Year) $r^2 = 0.78$

The rate of decrease (slope) of diversity at FEX and FCD was not significantly different (ANCOVA, $F_{1,18}=0.71$, $p>0.05$). In addition, the intercepts were found to be similar (ANCOVA, $F_{1,19}=0.18$, $p>0.05$). 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

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 1992.

YEAR	CORRELATION COEFFICIENT	PROBABILITY[1]
1983	0.600	0.416
1984	0.786	0.128
1985	0.886*	0.038
1986	0.657	0.312
1987	0.829	0.082
1988	0.671	0.288
1989	0.943*	0.010
1990	0.600	0.416
1991	0.771	0.144
1992	0.829	0.082

* INDICATES SIGNIFICANT CORRELATION EXISTS
[1]Sokal and Rohlf X^2 test: $X^2_{calc.} = 42.07$, $X^2_{20,0.05} = 28.4$ Significant. See Table 7.4 for further detail.

Table 7.7. BACI one-way ANOVA of log transformed data to test pre-operational vs. transitional vs. fully-operational catch by biomass data.

SPECIES	$F_{2,7}$	Probability[1]
Burbot	4.62*	0.053
Brook Trout	0.01	0.994
Creek Chub	0.54	0.605
Common Shiner	1.67	0.255
White sucker	0.27	0.768
Other	0.83	0.475

* Significant
[1]Sokal and Rohlf X^2 test: $X^2_{calc.} = 11.66$, $X^2_{12,0.05} = 18.5$. Not significant

Table 7.8. Mean daily Shannon-Weaver diversity index values for FEX and FCD from 1983 through 1993.

YEAR	FEX	FCD
1983	2.16 ± 0.26	1.94 ± 0.36
1984	2.20 ± 0.56	2.03 ± 0.33
1985	1.97 ± 0.39	2.15 ± 0.33
1986	1.62 ± 0.48	1.87 ± 0.31
1987	2.13 ± 0.18	2.11 ± 0.45
1988	1.62 ± 0.34	1.54 ± 0.27
1989	1.41 ± 0.36	1.47 ± 0.43
1990	1.42 ± 0.58	1.32 ± 0.27
1991	1.47 ± 0.32	1.56 ± 0.33
1992	0.87 ± 0.57	1.32 ± 0.31
1993	1.12 ± 0.52	1.06 ± 0.45

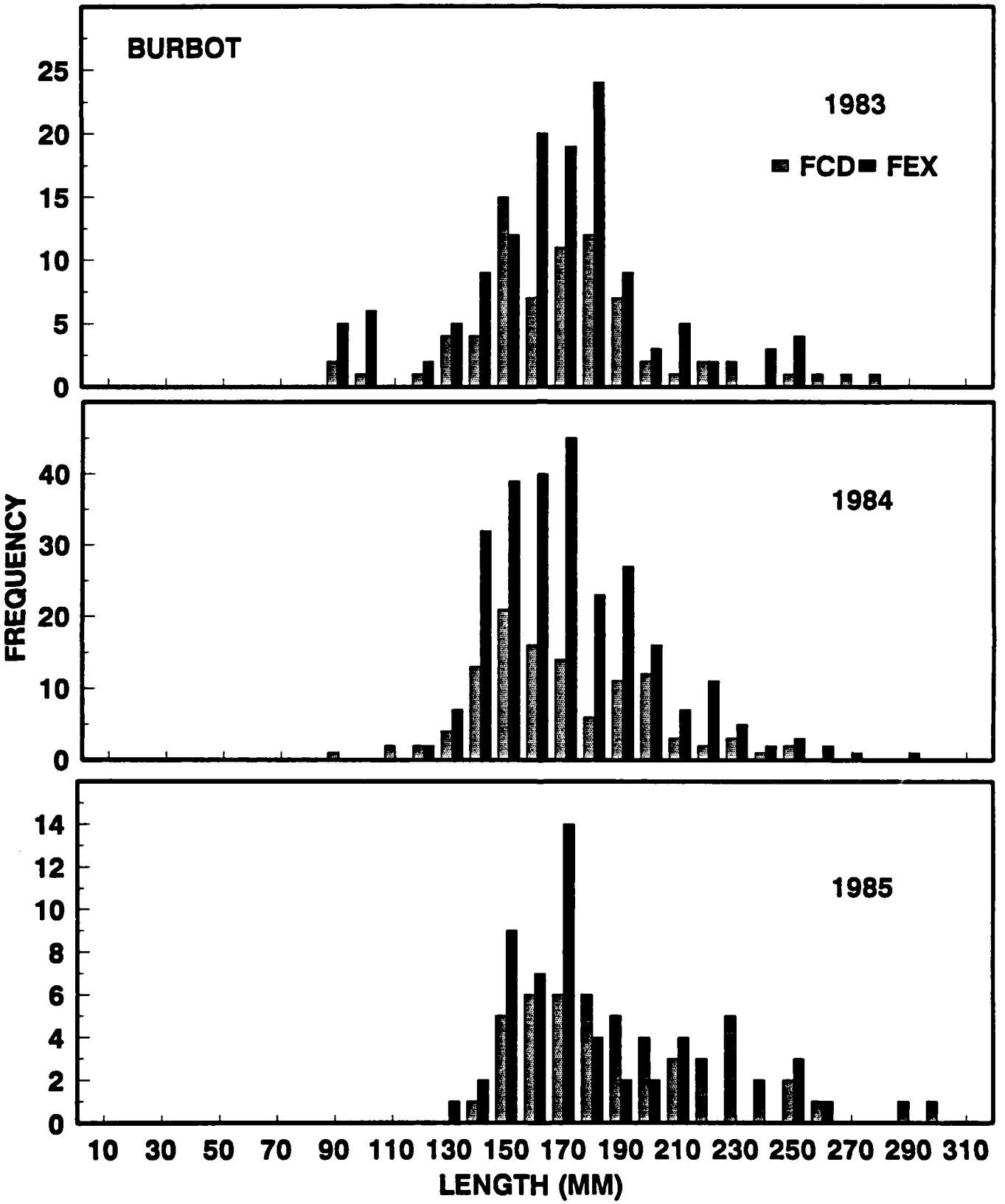

Figure 7.4a. Length frequency distribution of annual catch of burbot at FCD and FEX from 1983 to 1985.

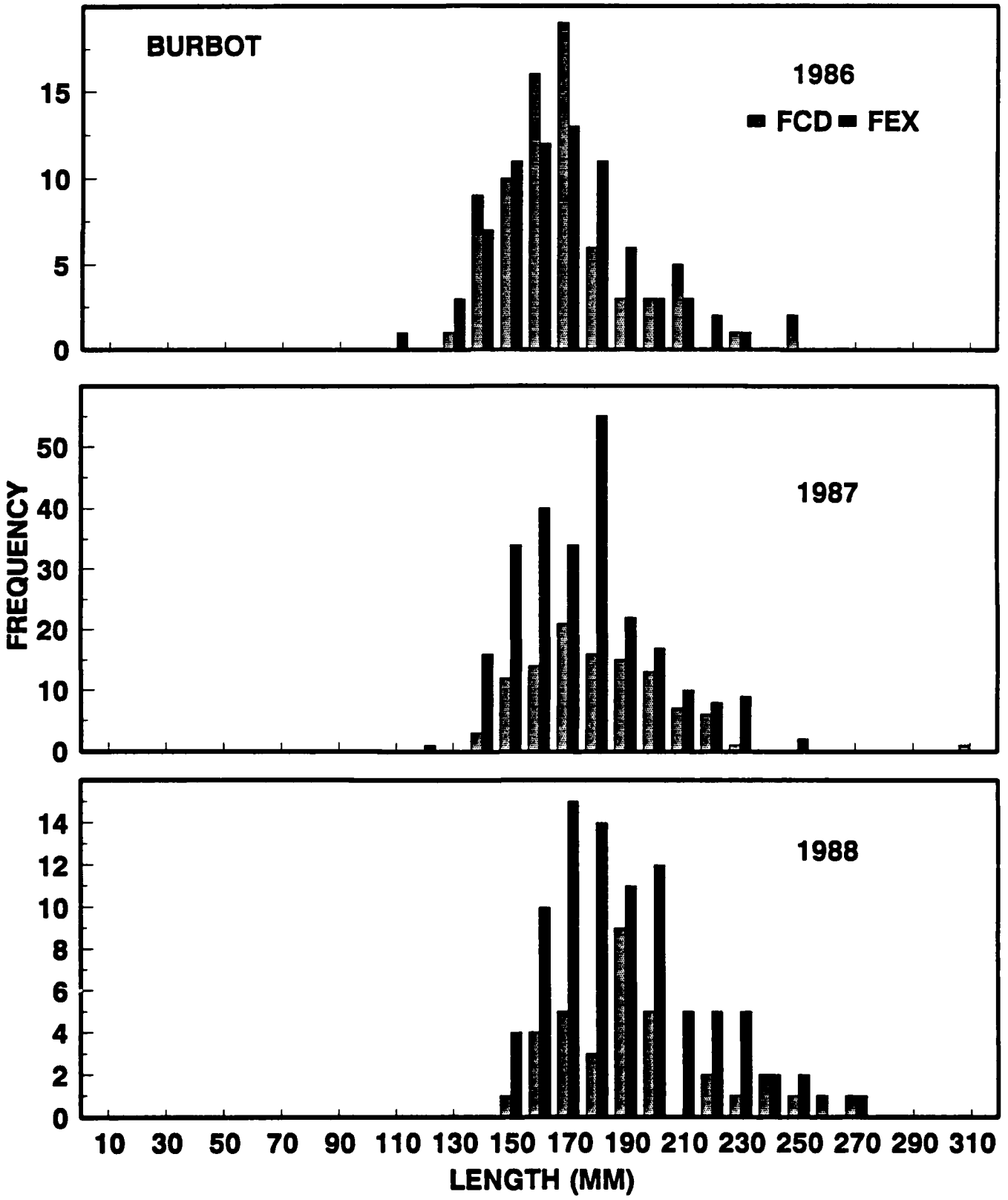

Figure 7.4b. Length frequency distribution of annual catch of burbot at FCD and FEX from 1986 to 1988.

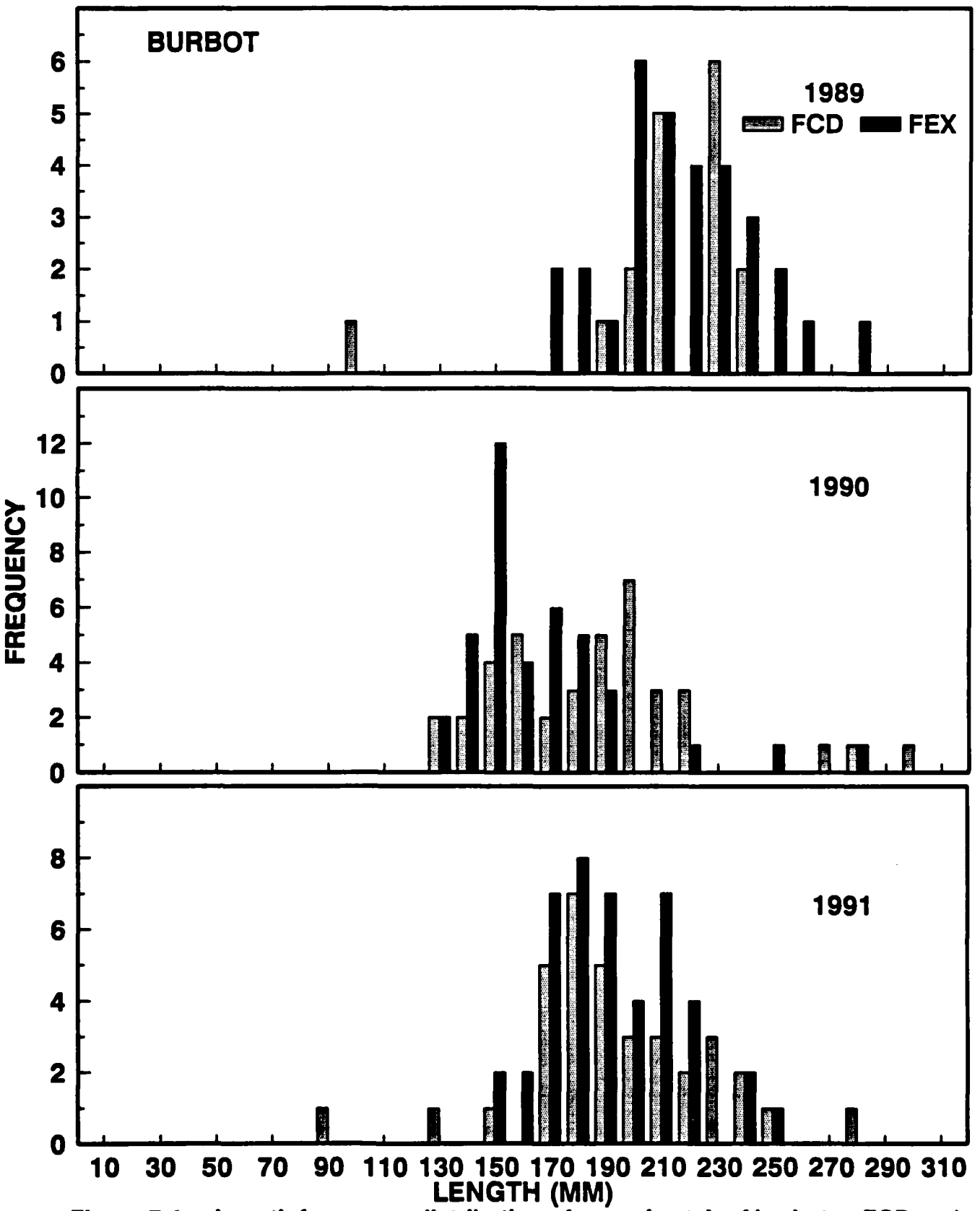

Figure 7.4c. Length frequency distribution of annual catch of burbot at FCD and FEX from 1989 to 1991.

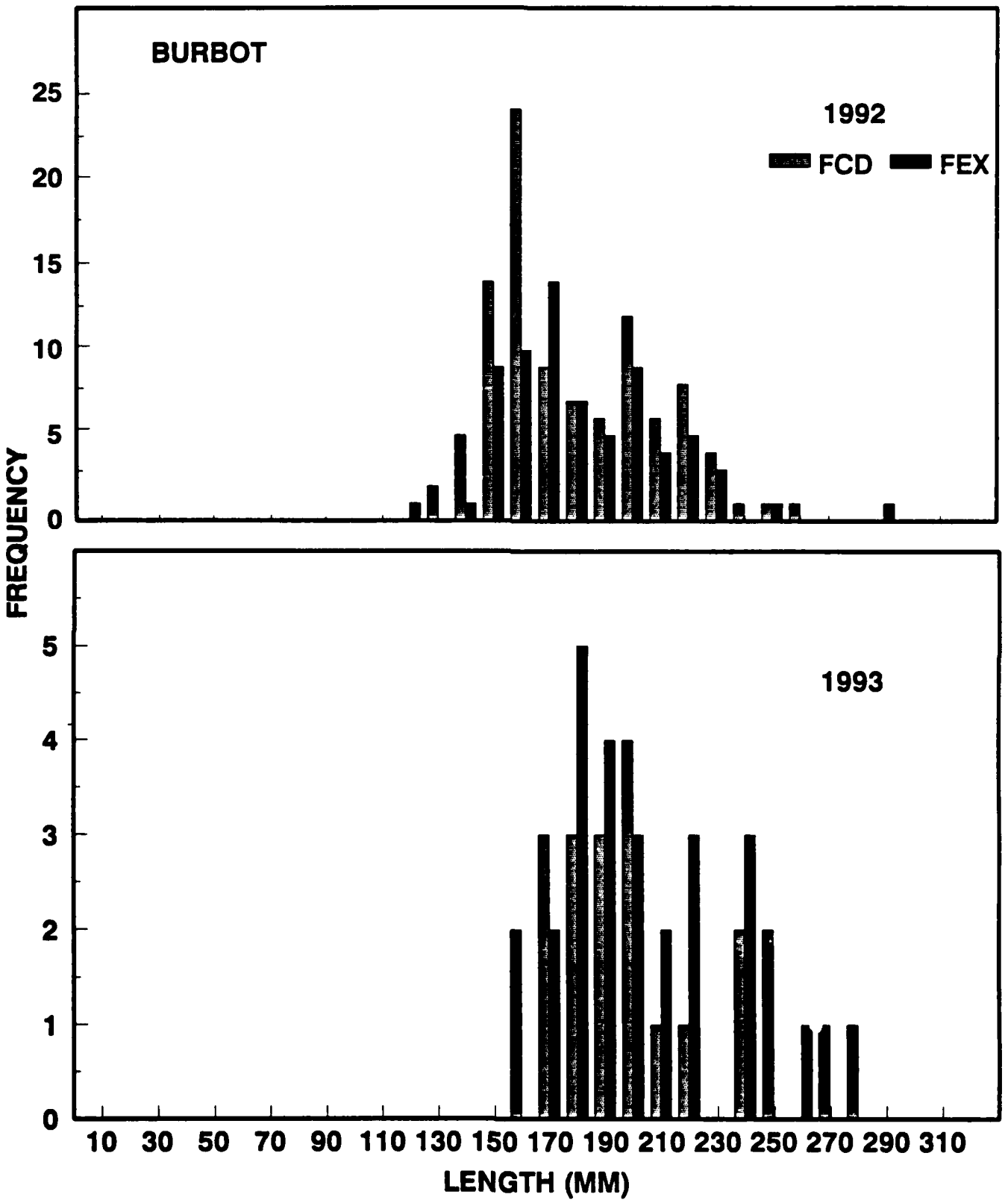

Figure 7.4d. Length frequency distribution of annual catch of burbot at FCD and FEX from 1992 and 1993.

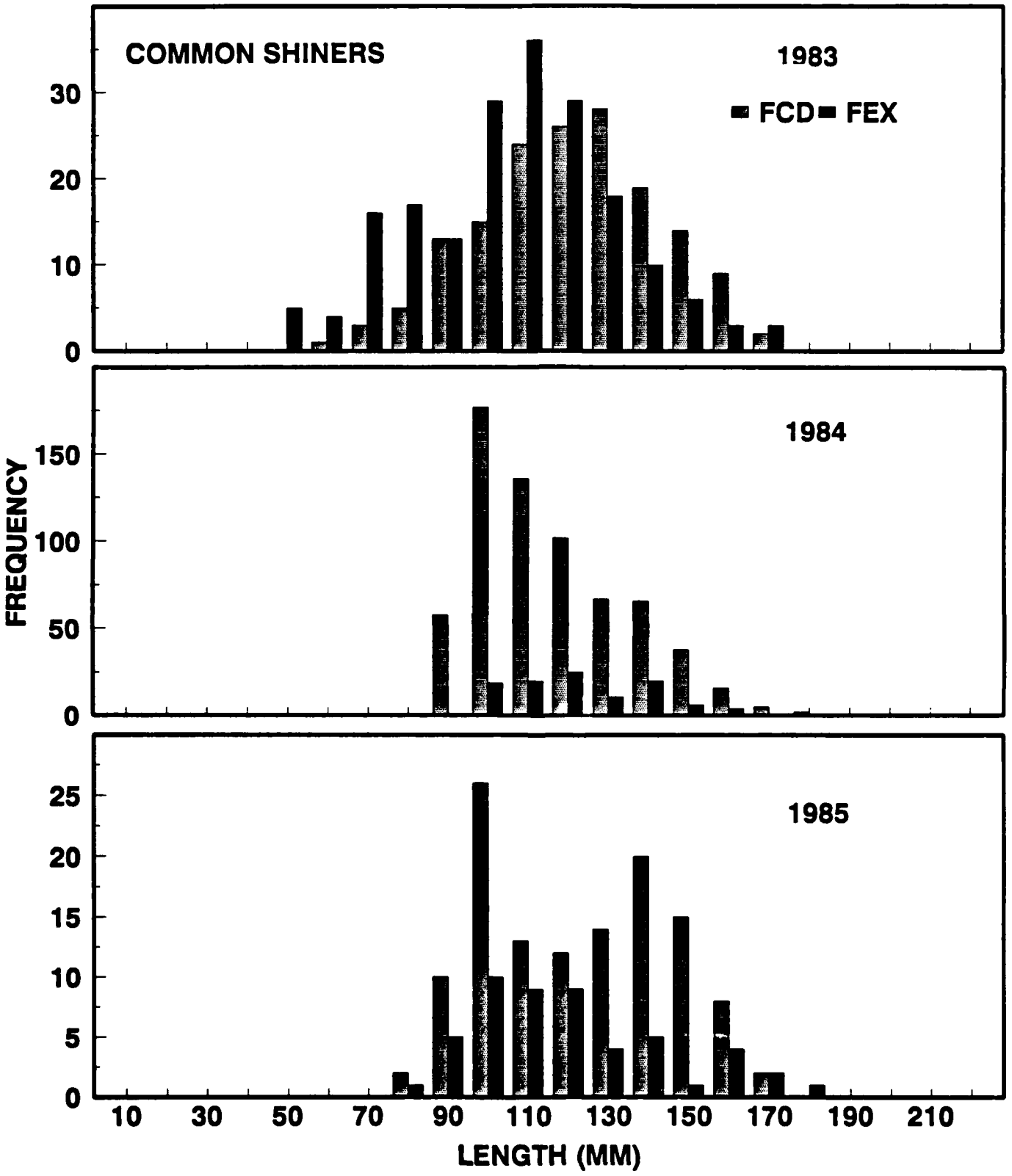

Figure 7.4e. Length frequency distribution of annual catch of common shiners at FCD and FEX from 1983 to 1985.

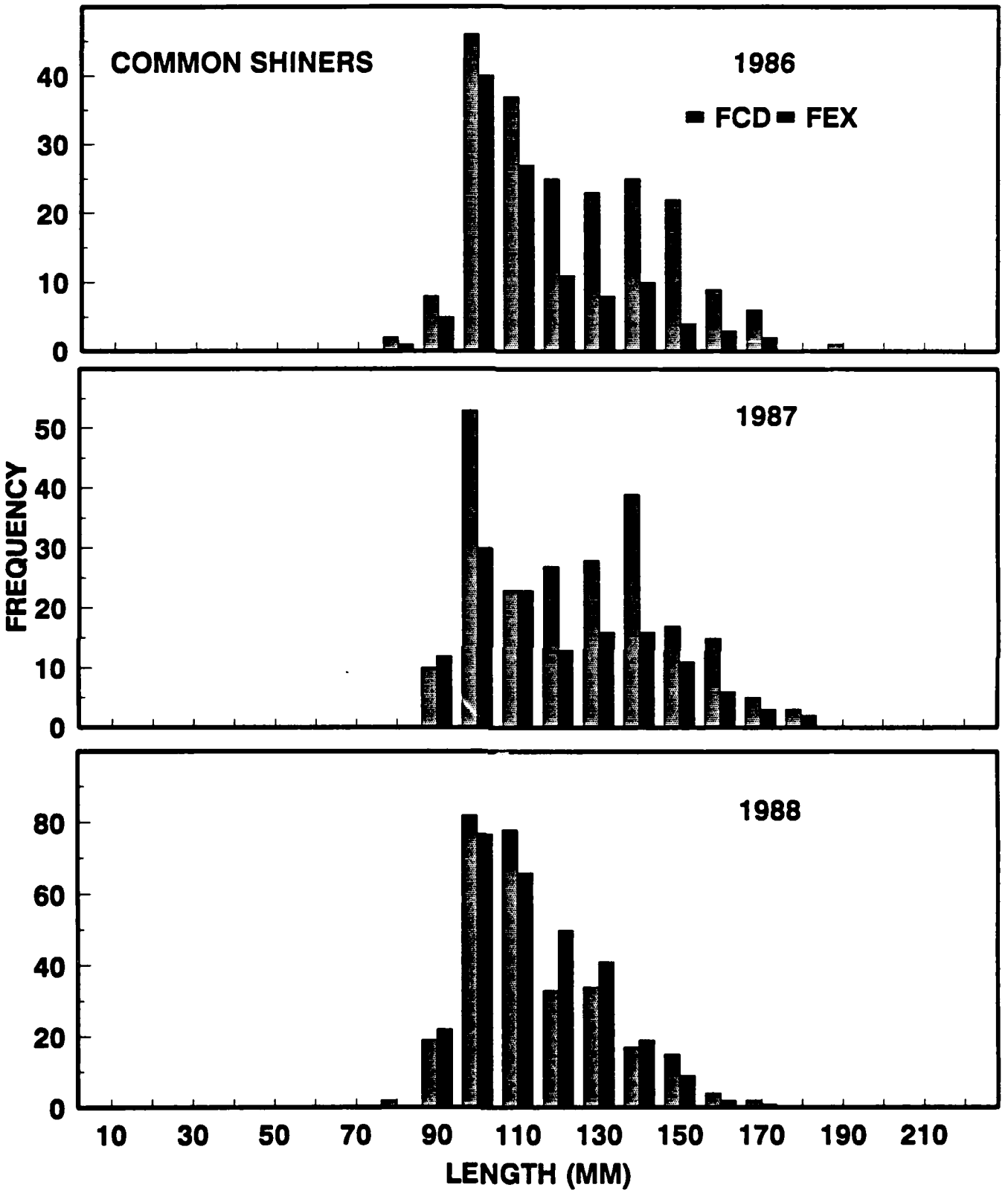

Figure 7.4f. Length frequency distribution of annual catch of common shiners at FCD and FEX from 1986 to 1988.

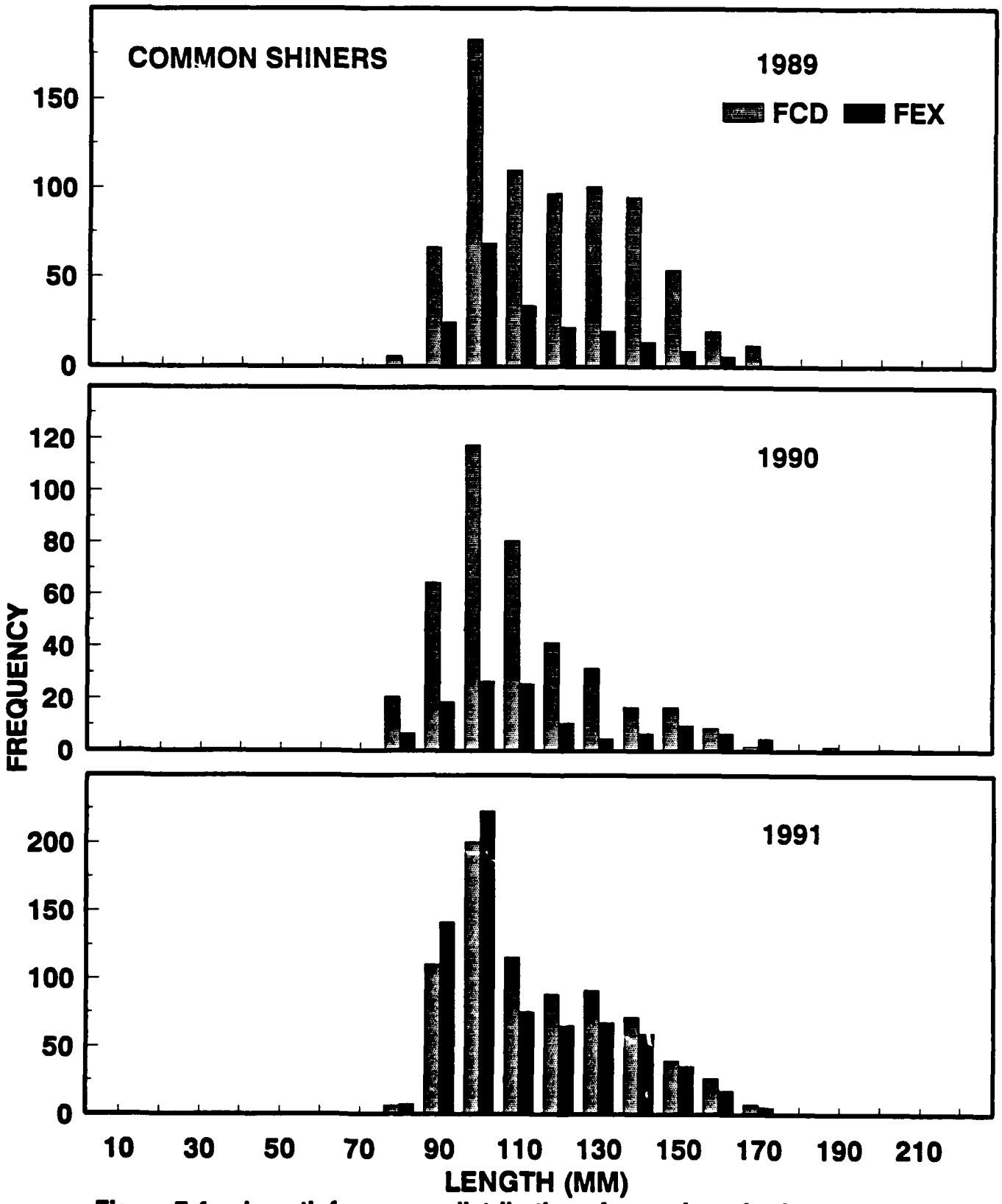

Figure 7.4g. Length frequency distribution of annual catch of common shiners at FCD and FEX from 1989 to 1991.

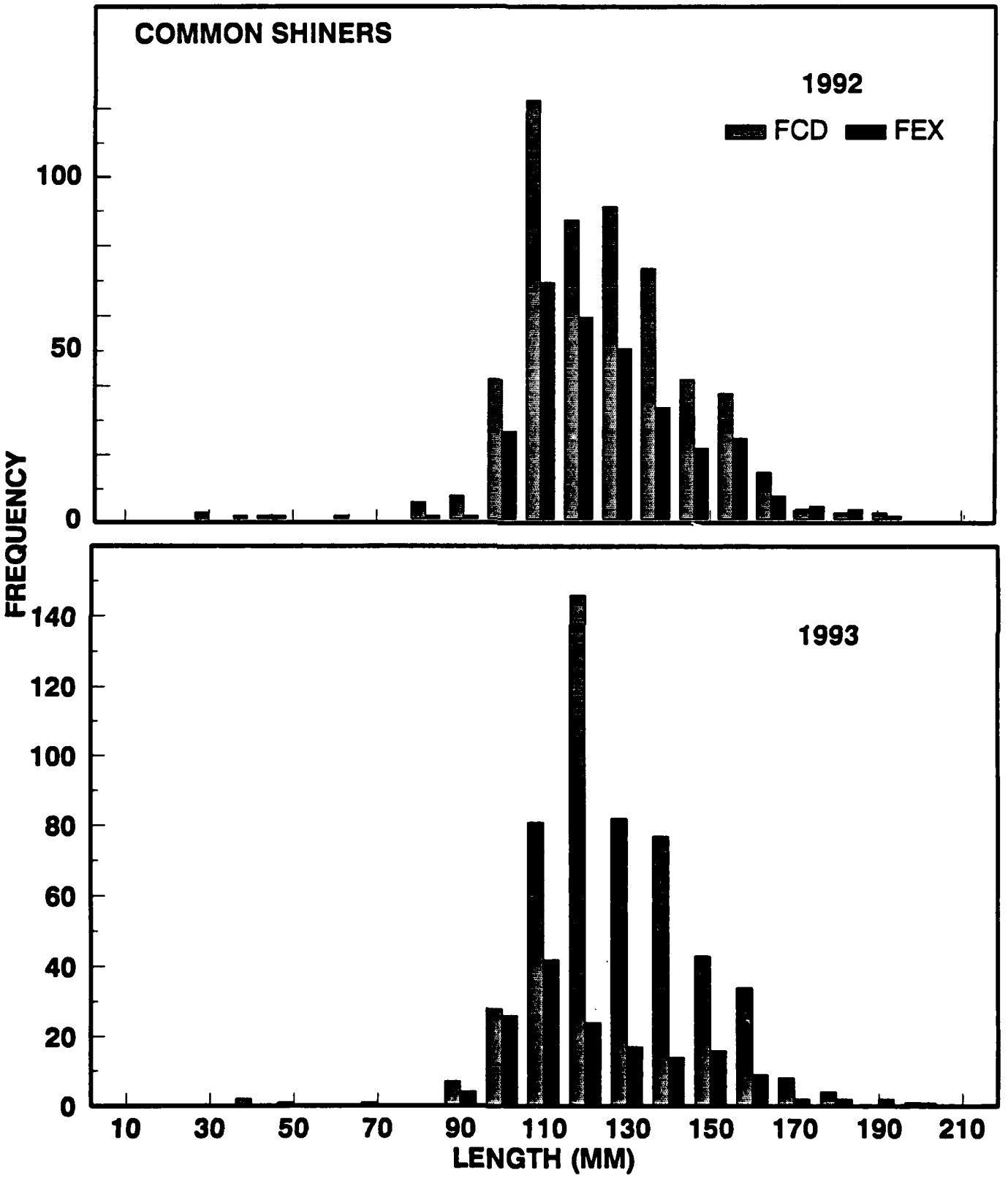

Figure 7.4h. Length frequency distribution of annual catch of common shiners at FCD and FEX from 1992 and 1993.

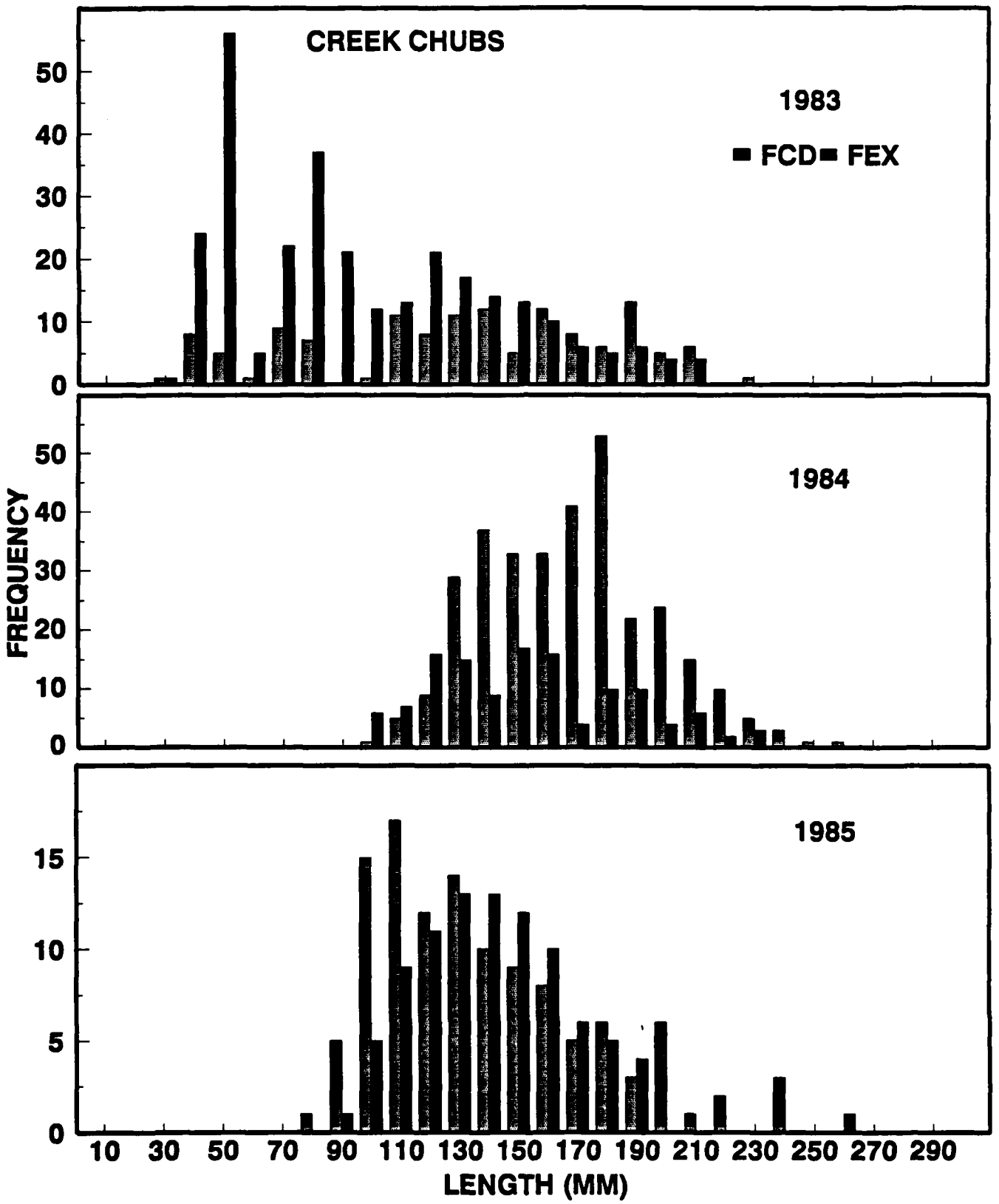

Figure 7.4l. Length frequency distribution of annual catch of creek chubs at FCD and FEX from 1983 to 1985.

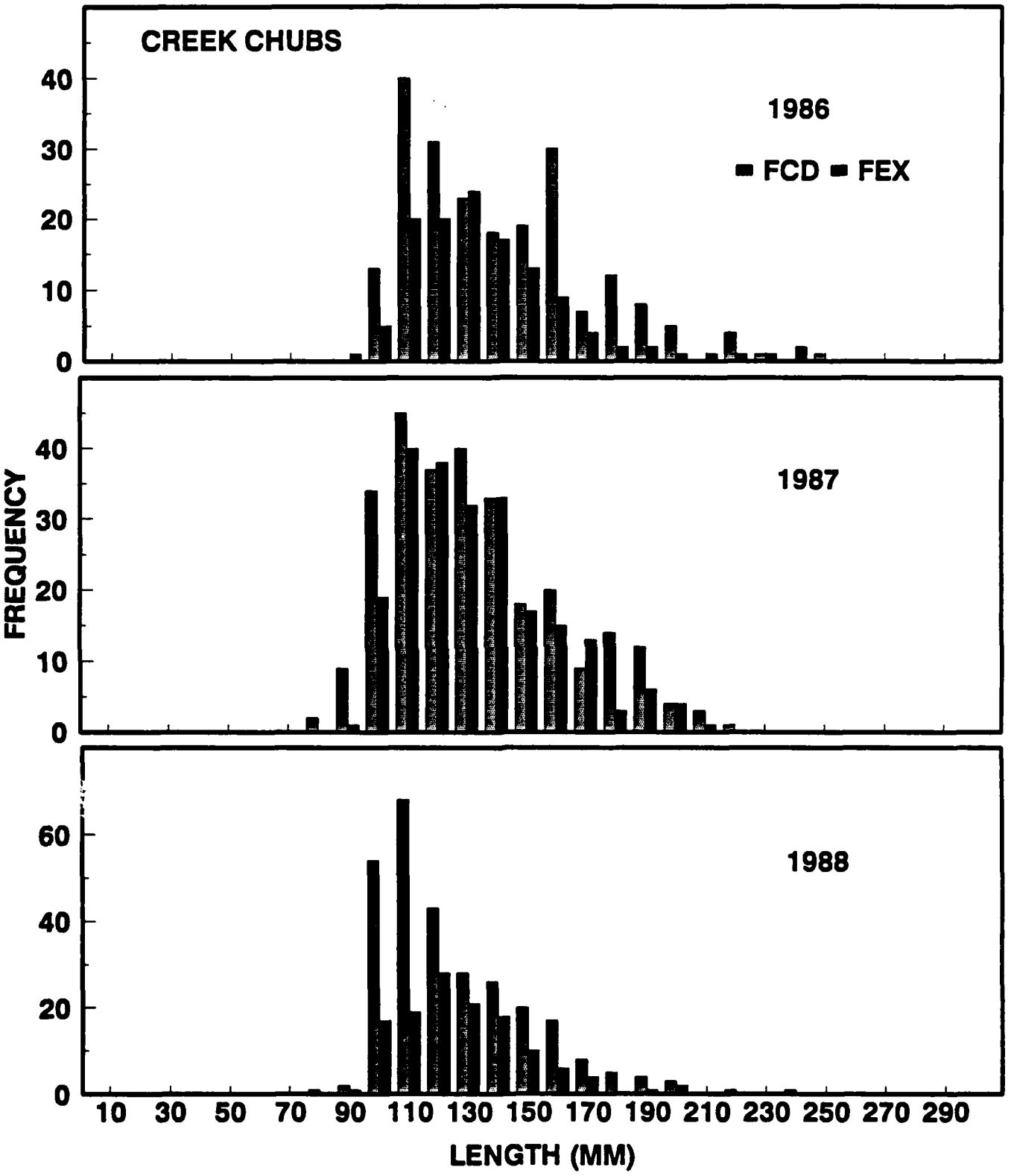

Figure 7.4j. Length frequency distribution of annual catch of creek chubs at FCD and FEX from 1986 to 1988

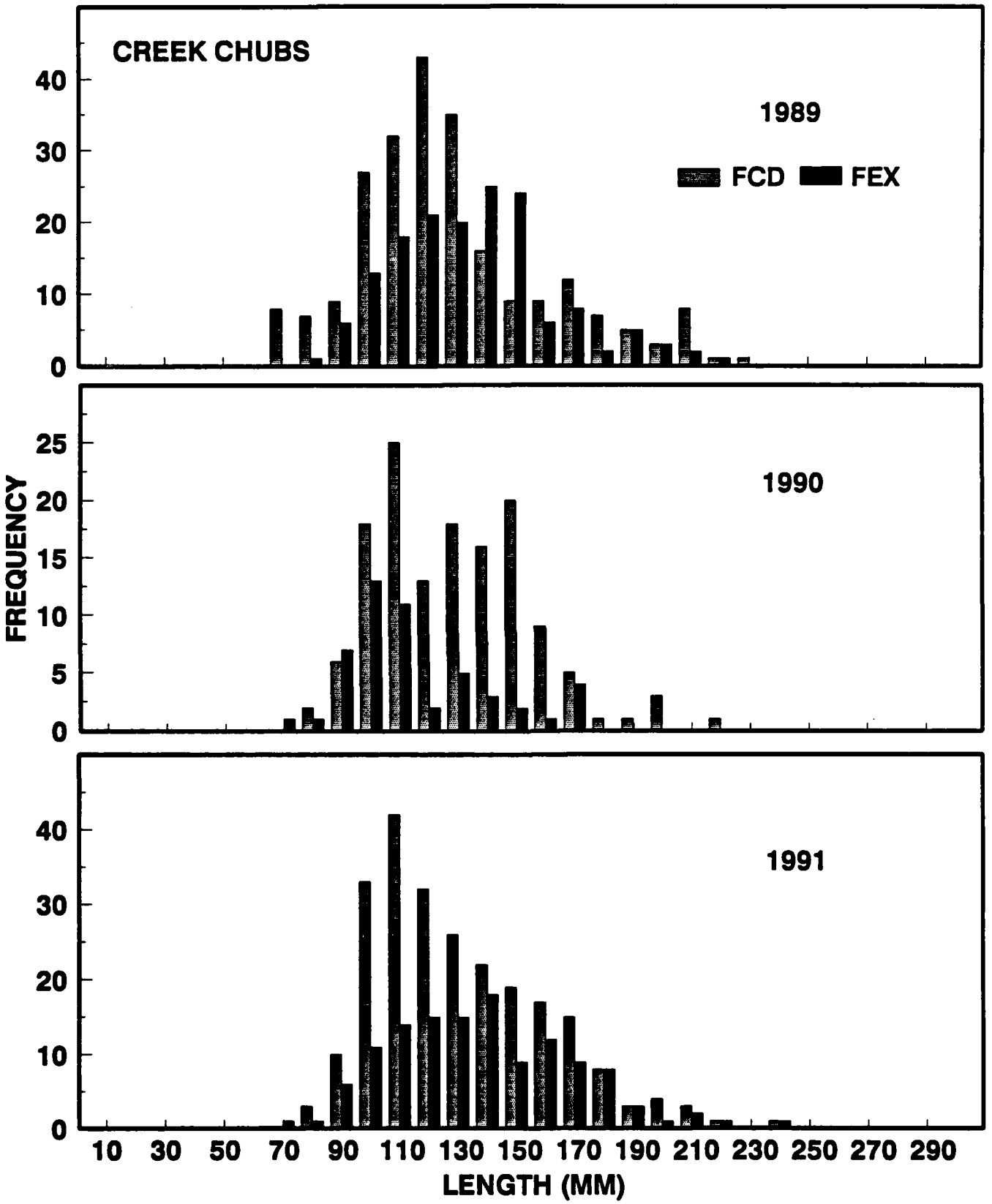

Figure 7.4k. Length frequency distribution of annual catch of creek chubs at FCD and FEX from 1989 to 1991.

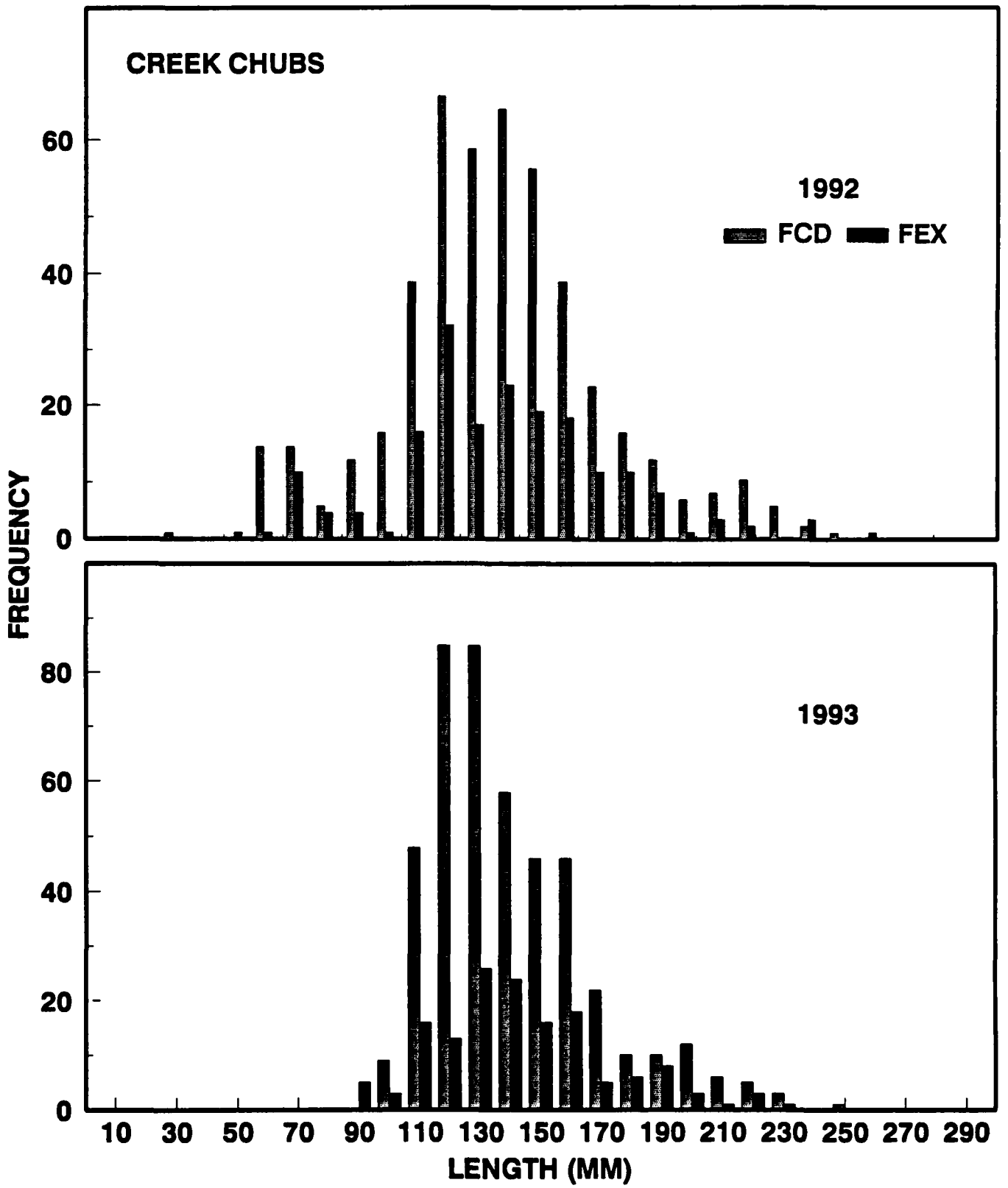

Figure 7.4l. Length frequency distribution of annual catch of creek chubs at FCD and FEX from 1992 and 1993.

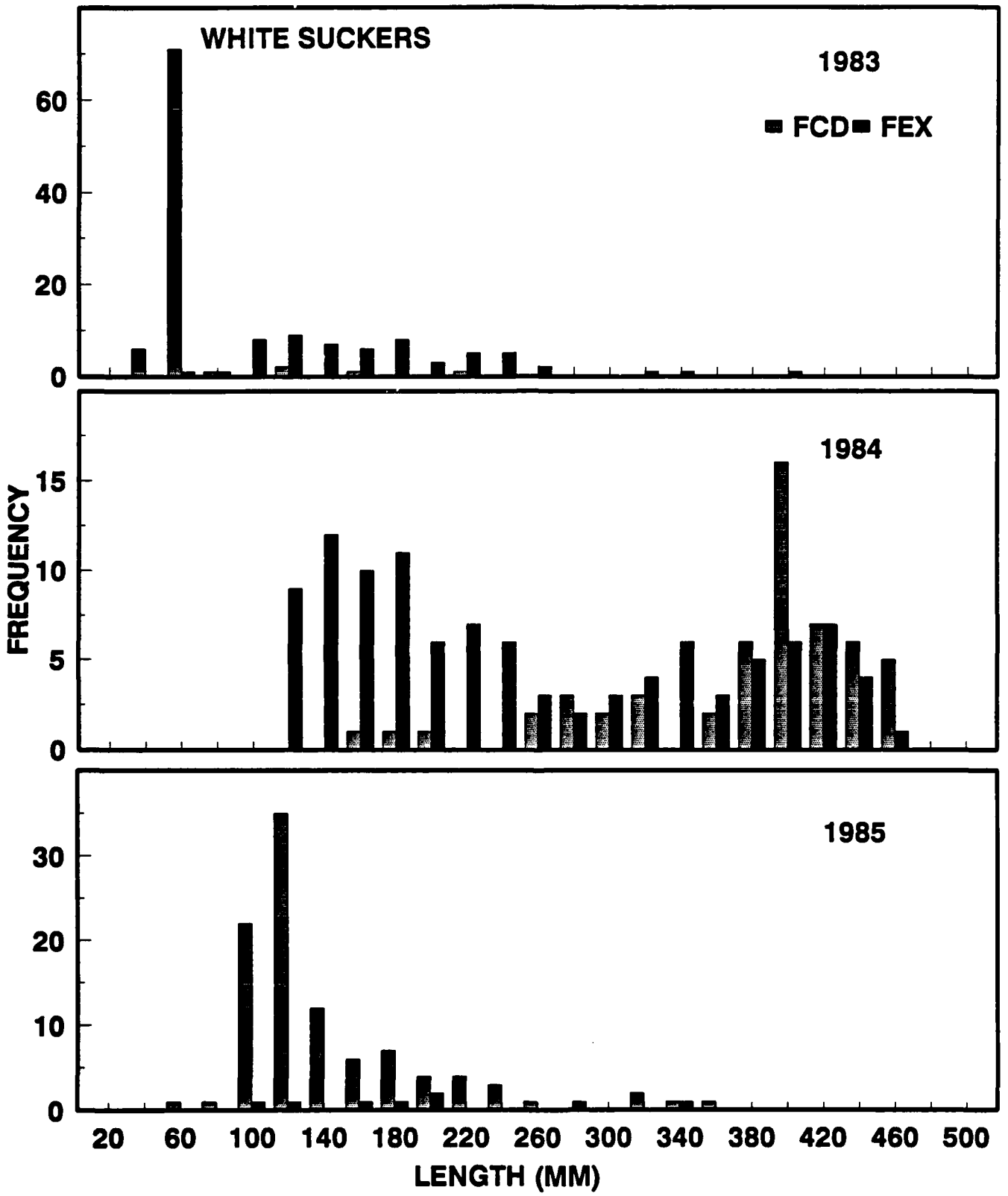

Figure 7.4m. Length frequency distribution of annual catch of white suckers at FCD and FEX from 1983 to 1985.

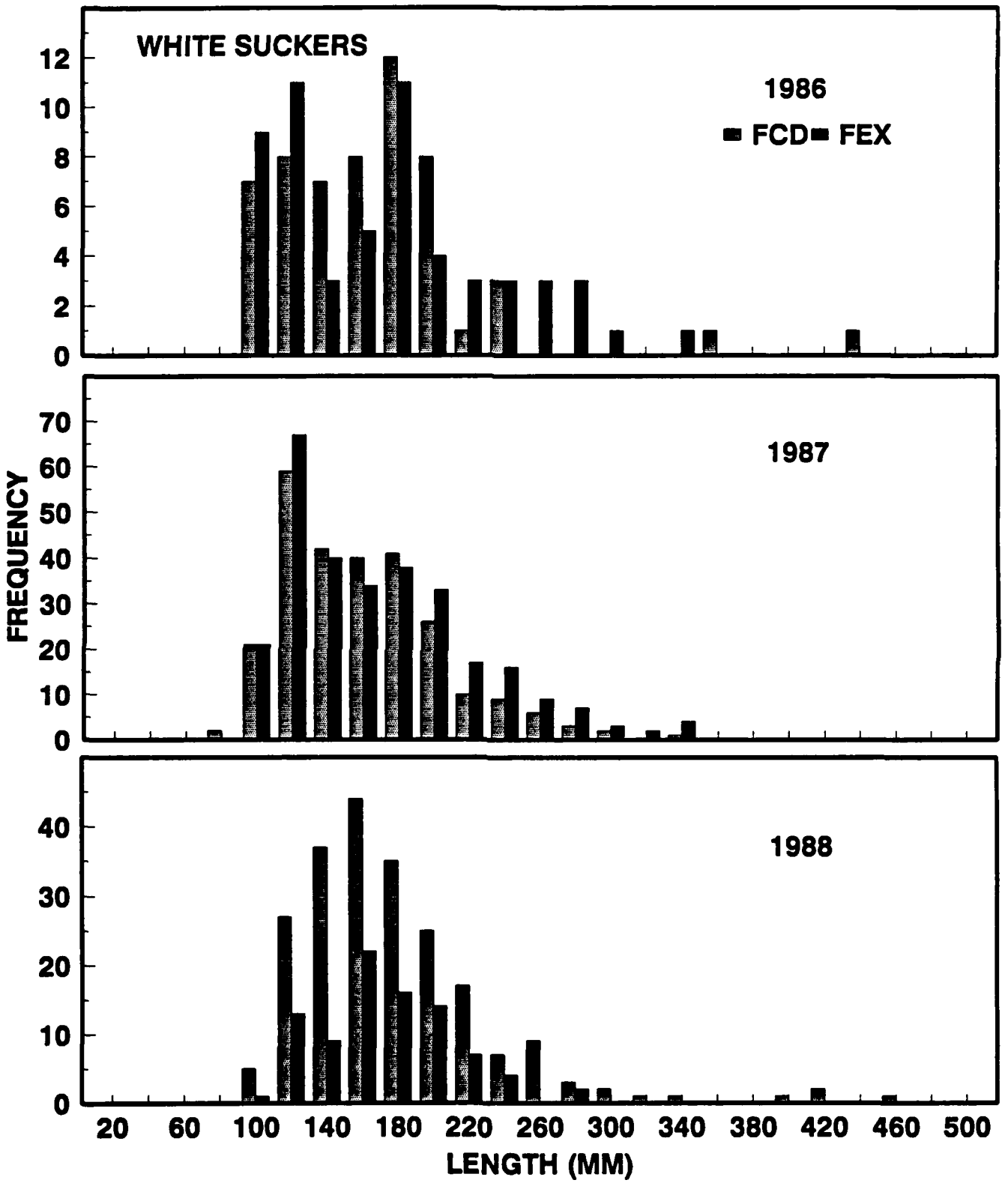

Figure 7.4n. Length frequency distribution of annual catch of white suckers at FCD and FEX from 1986 to 1988.

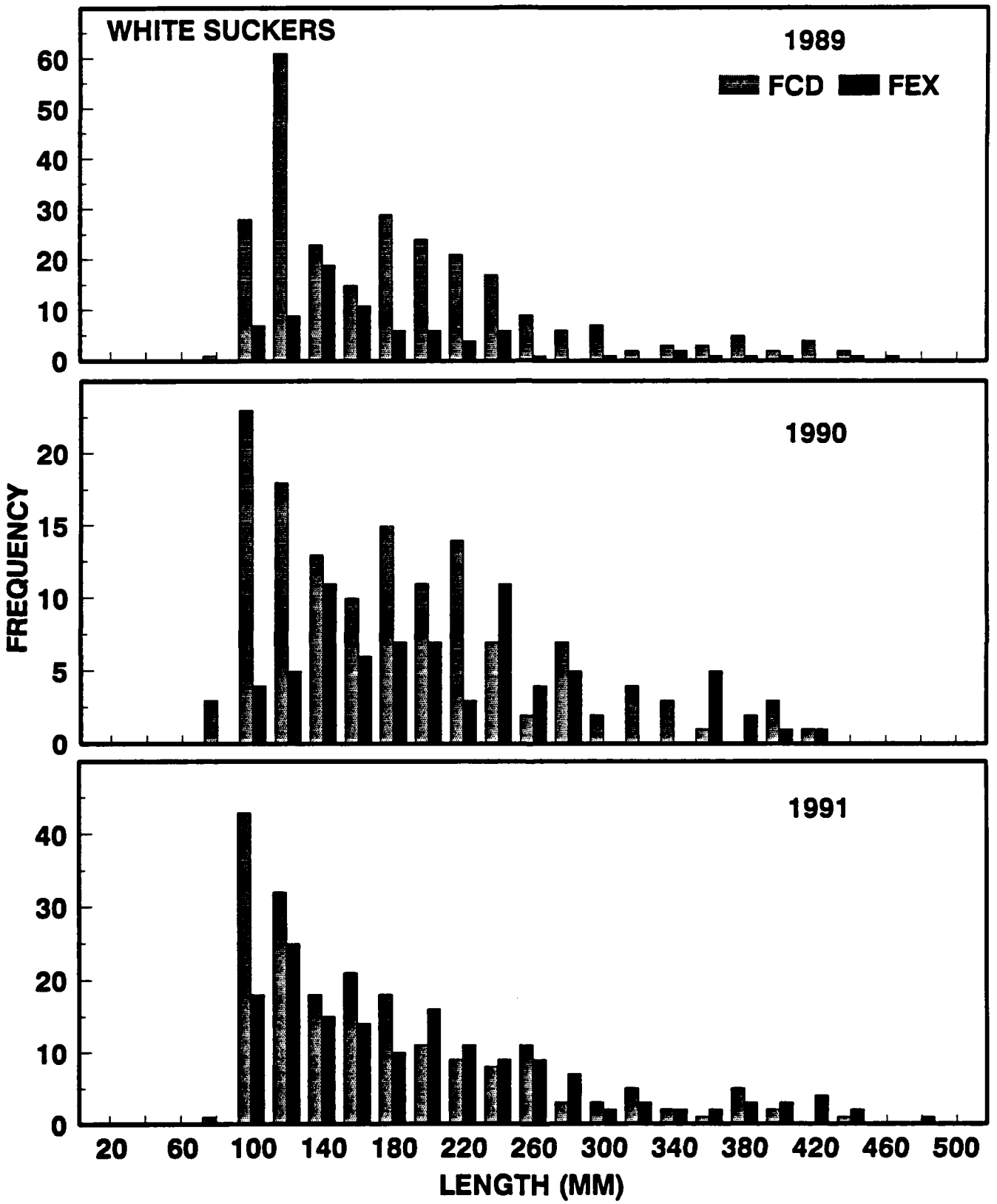

Figure 7.4o. Length frequency distribution of annual catch of white suckers at FCD and FEX from 1989 to 1991.

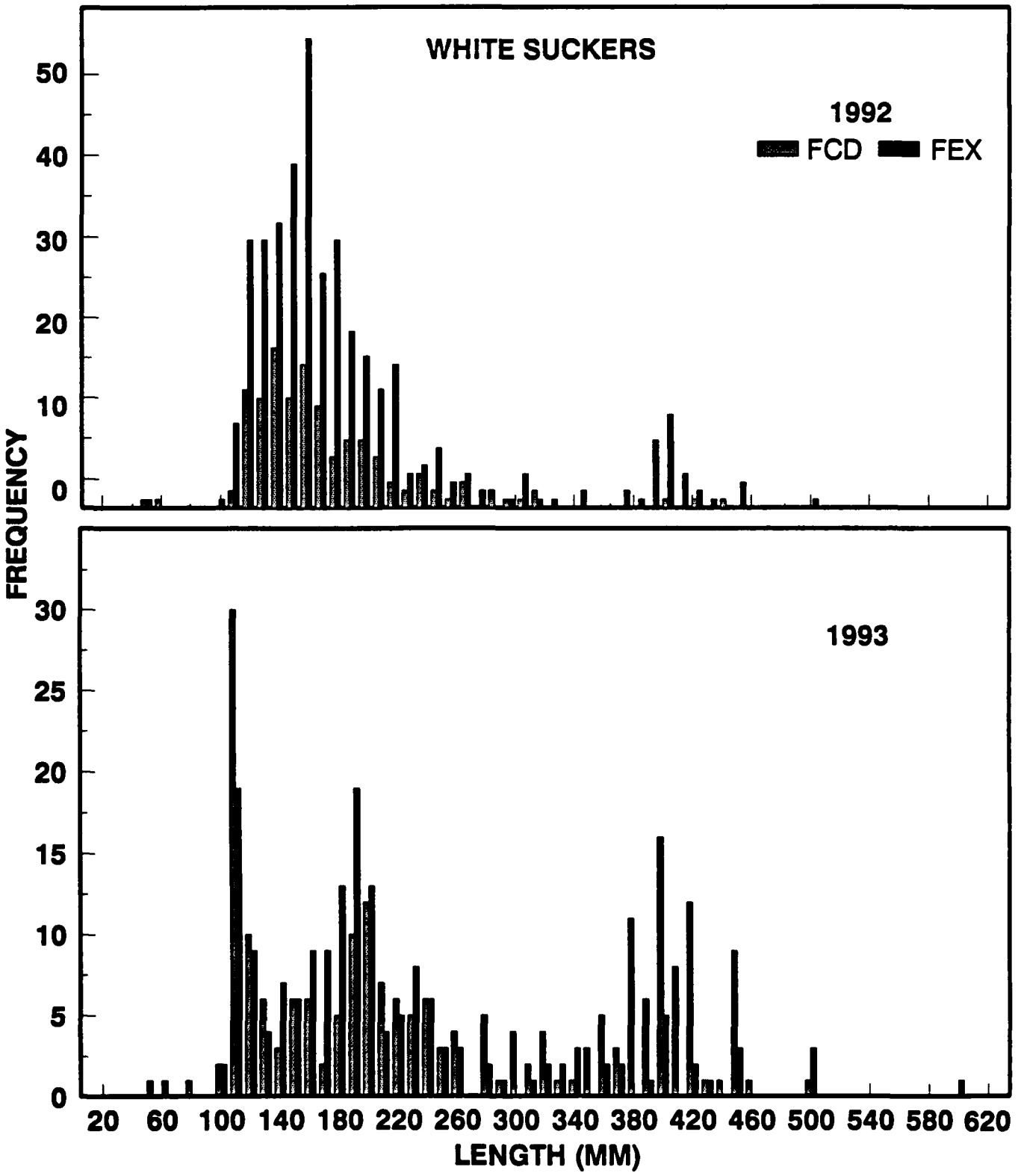

Figure 7.4p. Length frequency distribution of annual catch of white suckers at FCD and FEX from 1992 and 1993.

of variation for all species one would expect from catches having a negative binomial distribution. 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). The size distribution of the species commonly caught can be seen in Figure 7.4(a-p).

Mean lengths of the most abundant species at FEX have remained fairly constant through all years (Figure 7.5). Brook trout, 191.5 mm, showed an increase in mean length from 1992 but were just below the mean for all previous years combined (196.6 mm). Mean length of burbot was 197.9 mm, also higher than 1992 and well above the mean of previous years (177.6 mm). Common shiners, 120.1 mm, and creek chubs, 139.6 mm, both decreased slightly from 1992 yet were above the respective means for past years (111.6 mm and 130.1 mm). In contrast, white suckers, 206.8 mm, displayed a sizable increase in mean length from 1992 and were far above the mean of 174.6 mm for previous years. The marked increase in the value of white sucker mean length is likely an artifact of improved success at capturing larger specimens during the early spring spawning run. Overall changes in mean length have been minor, indicating that the size structure of the mobile fish community is consistent from year to year at FEX.

The size structure of the fish community sampled at FCD proved to be consistent with that at FEX. The mean length of brook trout, 216.1 mm, increased from 1992 and was barely less than the mean for all years (218.2 mm). Burbot, 201.4 mm, also increased from 1992 and was well above the mean of previous years (181.4 mm). The mean length of common shiners, 123.4 mm, and creek chubs, 136.8 mm, changed little from 1992 and both were greater than in past years (114.2 mm and 132.2 mm respectively). White suckers had a mean length of 257.6 mm and were far above the mean for all previous years combined (175.3 mm).

D. Fish Community Mobility

Burbot, common shiners, creek chubs, and white suckers demonstrated site to site movement as shown by the recapture of fish at sites other than the marking site (Table 7.9 a, b, and c). The total number of nonsalmonids marked at FEN, FEX, and FCD in 1993 were: burbot 177, common shiners 1276, creek chubs 1067, and white suckers 663. Recapture percentages in 1993 were greatly improved compared to previous years. Burbot and common shiners had the highest recapture percentages at 27.5% and 20.7%, respectively. A lower percentage of creek chubs, 13.2%, and white suckers,

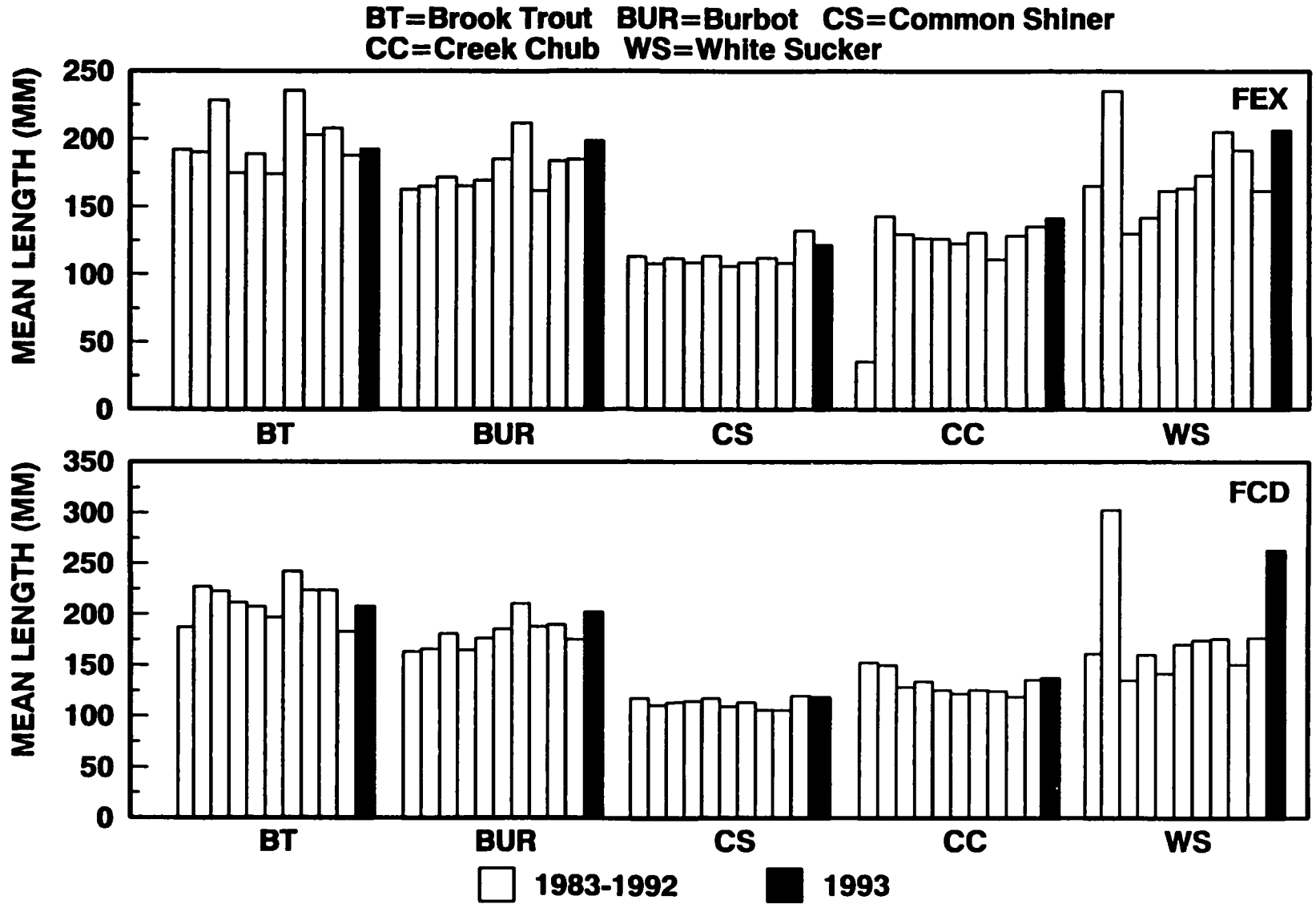

Figure 7.5. Mean length of fish dominating the fyke net catch at FEX and FCD for 1983 through 1993.

Table 7.9a. Recapture data summary for all dominant species except brook trout from FEX and FCD for 1984 - 1987.

Species	Total Marked	Number Recaptured	% Recaptured	% Recapture by Location: 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	
				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	

Table 7.9b. Recapture data summary for all dominant species except brook trout from FEX and FCD for 1988 - 1991.

Species	Total Marked	Number Recaptured	% Recaptured	% Recapture by Location: Marking Site	Upstream 1 site	Down 1 site	Up 2 sites
				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			
				1991			
Burbot	83	6	7.2	50.0	33.3	16.7	
Common shiner	2056	180	8.8	80.0	14.4	6.7	3.3
Creek chub	484	17	3.5	76.5	23.5		
White sucker	472	13	8.8	30.8	38.5	15.4	15.4

Table 7.9c. Recapture data summary for all dominant species except brook trout from FEN, FEX, and FCD for 1992 and 1993.

Species	Total Marked	Number Recaptured	Percent Recaptured	% Recapture by Location: Marking Site	Upstream 1 Site	Down 1 Site	Up 2 Sites	Dn 2 Sites
			1992					
Burbot	223	30	13.5	73.3	3.3	6.7		6.7
Common shiner	1476	179	12.1	72.1	8.9	13.4	1.1	3.4
Creek chub	845	49	5.8	71.4	12.2	14.3		
White sucker	1163	23	2.0	69.6	13.0	8.7		8.7
			1993					
Burbot	177	56	27.5	87.5	1.8	8.9		1.8
Common shiner	1276	264	20.7	38.3	8.7	14.8	4.6	1.5
Creek chub	1067	141	13.2	63.8	9.2	14.2	2.8	0.7
White sucker	663	45	6.8	44.4	15.6	6.7	11.1	

6.8%, were recaptured consistent with a trend established in past years.

Movement upstream under the antenna from FEX to FEN was indicated by the recapture of 1 burbot, 14 common shiners, 11 creek chubs, and 7 white suckers. Upstream movement under the antenna from FCD to FEN was recorded for 12 common shiners, 4 creek chubs, and 3 white suckers. Downstream movement under the antenna from FEN to FEX was demonstrated by 5 burbot, 33 common shiners, 18 creek chubs, and 2 white suckers. In addition, 1 burbot, 4 common shiners, and 1 creek chub moved downstream under the antenna from FEN to FCD.

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 community to examine the potential effects of the ELF project on growth and condition. Brook trout data are reported on in element 8.

The age and growth of common shiners, creek chubs, and white suckers has not been completed as of date due to a change in analysis methods. Length frequency distribution analysis has been determined to be a better method for determining age and growth of these species. The length frequency distributions for these species are given in Figure 7.4(d-l).

Fish condition factors for common shiners, creek chubs and white suckers were calculated using relative weight (Wr) condition analysis 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=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)

where,

wt = weight
tl = total length

Condition factors were not analyzed in 1993 as a result of biased biomass data. In 1992, condition factor (Wr value) for white suckers continued to be more than 10% below the species means from populations reported in the literature, yet consistent with previous years (Figure 7.6). Common shiner and creek chub Wr values were well above literature means. Wr value for common shiners recovered from 0.1% below the literature mean in 1991 to over 10% above the mean in 1992. Creek chub Wr values showed the greatest increase, to almost 22% above the literature mean, from a value nearly 3% below the mean in 1991.

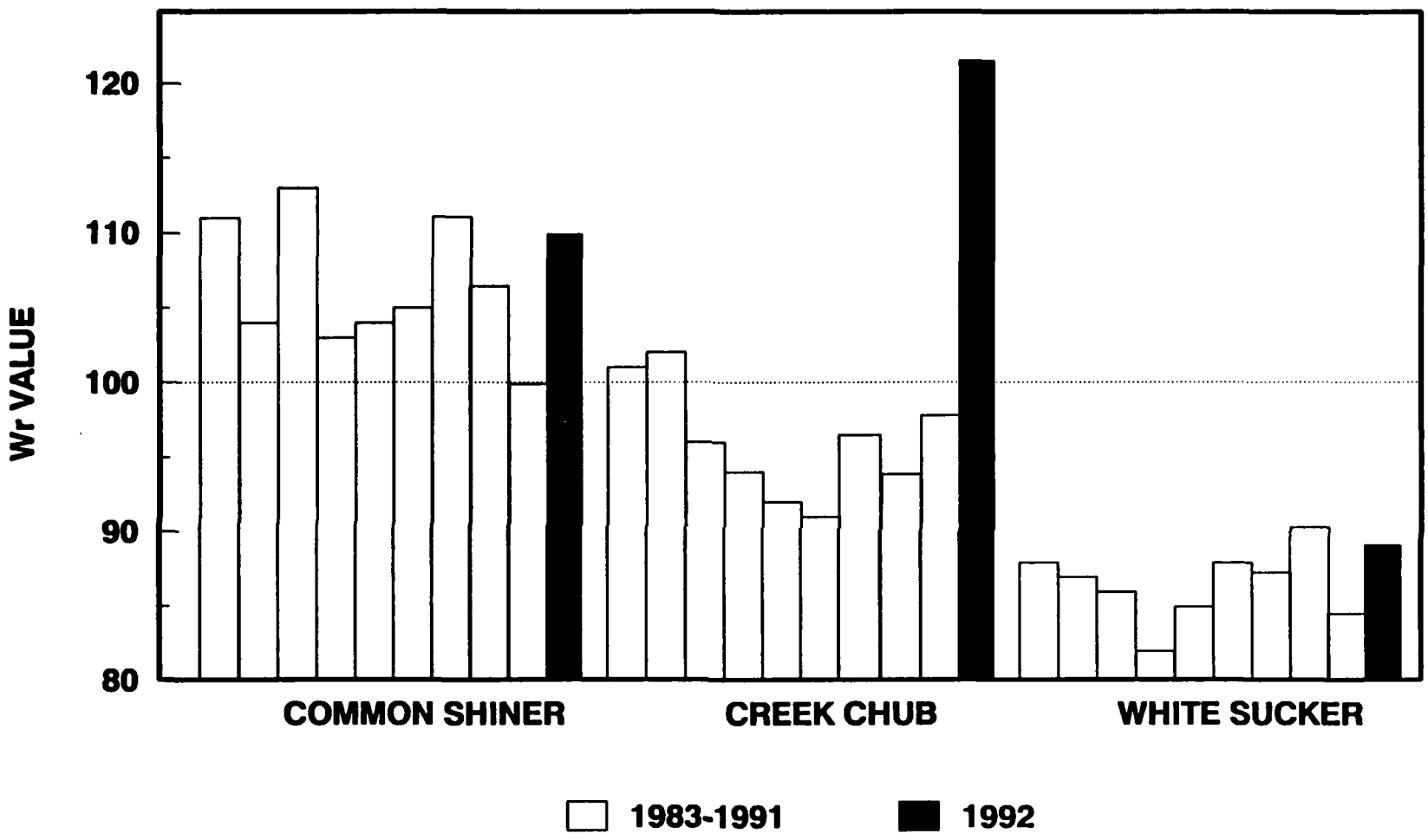

Figure 7.6. Yearly unweighted relative weight values for common shiners, creek chubs and white suckers in the Ford River. Dotted line at 100 indicates a condition equal to the average calculated from several populations in the literature.

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Element 8 - Brook Trout Population Characteristics and Movement

Changes from workplan: Data analysis design structured in this manner: pre-operational years (1983-1985), transitional years (1986-1988), and fully-operational years (1989-1993). In the previous report, 1989 was analyzed as a transitional year. We have treated 1989 as an operational year after discussion with IITRI engineers. The primary analyses presented in this report compare pre-operational years with transitional and fully-operational years.

Fishing at the wire mesh weir sites FCU and TM was discontinued. The fyke net site FEN, added in 1990 400m upstream of FEX, was again fished in 1993.

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 are 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 under the ELF antenna; 2) The proximate cause(s) for these movements; 3) The rate of brook trout movement under the ELF antenna; 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 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, weighed, and given a site specific fin clip. Scale samples were removed from each fish for age determination and backcalculation of growth in 1983-1991. 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 through 1993 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 1984-1991. Discharge was calculated from a calibrated staff gauge at both FCU and TM on a daily basis. Temperature data were collected continuously using a calibrated max-min thermometer at TM and FCU. In addition, Ryan tempmentors and/or thermographs were deployed in 1988 through 1991 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 were done using the body-scale relationship technique described in Smale and Taylor (1987) for data from 1983-1991. Backcalculations were made using the linear technique described 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 the outside edge of each scale were digitized and recorded on a microcomputer for determination of backcalculated length at age.

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, suggesting a decline in the brook trout population (Table 8.1). Numbers of fish tagged increased to 170 fish in 1987 and dropped slightly to 135 in 1989 (no fish were tagged in 1988). Only 74 fish were tagged in 1990, but the number of trout tagged at FEX and FCD in 1991 increased dramatically to 187, reflecting favorable environmental conditions over the previous 2 years. A total of 125 trout were tagged in 1992. The number of brook trout tagged in 1993 at FEX and FCD increased to 166, a total above the mean of previous years combined (135). In addition we also tagged 25 trout at FEN in 1992, a total that increased to 81 fish in 1993.

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 (Table 8.1). The recapture percentage increased to 6.7% in 1989 and to 9.7% in 1990 at FEX and FCD. Recapture percentages in 1991 were the highest ever at 34.2%. However, tag recapture percentage dropped in 1992 to 4.7%. A modest recovery was made in 1993 as recapture rates rose to 10.5%.

Observed handling and tagging mortality (Table 8.1) averaged 6.2% from 1984 to 1987 (Table 8.1). No tagging mortality was observed in 1988 and only 2.2% was recorded in 1989. Tagging mortality in 1990 and 1991 was 1.2% and 4.1%, respectively. Estimated handling mortality was 1.6% in both 1992 and 1993.

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 and 2.1% in 1991 (Table 8.1). There were no tags returned in 1992, however we did not post signs to inform anglers of whom to contact if they caught a tagged fish. One tag was returned in 1993 (0.4%). The decline in angler returns may

Table 8.1. Brook trout marking and recapture summary for FEX and FCD for 1984 - 1993.

			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%		
	Percent Angler Recapture	3.0%		
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 tagged		0	0
	Number Clipped		57	85
	Percent Tag Recapture	0.0%		
	Estimated Handling Mortality	0.0%		
	Percent Angler Recapture	0.0%		
1989	Number Tagged		49	86
	Number Clipped		12	11
	Percent Tag Recapture	6.7%		
	Estimated Handling Mortality	2.2%		
	Percent Angler Mortality	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%		

Table 8.1.(continued)

			FEN	FEX	FCD
1991	Number Tagged			78	109
	Number Clipped			36	21
	Percent Tag Recapture	34.2%			
	Estimated Handling Mortality	4.1%			
	Percent Angler Recapture	2.1%			
1992	Number Tagged		25	50	75
	Number Clipped		12	45	40
	Percent Tag Recapture	4.7%			
	Estimated Handling Mortality	1.6%			
	Percent Angler Recapture	0.0%			
1993	Number Tagged		81	80	86
	Number Clipped		26	8	2
	Percent Tag Recapture	10.5%			
	Estimated Handling Mortality	1.6%			
	Percent Angler Recapture	0.4%			

reflect a decrease in the total number of fish harvested in the Ford during the entire study period; however, we present no quantitative data on angling pressure.

B. Brook Trout Catch Patterns

Over the entire study period, brook trout catches have been greatest in late May to early July, depending on weather patterns during the year. Summer catches usually dropped to < 1 fish/day and this condition persisted through late August to early September. At this time, daily catch usually increased, perhaps due to pre-spawning activity. Because movement patterns have been similar at all sites, data will be presented from FCD to depict among year differences (Figures 8.1 a-e). 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 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. The brook trout catch in 1991 increased from late May until mid June and rates stayed high until early July. Catch rates also peaked in the final weeks of May in 1992, though to a much lesser degree than in 1991. A similar pattern occurred in 1993 as catch rates reached a high in mid to late May and increased slightly in early July. Fyke net fishing was concluded at all sites on August 18, 1993.

Movement in the upstream direction dominated in all years at all sites; 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.

Observations of brook trout movements are based on recaptures of marked fish at sampling sites different from

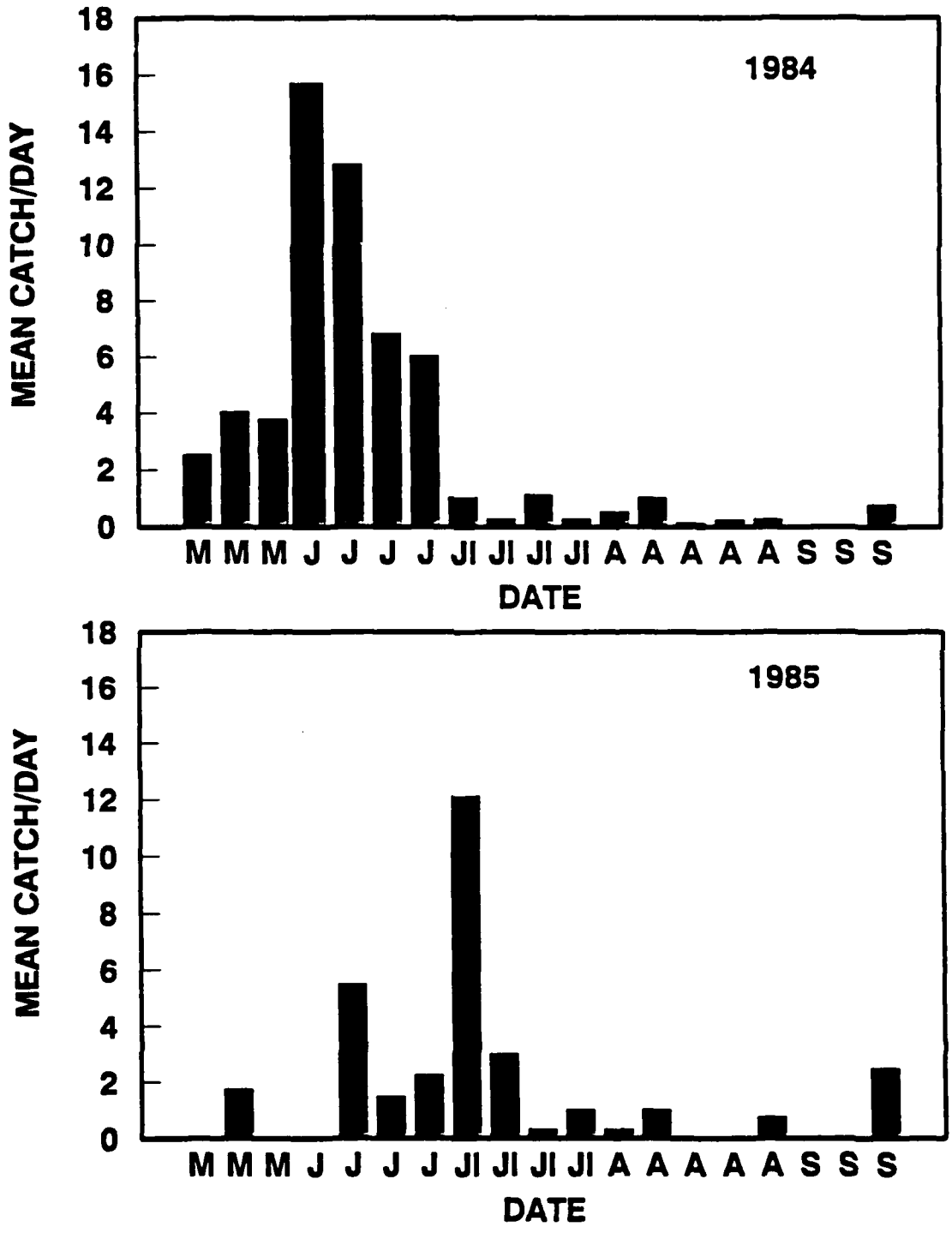


Figure 8.1a. Mean daily catch of brook trout plotted on a weekly basis at FCD from 1984 and 1985.

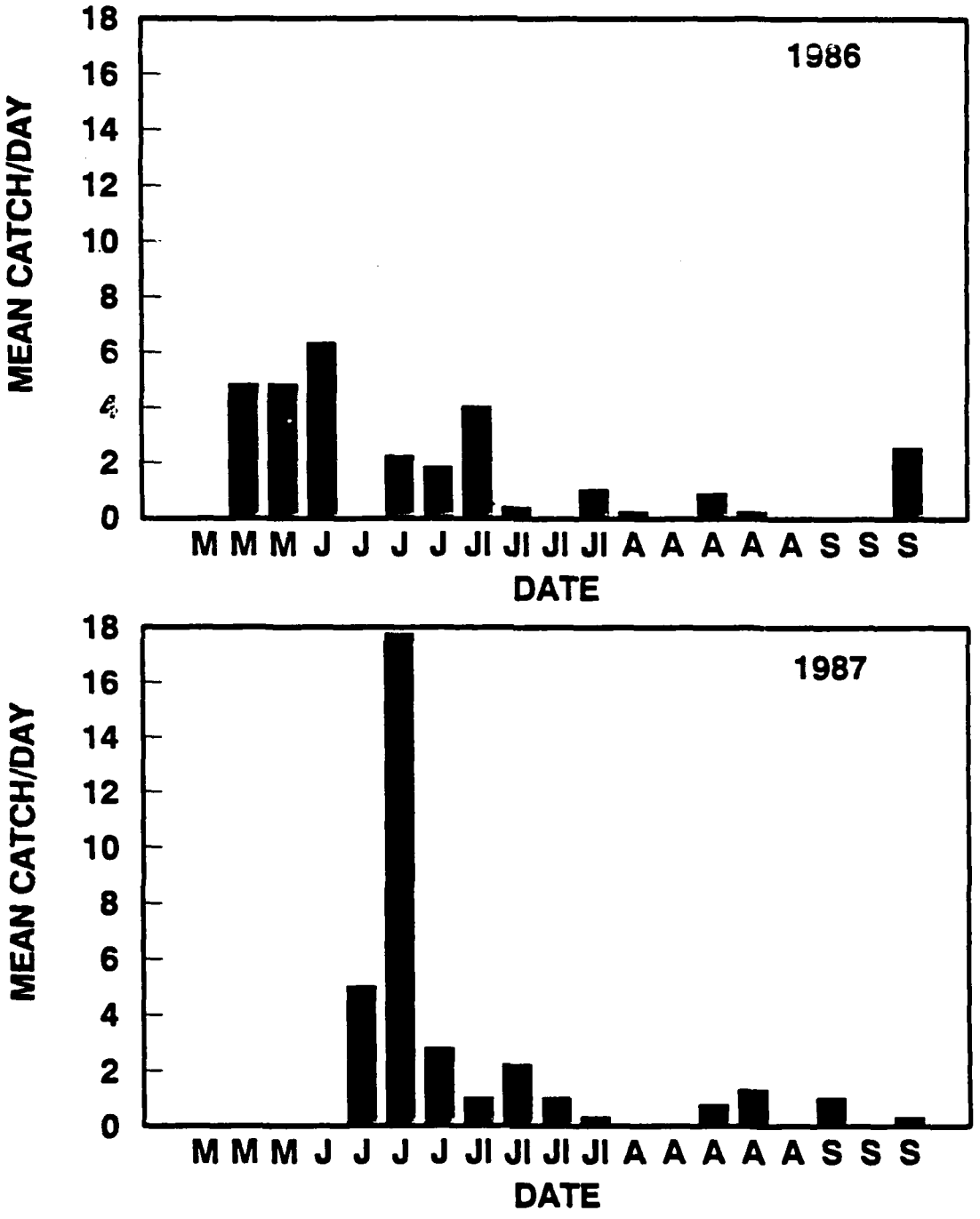


Figure 8.1b. Mean daily catch of brook trout plotted on a weekly basis at FCD from 1986 and 1987.

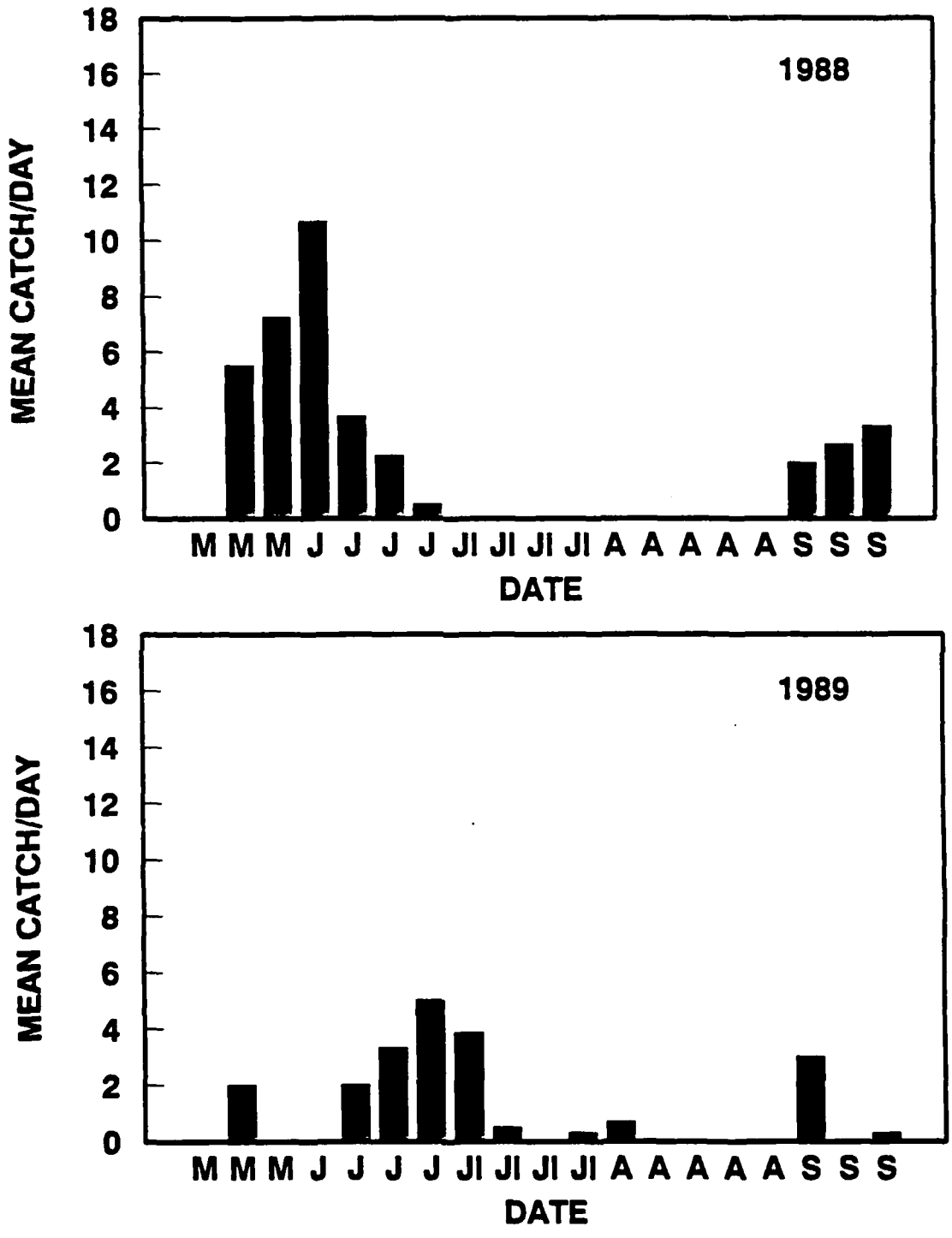


Figure 8.1c. Mean daily catch of brook trout plotted on a weekly basis at FCD from 1988 and 1989.

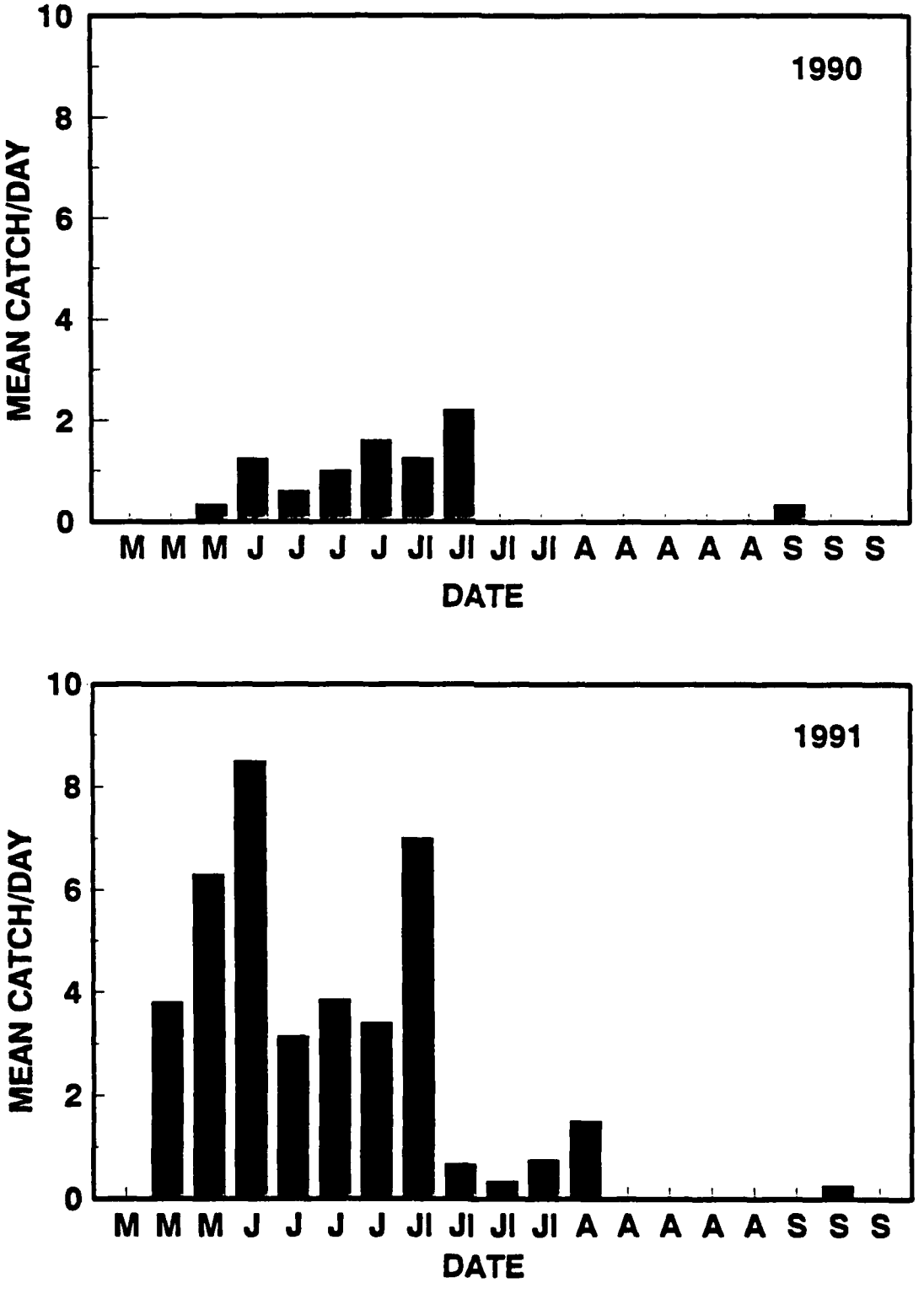


Figure 8.1d. Mean daily catch of brook trout plotted on a weekly basis at FCD from 1990 and 1991.

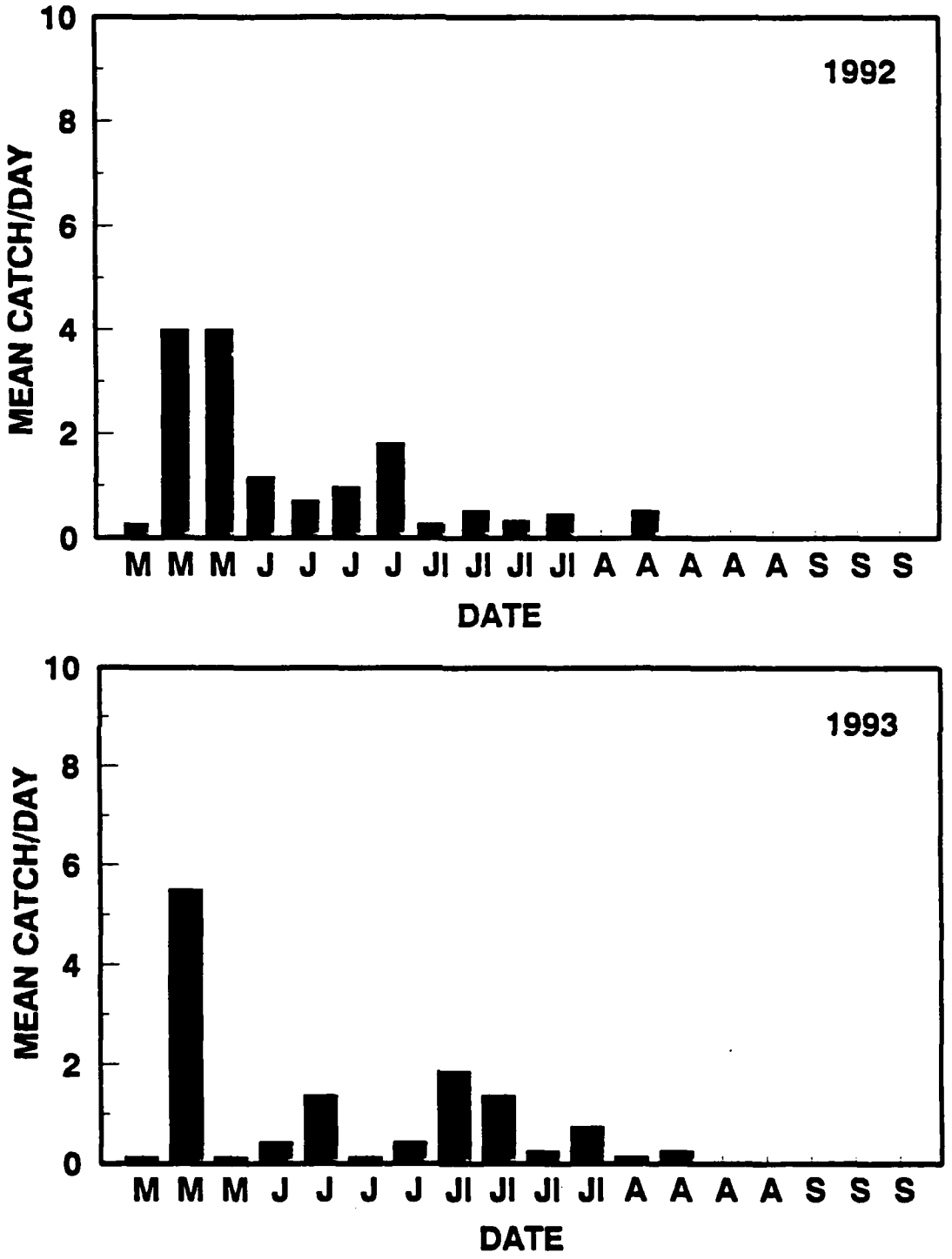


Figure 8.1e. Mean daily catch of brook trout plotted on a weekly basis at FCD for 1992 and 1993.

their initial capture site. Our summary here refers to these recaptured fish, which are assumed to be representative of the entire brook trout population. Brook trout movements have been directed from FEX and FCD upstream toward a coldwater tributary, Two Mile Creek (TM). 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 (1986-1988), one trout moved from FEX to TM, and 25 made this movement during fully-operational years (1989-1991: TM was not censused in 1992 or 1993, so no movement data to TM are available after 1991). Pre-operational movement from FCD to FEX was observed for ten brook trout. Two fish moved from FCD to FEX in the transitional period and sixteen made this movement during fully-operational years (1989-1993). Movement from FCD to TM was observed for forty-five brook trout from 1984-1985. No fish moved this distance during the transitional period. Thirty-four fish made this movement during the fully-operational years (1989-1993), however, all of this movement occurred in 1989 and 1991. Few movements occurred in 1990, and no samples were taken at TM in 1992 or 1993.

Movement from site to site was greater for fish larger than 190 mm than those smaller than 190 mm. Only six clipped fish under 190 mm were captured at TM in 1984 and no clipped fish under 190 mm were collected at TM from 1985 through 1990. In addition, only three fish moved from TM to FCD or FEX from 1984 through 1991 during the summer sampling period. Evidence of fall or early spring downstream movement was supported by the movement of three marked fish from the TM site in 1984 to FCD in 1985. One trout marked in 1990 from FCU was recaptured at FCD in 1991 and a second trout tagged at TM in 1990 was recaptured at FEX in 1991. A trout tagged at TM was also recaptured at FCD in 1992, further suggesting that there is limited movement from fall to early spring.

During the pre-operational period (1984-1985), we recorded the movements of 50 brook trout. 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 (1986-1988), the movement of 3 brook trout were known. Two of these fish moved upstream but did not cross under the antenna, and 1 moved upstream past the antenna.

During the operational period (1989-1993) we observed the movements of 96 brook trout. A total of 77 trout moved upstream under the antenna and 19 moved downstream under the antenna. In 1989, 2 tagged brook trout moved upstream from FEX to TM. To more closely examine the movement of brook trout under the ELF antenna, in 1990 an additional net site

Table 8.2. Brook trout site to site movement rate summary for 1984 through 1993.

Year	Recapture Type	Site Marked to Site Recaptured	Distance (km)	N	Mean Rate (km/day + 1SD)	Mode (km/day)
1984	Recaptured Fish	FEX- TM	12.7	11	1.4 ± 0.9	1.2
		FCD- TM	26.8	39	2.9 ± 1.7	2.5
		FCD-FEX	14.1	7	2.7 ± 1.6	2.0
1985	Recaptured Fish	FEX- TM	12.7	7	1.6 ± 0.9	1.1
		FCD- TM	26.8	6	5.0 ± 3.2	4.2
		FCD-FEX	14.1	3	1.2 ± 0.3	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 ± 0.7	1.0
1989	Recaptured Fish	FEX-TM	12.7	2	0.7	
		FCD-TM	26.8	1	4.5	4.5
		FCD-FEX	14.1	1	2.8	2.8
		FEX-FCD	14.1	2	1.9	
		TM-FCD	26.8	1	6.7	6.7
1990	Recaptured Fish	FCD-FEX	14.1	2	2.2 ± 1.87	2.2
1991	Recaptured Fish	FCD-FEX	14.1	6	2.1 ± 1.67	1.35
		FCD-FEN	15.0	3	2.6 ± 2.25	2.14
		FEX- TM	12.7	16	1.6 ± 1.02	1.53
		FCD- TM	26.8	29	3.5 ± 1.54	2.98
		FCU- TM	3.0	4	0.7 ± 0.95	0.25
		FEX-FCD	14.1	1	3.5	3.5
		TM- FCD	26.8	1	1.0	1.0
		TM- FEX	12.7	1	12.7	12.7

Table 8.2 continued.

Year	Recapture Type	Site Marked to Site Recaptured	Distance (km)	N	Mean Rate (km/day + 1SD)	Mode (km/day)
1992	No Recaptures of Tagged Fish					
1993	Recaptured Fish	FCD-FEX	14.1	1	3.5	3.5
		FEX-FEN	0.9	3	0.8 ± 0.26	0.9
		FEN-FEX	0.9	10	0.8 ± 0.22	

(FEN) was established upstream from the antenna approximately 400 meters from FEX. Of 42 fish captured and marked at FEX in 1990, 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. In 1991, only 1 of 109 brook trout tagged at FEX was recaptured at FEN. However, 3 fish marked at FCD were recaptured at FEN and 2 radio tagged brook trout from FEX were followed past the antenna directly, indicating that the antenna's electromagnetic field did not impede their passage. The most significant evidence of unimpeded passage, however, was shown by 33 fish marked at FCD and 23 fish marked at FEX that were recaptured at the TM site in 1991. In 1992, only 1 of the trout marked at FEX and 1 of those marked at FCD were known to have moved upstream under the antenna to FEN, though in 1993 9 brook trout moved upstream, 5 from FCD to FEN and 4 from FEX to FEN. In 1989, one brook trout moved downstream past the antenna, while none moved downstream past it in either 1990 or 1991. However, 3 brook trout marked at FEN in 1992 and 15 in 1993 were recaptured at FEX.

The 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 fully-operational years is presented in Figure 8.2a and Figure 8.2b. In addition, a distribution of the proportion of marked fish completing their movement (in days) within each period is presented in Figure 8.3. No difference in the movement pattern (days to move) was detectable when pre-operational and fully-operational periods were compared (X^2=0.98, df=2, p>0.05). Because movement data are available for only 3 fish during the transitional period, no comparisons can be made involving this period. At this time, no definitive conclusions can be drawn as to ELF effects on movement; however, it appears that ELF does not have an effect on movement because there are similar distributions of days since tagged values in pre-operational years and fully-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 fish was lost the day after it was observed below a small

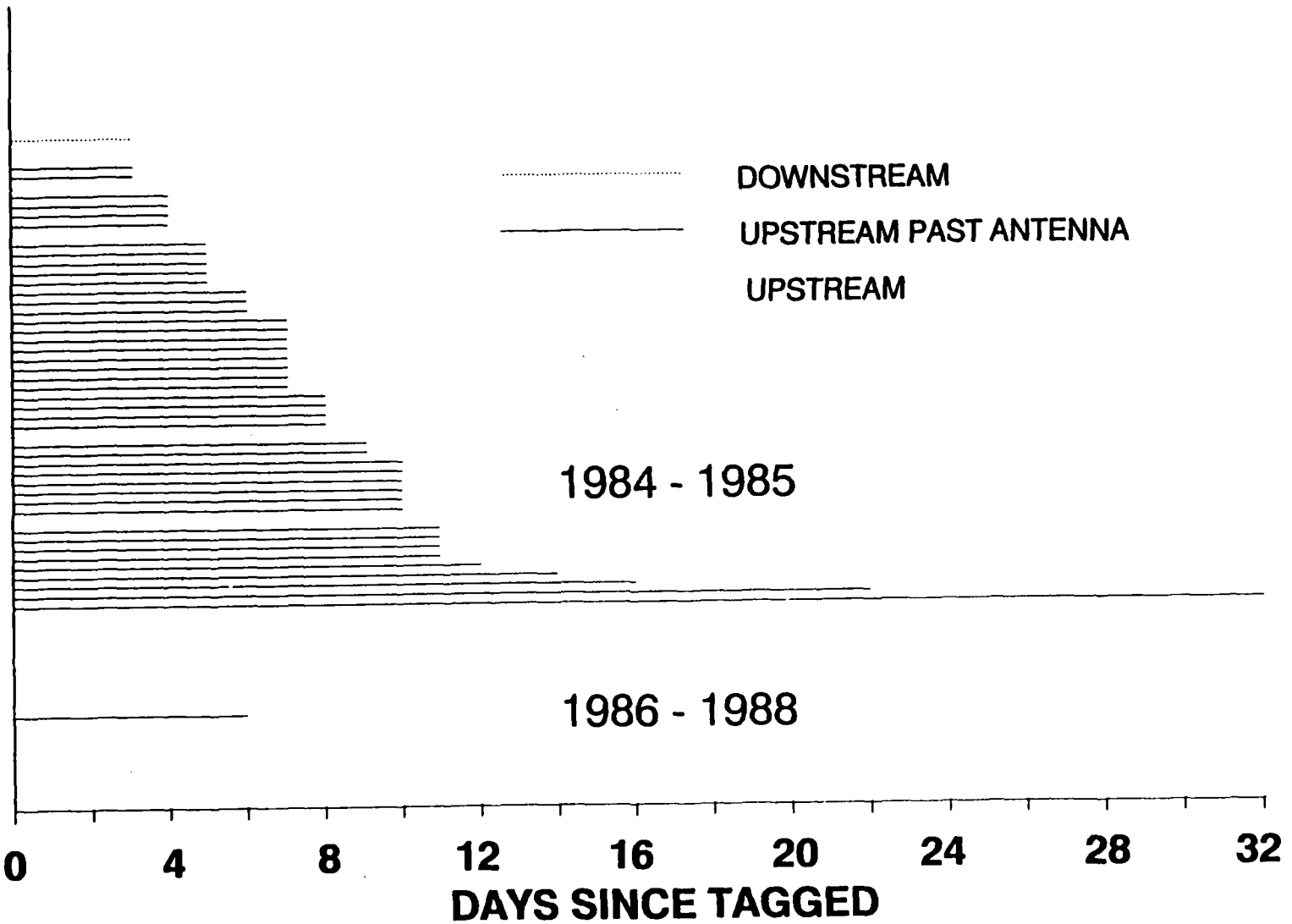


Figure 8.2a. Range of individual movement times of brook trout during pre-operational (1984-1985), and transitional (1986-1988) study periods.

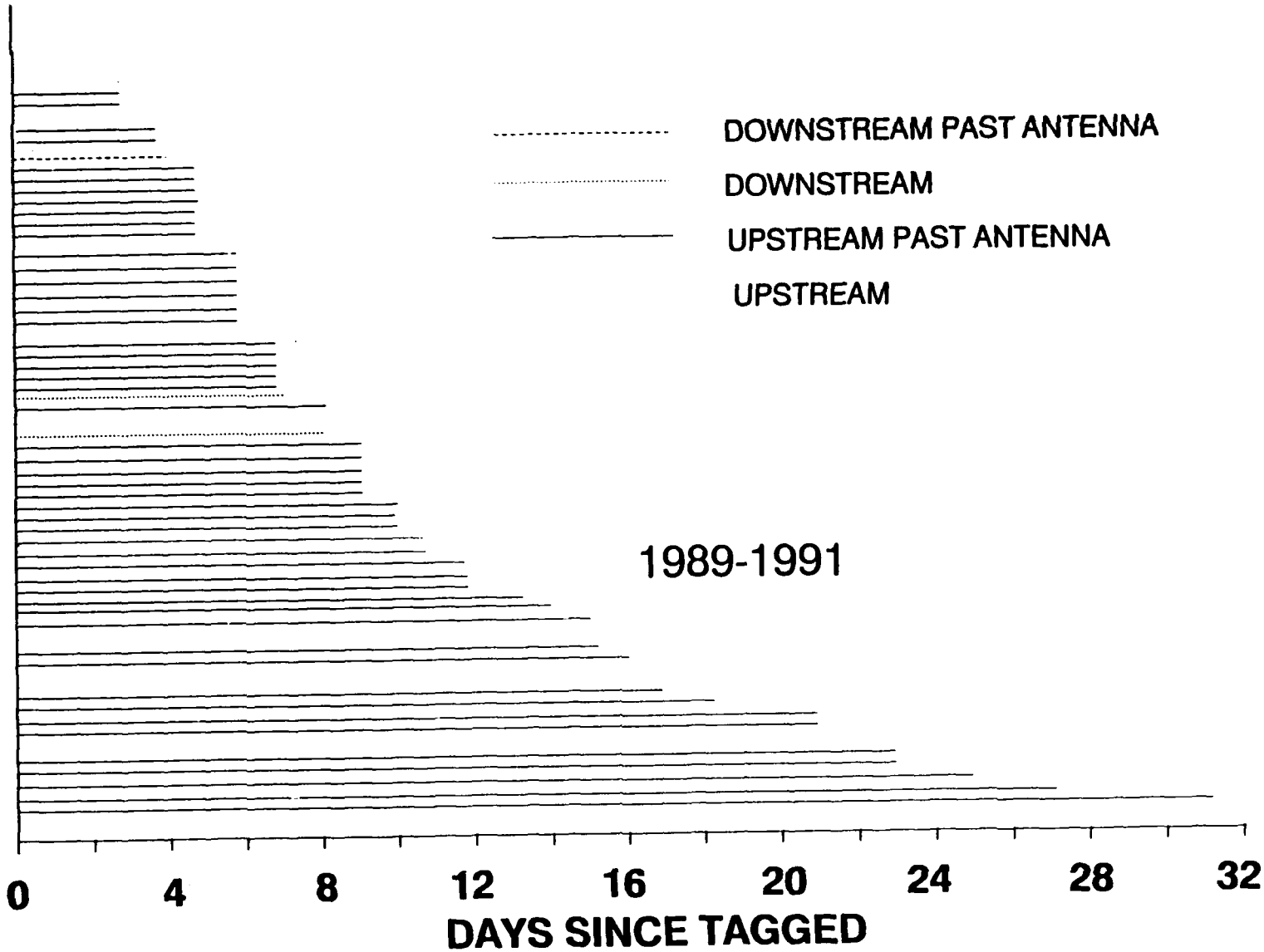


Figure 8.2b. Range of individual movement times of brook trout during fully-operational (1989-1991) study period.

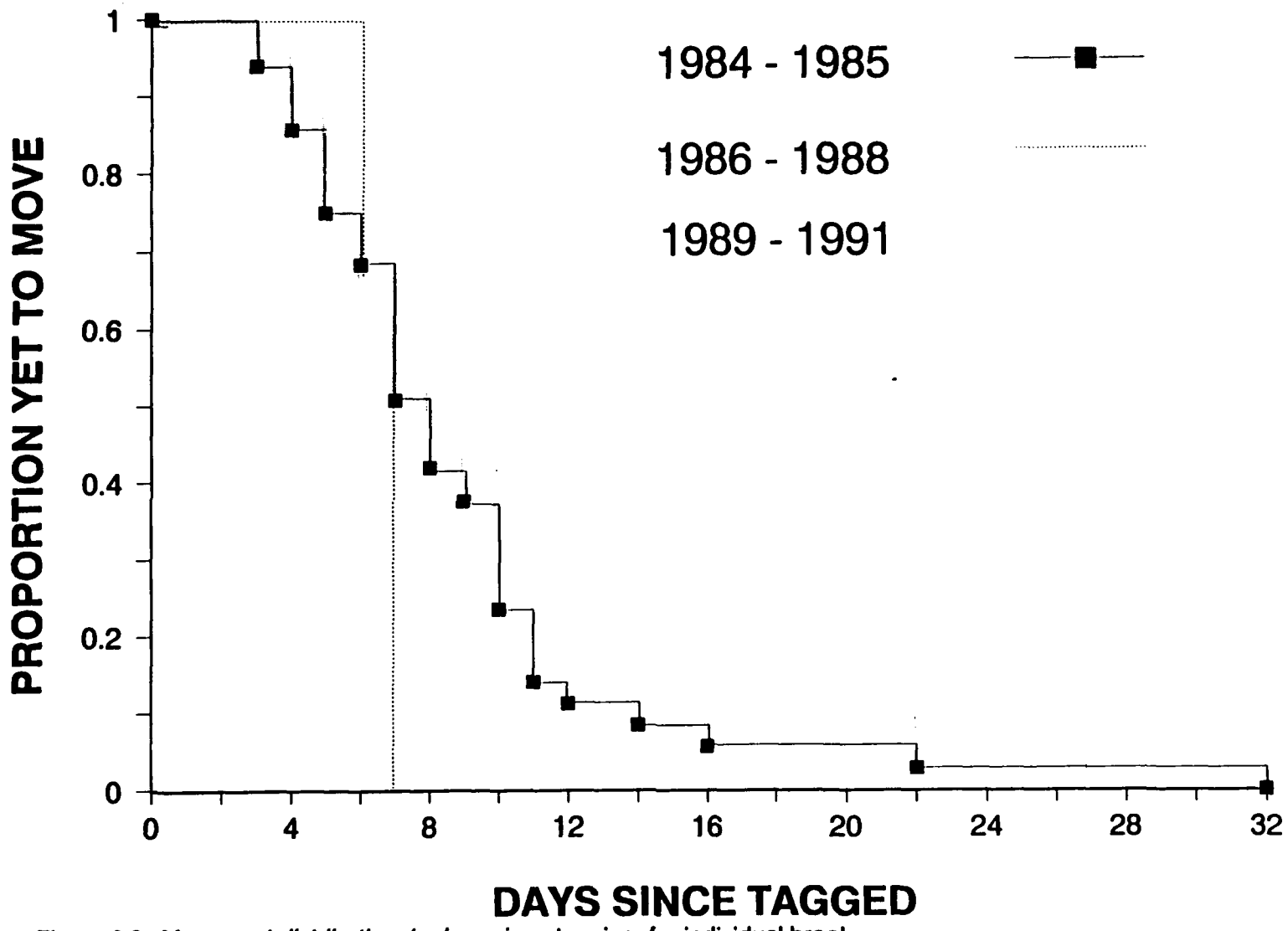


Figure 8.3. Movement distribution, in days since tagging, for individual brook trout during the pre-operational, transitional, and fully-operational study periods.

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 fully-operational years. A major dam made in 1986 upstream of FEX was destroyed during the spring of 1991 by high flows. This may partially explain the high recapture percentages observed at the TM weir site in 1991 and the low recapture percentages from 1986 through 1990. No such impediments were observed in 1992. In 1993, three dams were discovered between the mouth of Two Mile Creek and FEN, two of them large enough to pose as potentially impassable barriers to brook trout upstream movement. However, we offer no sampling evidence to describe the possible effects of these dams on brook trout movement patterns.

From bioenergetics considerations, 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 8.4a and b). In all years peak movement times coincided with mean daily temperatures that exceeded 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 were greatest and exceeded the optimum during the last week of June, and peak movement times for these three 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, 1988, and 1991 were greatest during the last week of May, and movements in 1986 and 1988 peaked during the first week of June and in 1991 during the second and third week of June. In 1987, water temperature and movement both were greatest during the third week of June. Temperature in 1992 exceeded 16 C in the first week of June, following closely the period of maximum brook trout movements (the final two weeks of May). A similar trend was evident in 1993 when temperatures also

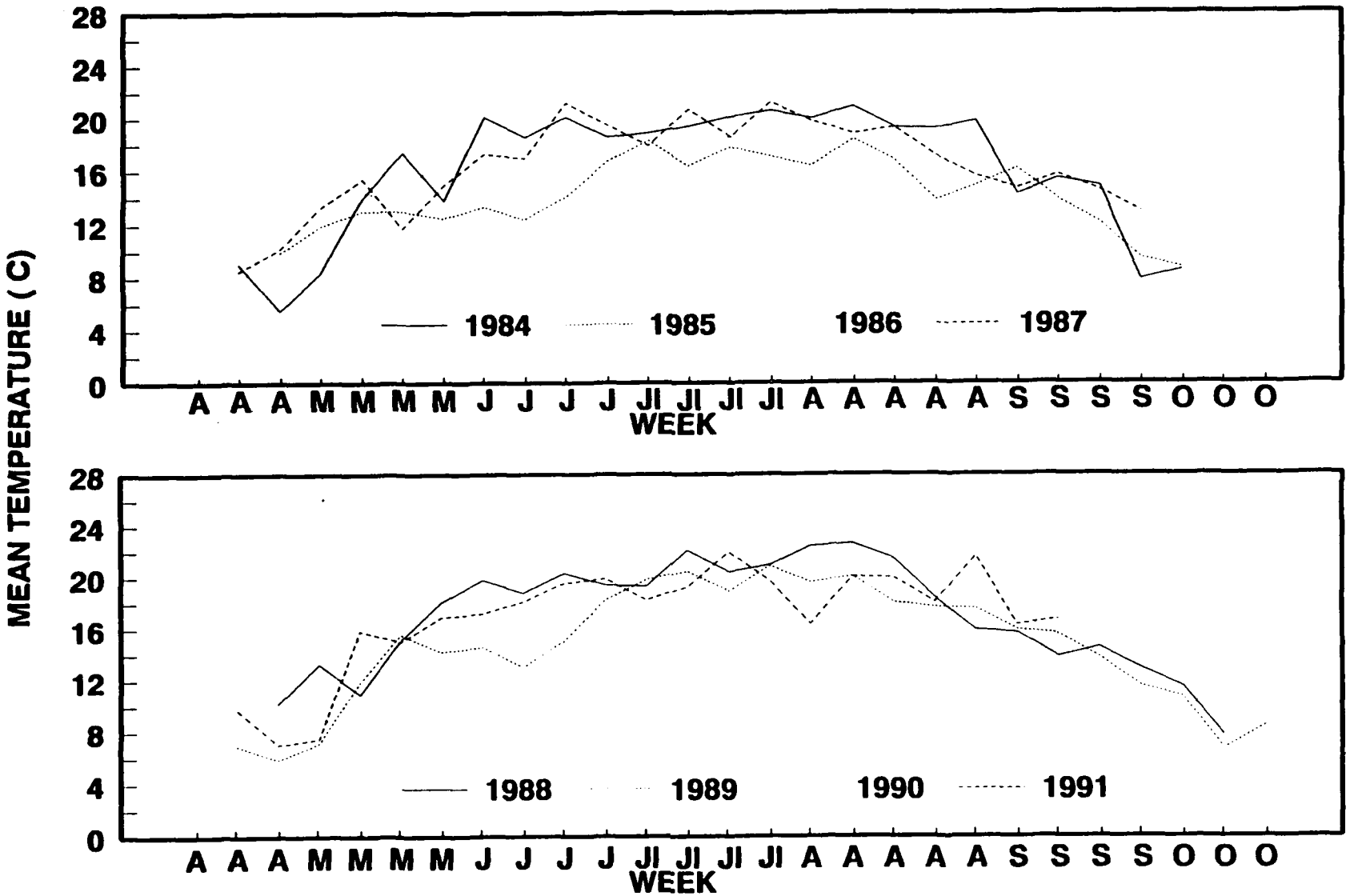


Figure 8.4a. Mean daily water temperature calculated on a weekly basis at FCD for 1984-1987 and 1988-1991.

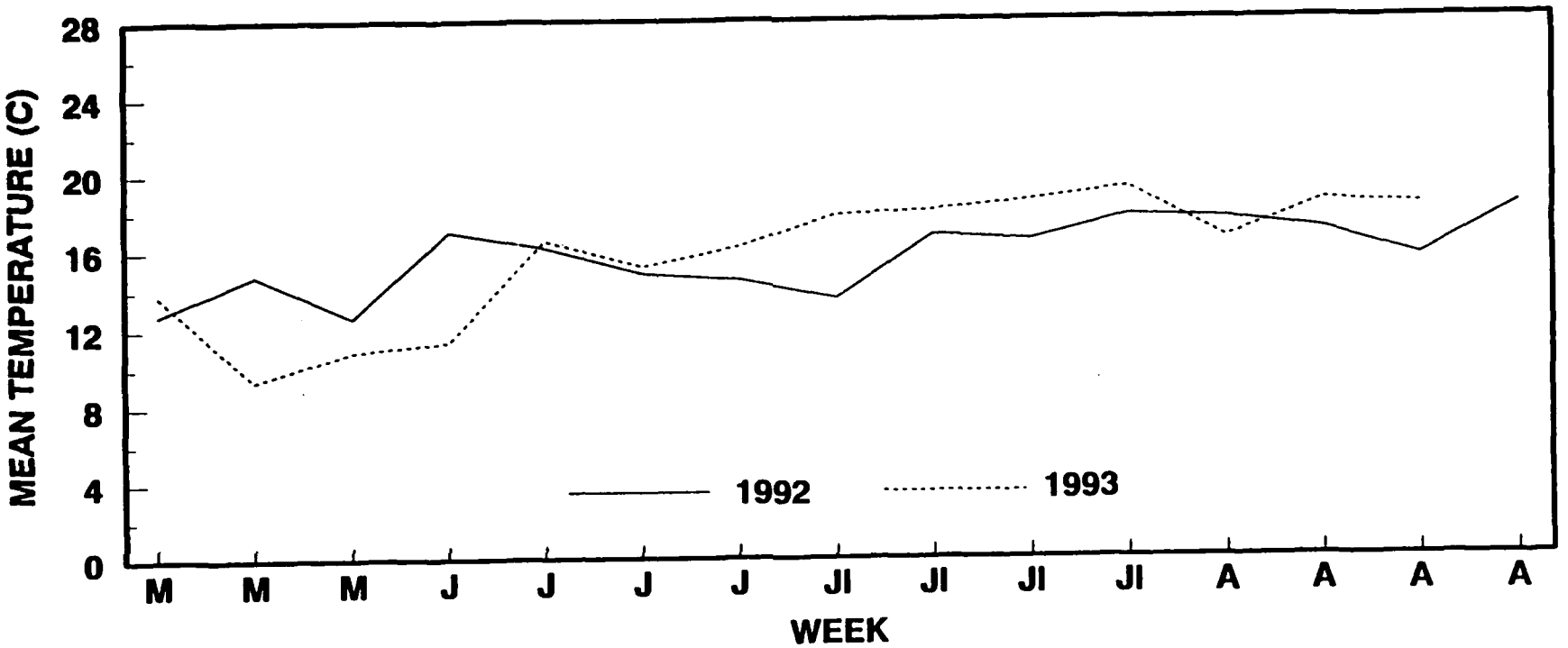


Figure 8.4b. Mean daily water temperature calculated on a weekly basis at FCD for 1992 and 1993.

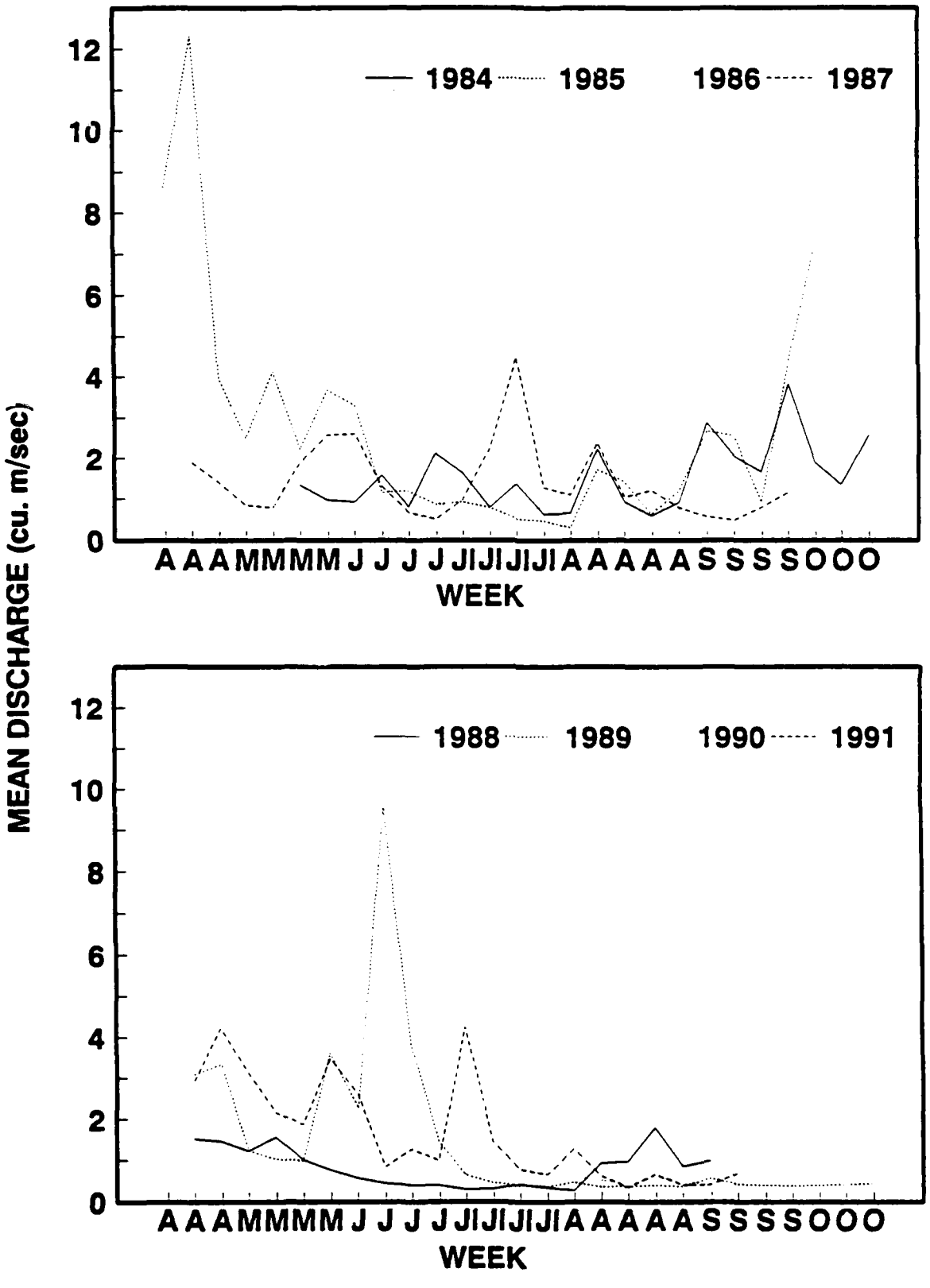


Figure 8.5a. Mean daily discharge calculated on a weekly basis at FCD from 1984-1987 and 1988-1991.

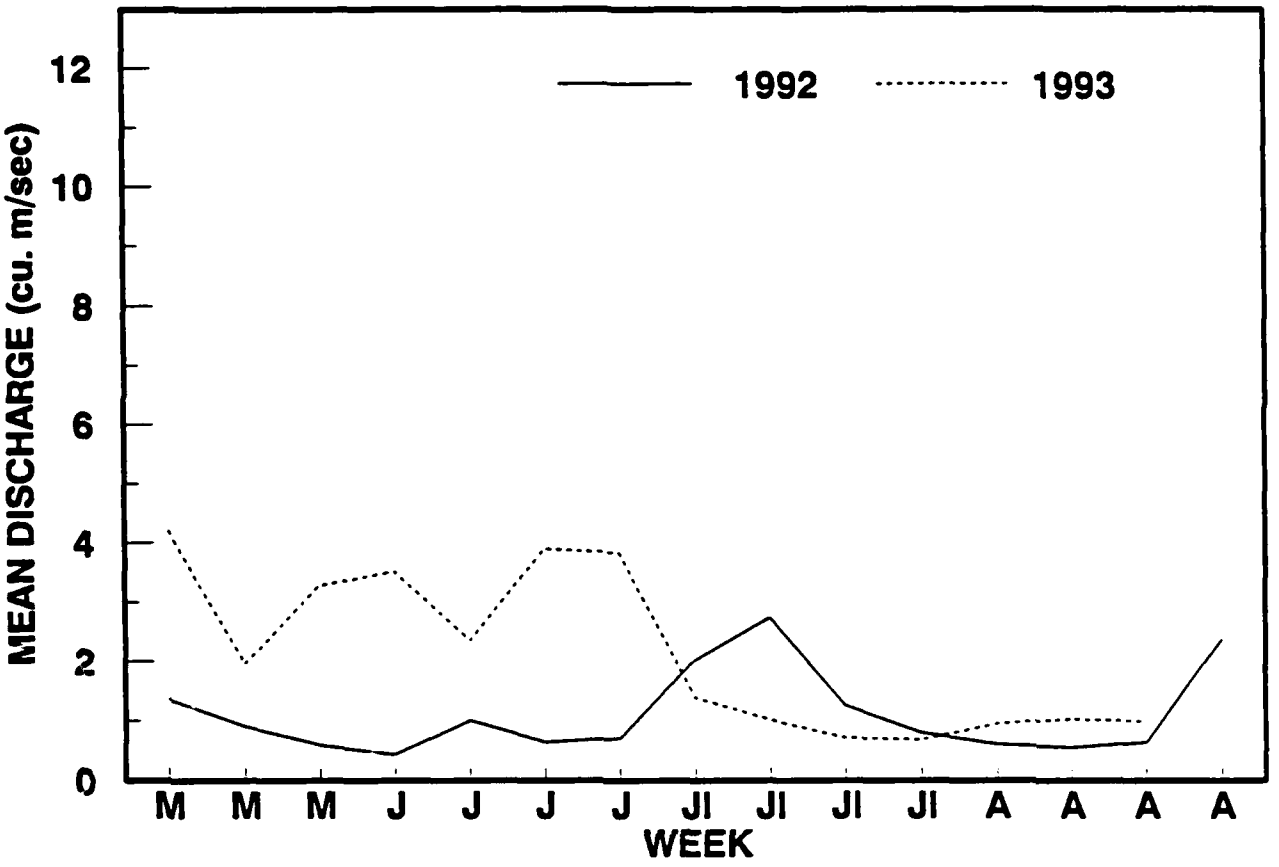


Figure 8.5b. Mean daily discharge calculated on a weekly basis at FCD for 1992 and 1993.

rose above optimal in the first week of June and brook trout catch rates peaked during the later part of May.

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 8.5a and b). Discharge patterns in 1984 and 1991 showed periodic maxima throughout the year, indicating that evenly spaced precipitation events occurred. Patterns for 1985, 1987, 1989, 1990, and 1993 displayed high discharge values during spring and early summer, but low values during summer. Spring and summer values were low in 1986 and 1988, and increased in autumn. Discharge in 1992 was comparable to 1987, in that flow was greatest in midsummer and was elevated during the spring and 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 population densities during these years. When densities are low, individuals may be able to find adequate coldwater microhabitats without intra- or interspecific competition from other fishes. In summary, it appears that if the brook trout populations are abundant, water temperatures suboptimal, (>16 C) and discharge is high, substantial upstream movement characterized by high daily catches in spring and/or early summer occurs.

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. Average movement rates for pre-operational, transitional, and fully-operational periods are given in Table 8.3. A one-way ANOVA detected significant differences in movement rates between the operational and pre-operational periods. No differences were discovered between the pre-operational and transitional periods or between the transitional and operational periods. However, these results should be interpreted with caution for two reasons. First, note the small sample size for the transitional period. Second, fewer sites were sampled throughout the operational period (FEN, FEX, and FCD) than were sampled during the pre-operational period (FCU, TM, FEX, and FCD). A summary of brook trout site to site movement for all years is given in Table 8.2. 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 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. In 1991, a Peterson population estimate was attempted at TM where a logging operation had cleared the forest to the bank. A total of 7 trout were captured on the marking run which included 3 adults and 4 young of the year. No recapture run was attempted. 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

Table 8.3. One-way ANOVA between pre-operational (1983-1985), transitional (1986-1988), and fully-operational (1989-1993) brook trout movement rates.

	1984-1985	1986-1988	1989-1993
n	50	3	77
MEAN	3.14	1.93	2.40
VARIANCE	2.21	0.02	2.86

SIGNIFICANT ($F_{2,120}=3.54$, $p<0.05$)

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 %

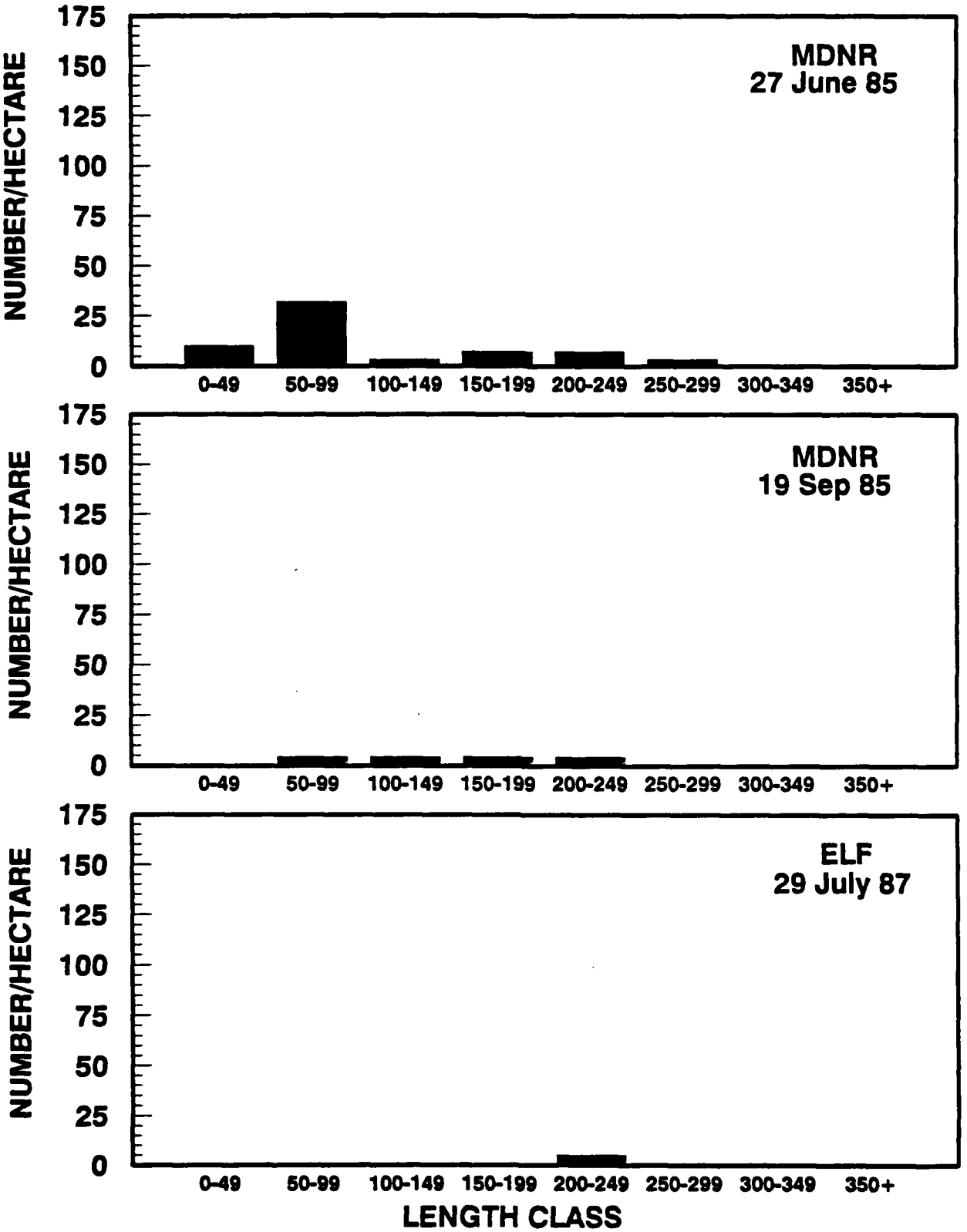
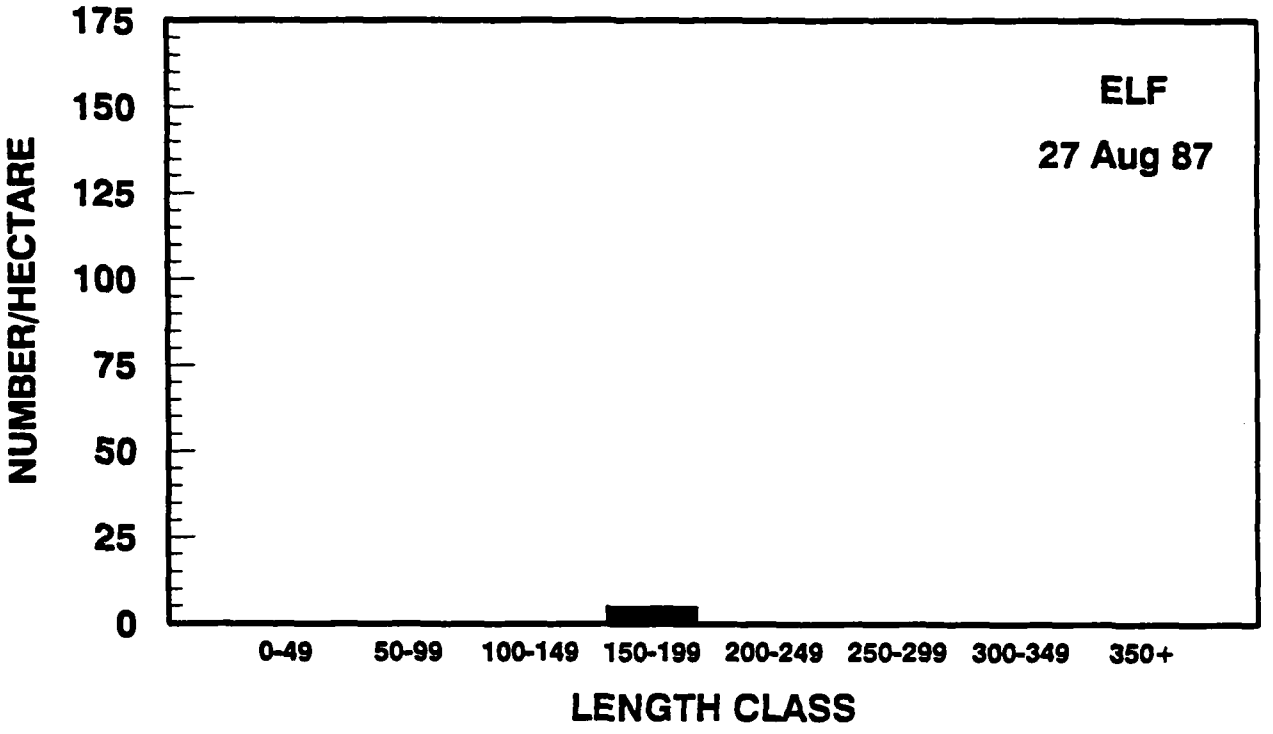


Figure 8.6a. Length frequency of brook trout taken by MI DNR and ELF personnel at FCD. Dates are included on graphs.



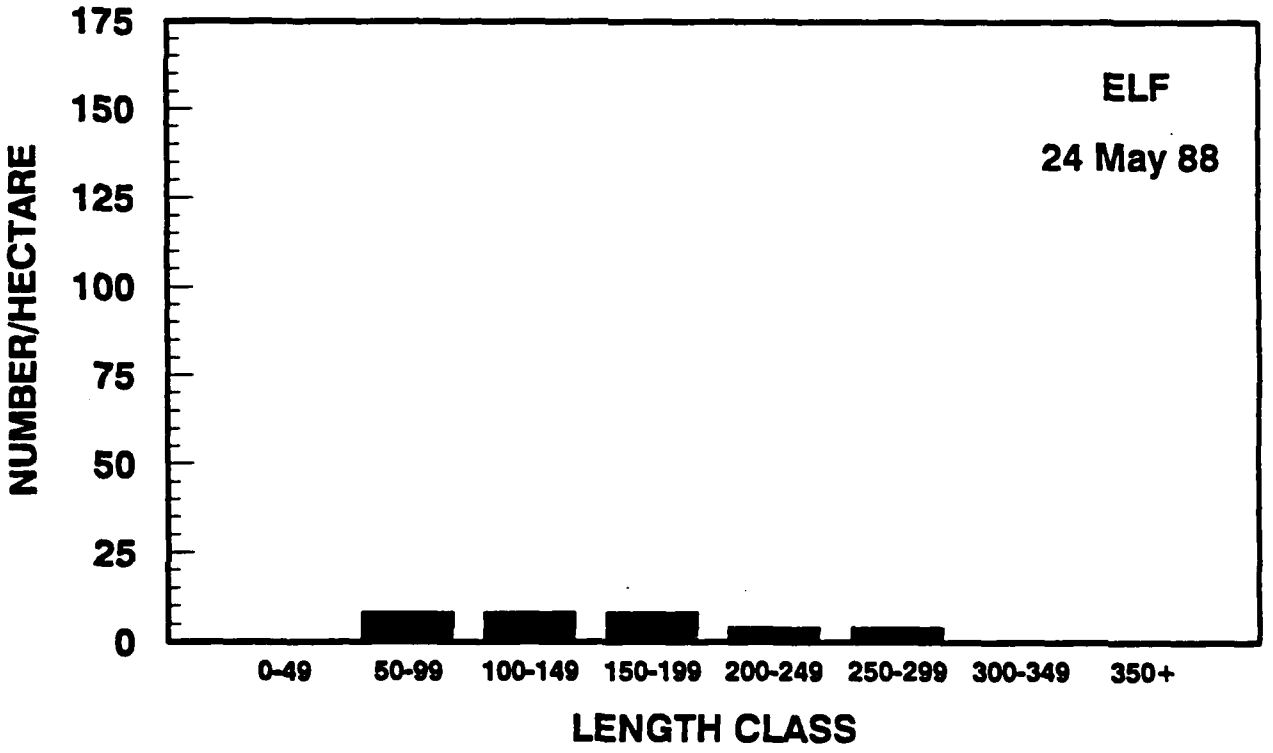


Figure 8.6b. Length frequency of brook trout at FCD taken by ELF personnel.

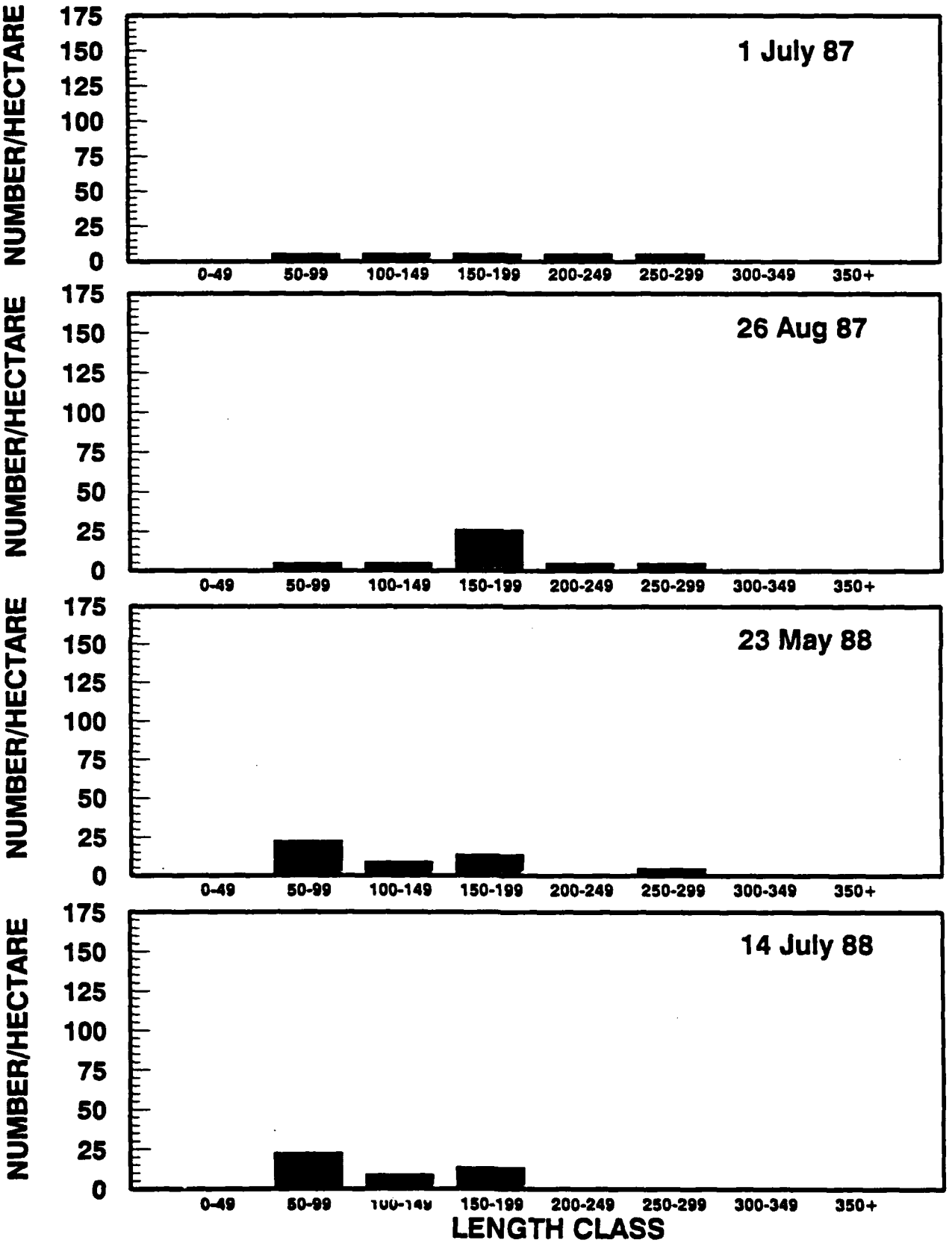


Figure 8.7. Length frequency of brook trout taken by ELF personnel at FEX.

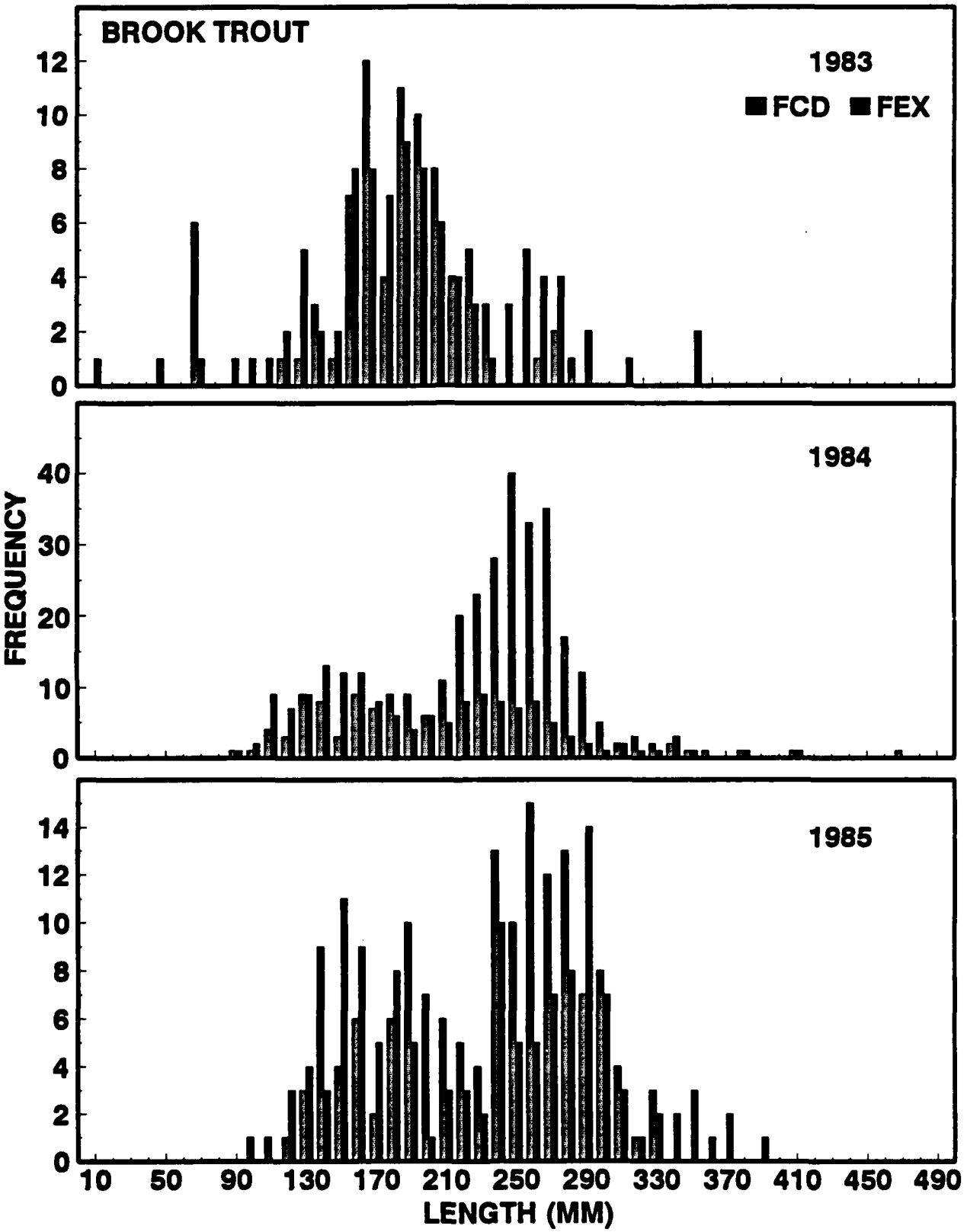


Figure 8.8a. Length frequency distribution of the annual catch of brook trout at FCD and FEX from 1983 to 1985.

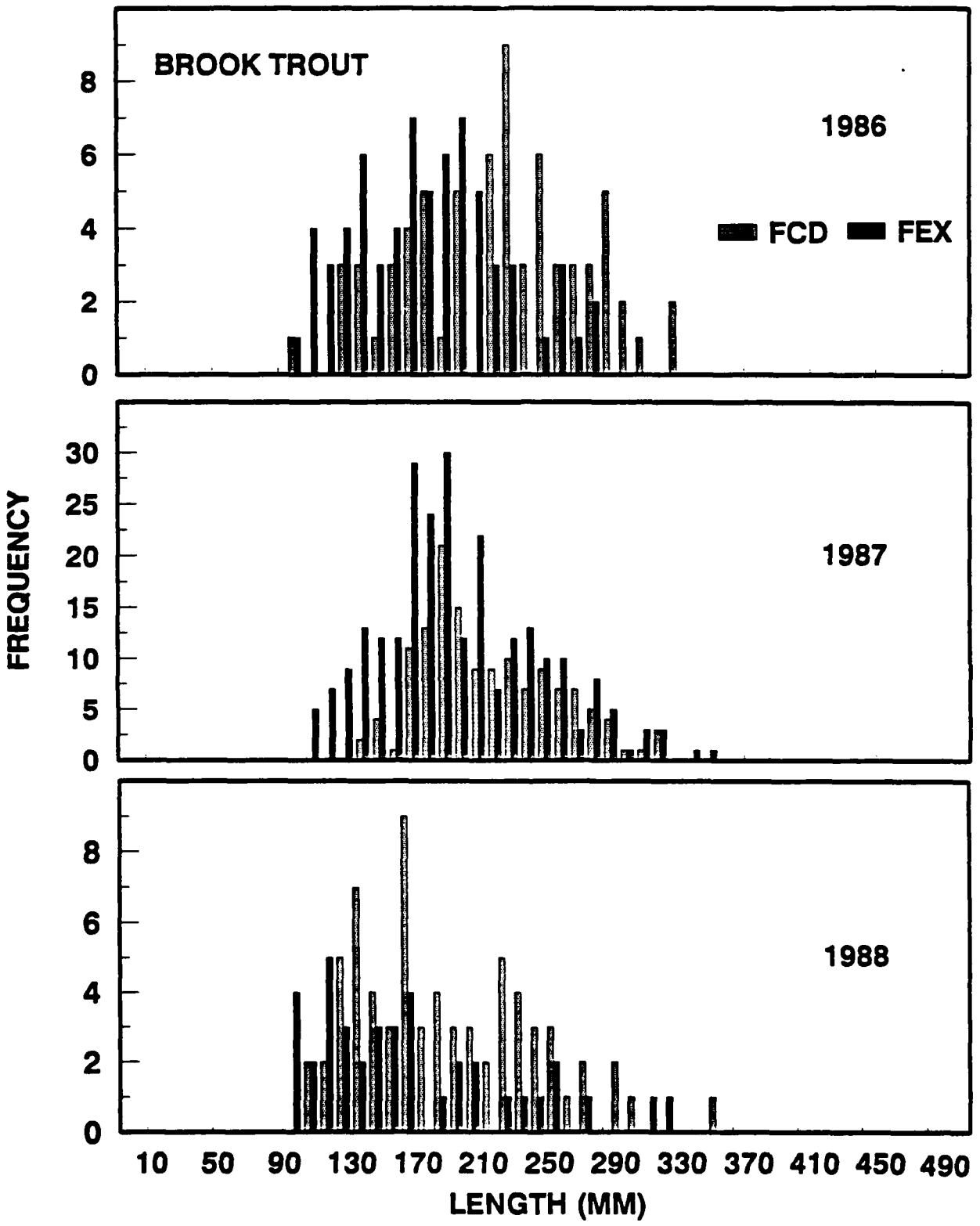


Figure 8.8b. Length frequency distribution of the annual catch of brook trout at FCD and FEX from 1986 to 1988.

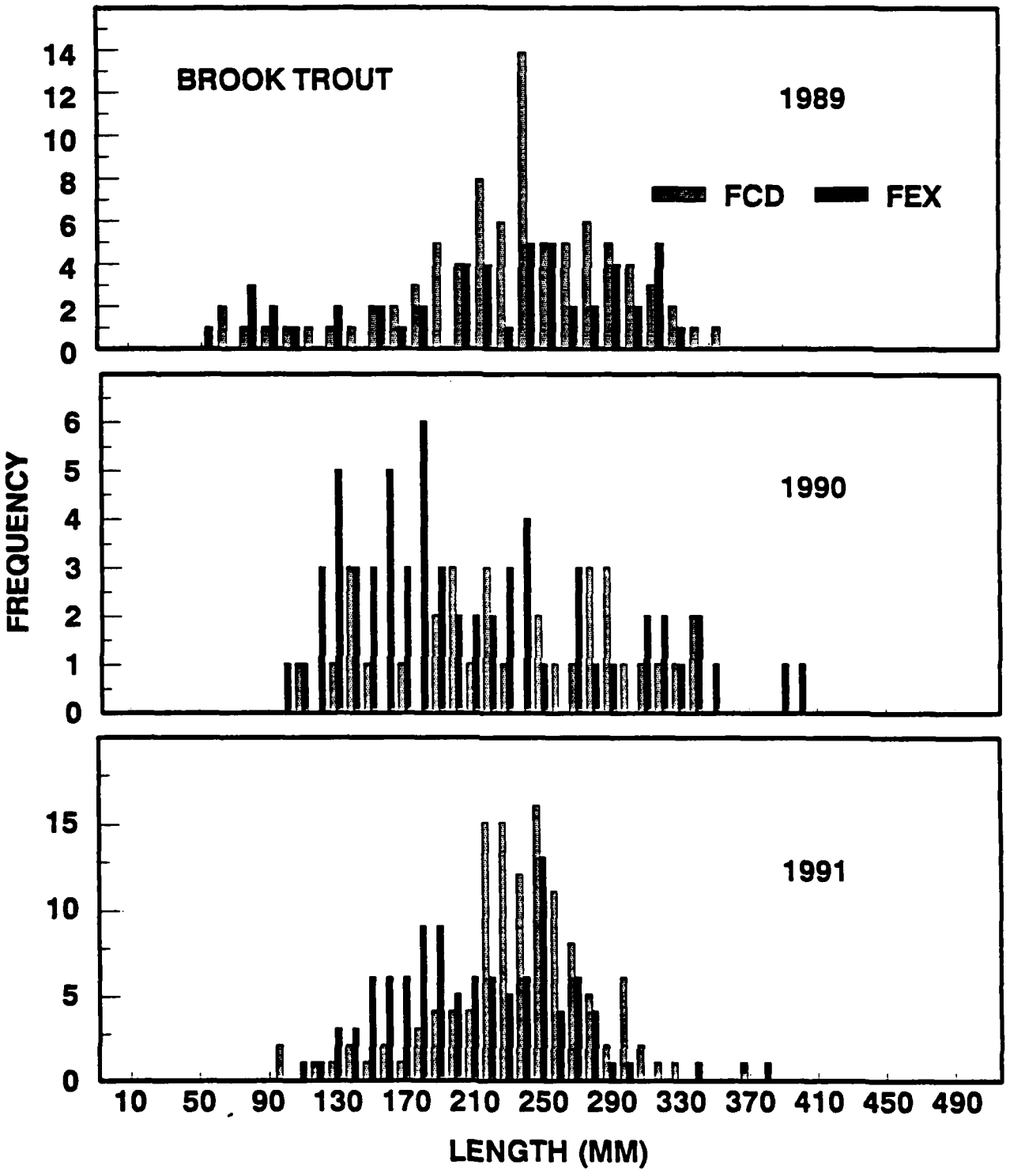


Figure 8.8c. Length frequency distribution of the annual catch of brook trout at FCD and FEX from 1989 to 1991.

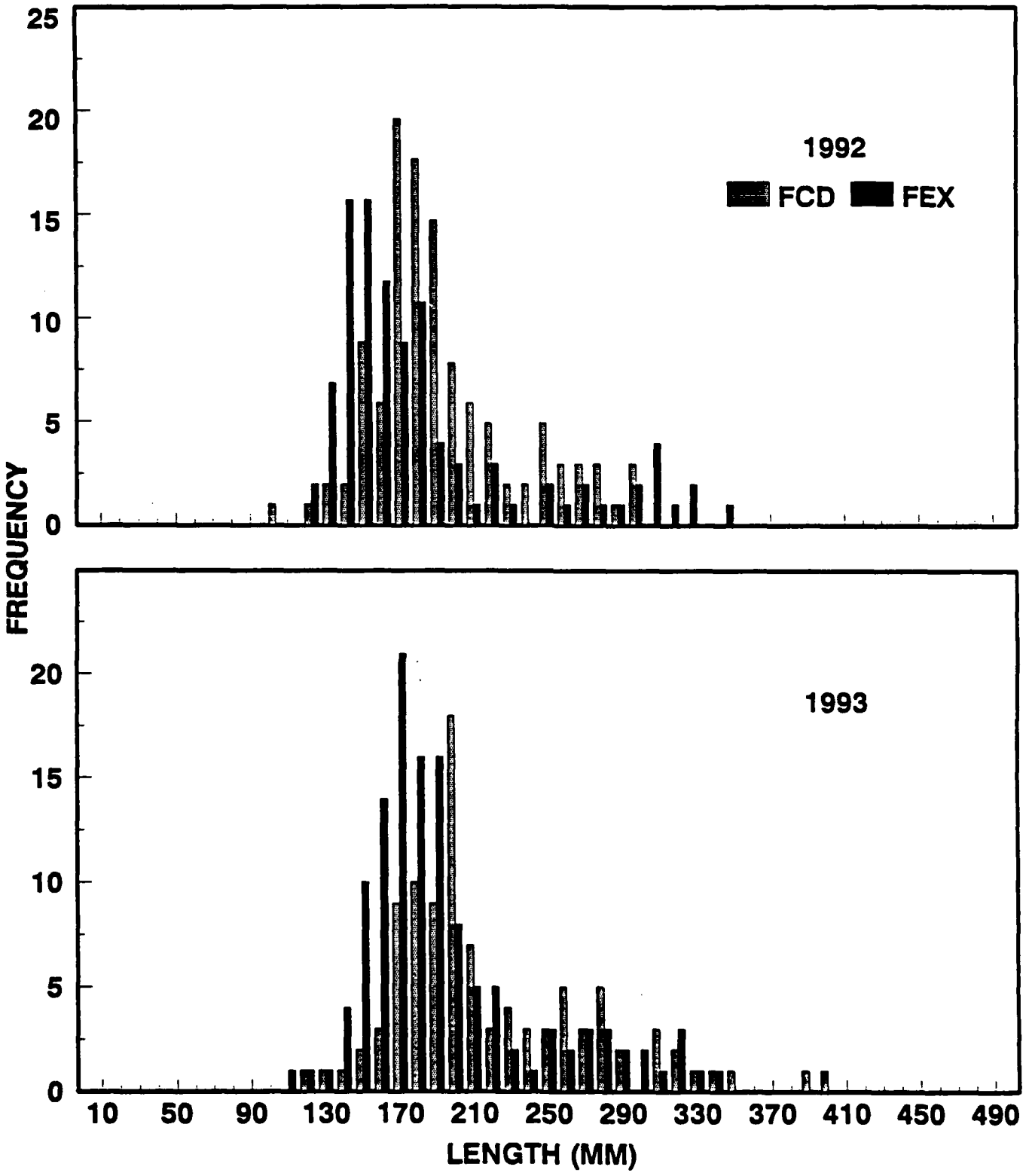


Figure 8.8d. Length frequency distribution of the annual catch of brook trout at FCD and FEX during 1992 and 1993.

Table 8.5. Regression equations used in between site comparison of length versus total radius data for 1983 through 1991.

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)
1989		
FCD	y=111.88 + 297.17x	NS(1,55)
FEX	y=103.52 + 347.91x	(0.60)
1990		
FCD	y=18.47 + 526.10x	NS(1,42)
FEX	y=22.51 + 500.29x	(0.06)
1991		
FCD	y=62.00 + 405.69x	NS(1,77)
FEX	y=45.62 + 410.89x	(0.005)

* SIGNIFICANT p<0.05

Table 8.6. Regression equations used in covariance analysis of between period (pre-, trans-, and fully-operational) comparisons of length versus total scale radius at FCD and FEX.

	EQUATIONS	n	SLOPE
PRE-OPERATIONAL (1983-1985)			
FCD	y=52.01 + 361.59x	119	b
FEX	y=43.65 + 390.16x	112	a
TRANSITIONAL (1986-1988)			
FCD	y=60.79 + 348.58x	139	c
FEX	y=48.55 + 366.82x	221	b
POST-OPERATIONAL (1989-1991)			
FCD	y=68.32 + 391.09x	119	a
FEX	y=40.71 + 456.13x	67	d

NOTE - Overall test for equal slopes using covariance analysis was significant ($p<0.05$) with $F_{(5,765)}=2.35$. Same letters indicate that periods have a similar slope using Tukey - Kramer Multiple Comparison Test, alpha=0.05 (Miller 1986).

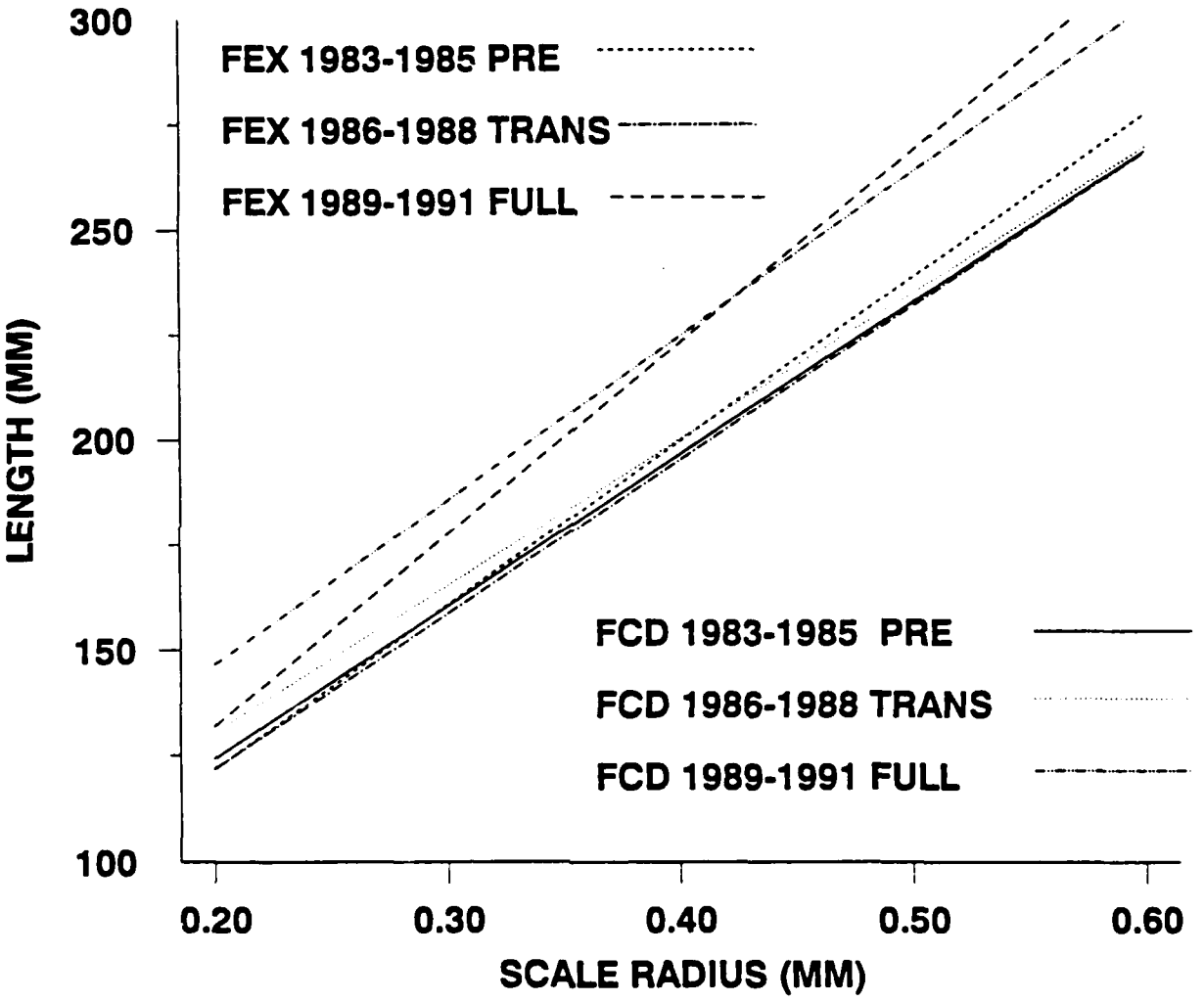
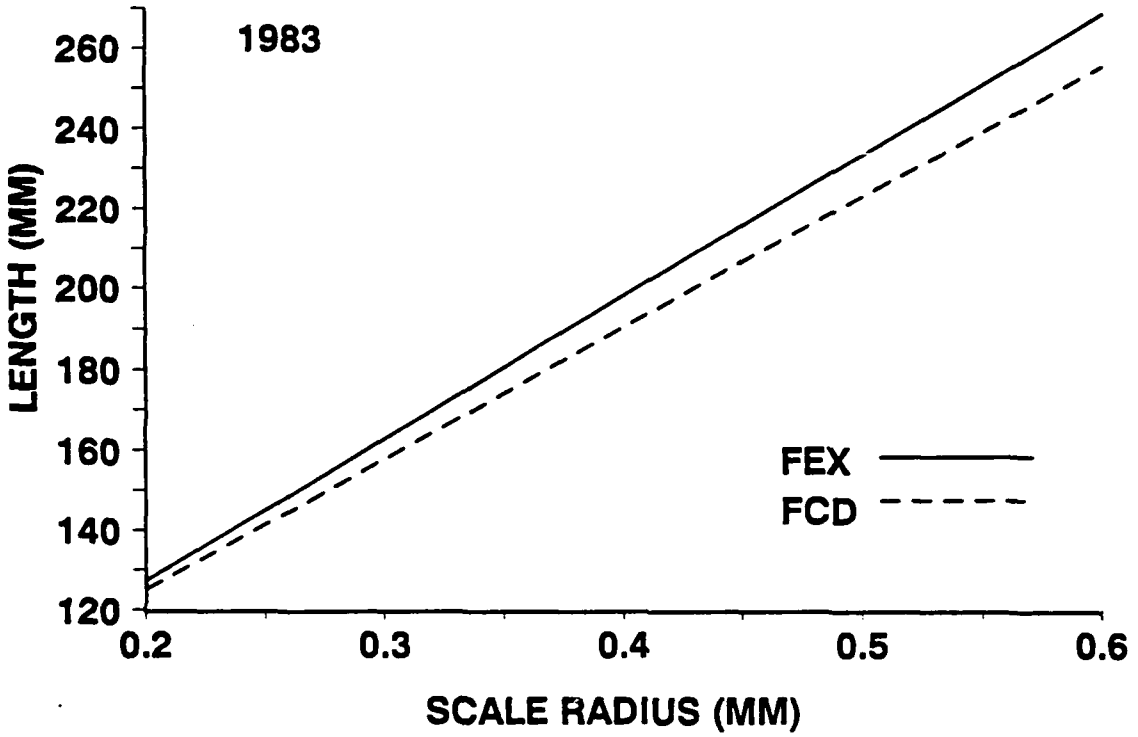


Figure 8.9. Plots of the regression lines used in the covariance analysis of length vs. total scale radius.



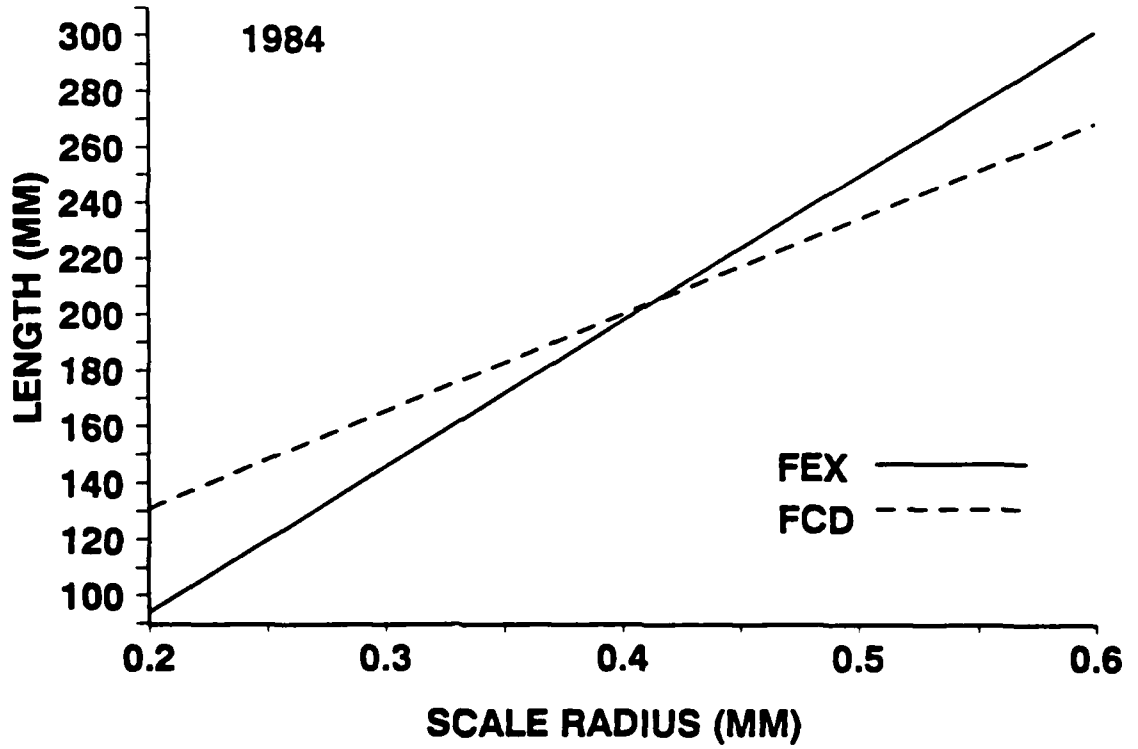
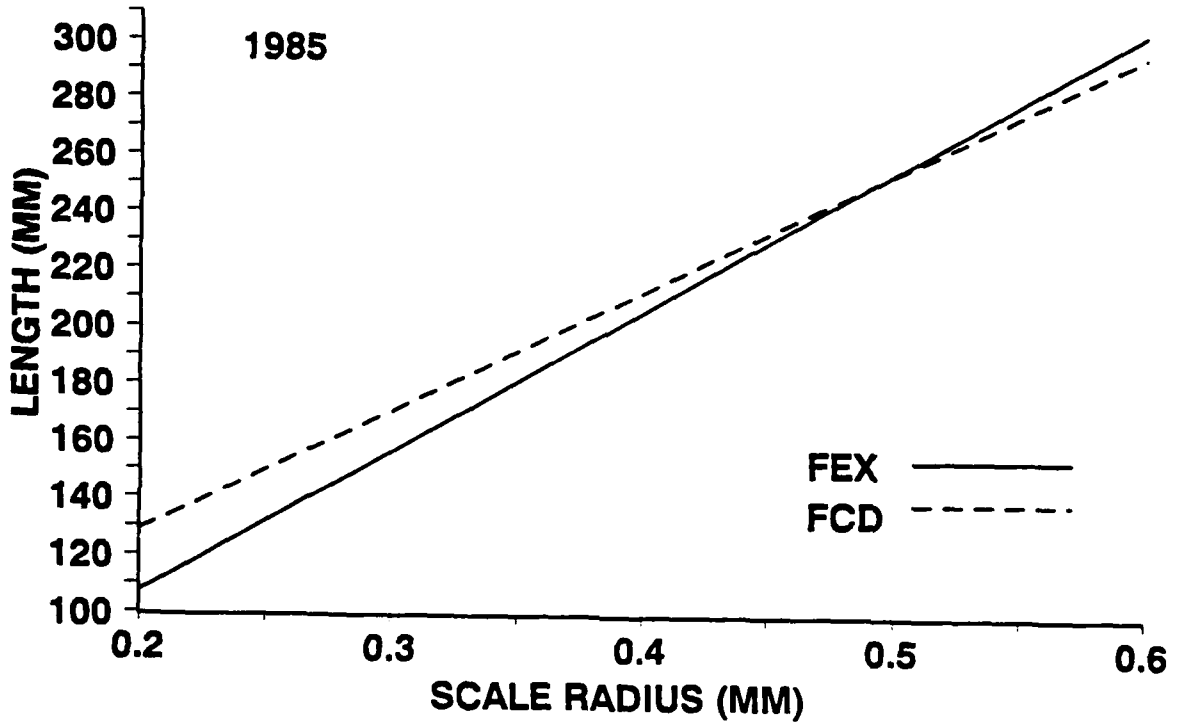


Figure 8.10a. Plots of the regression lines used in analysis of total fish length versus total scale radius between sites in 1983 and 1984.



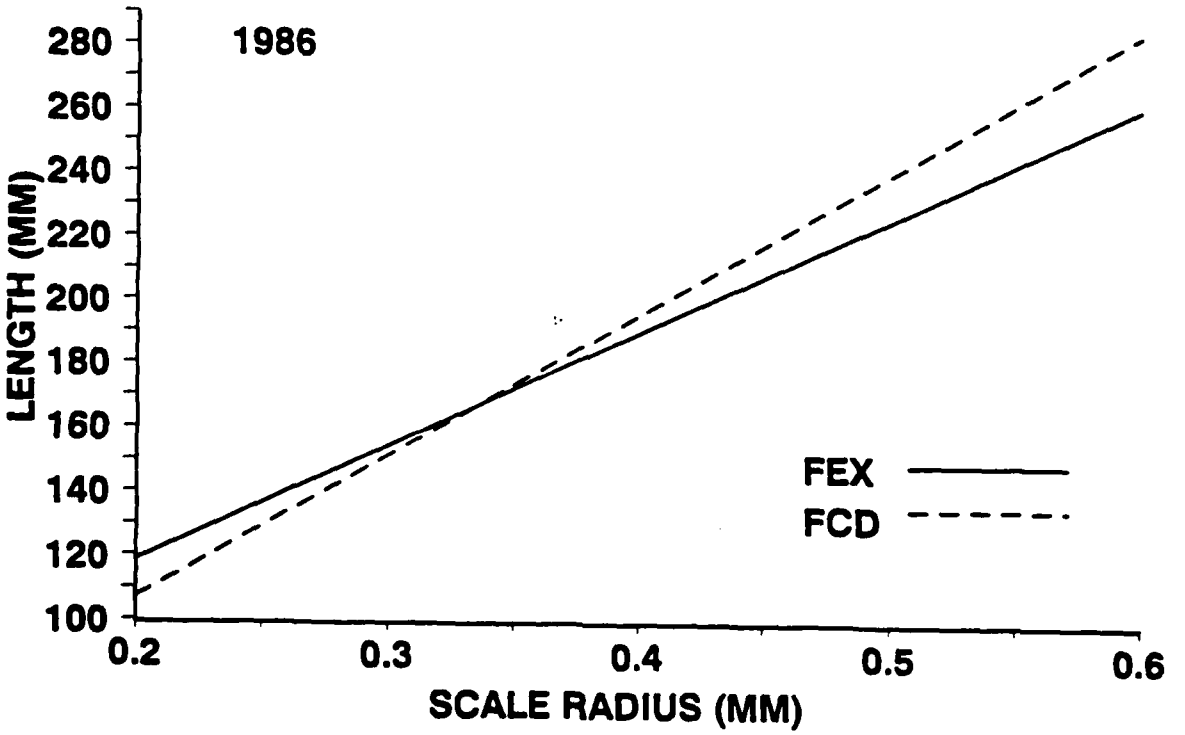
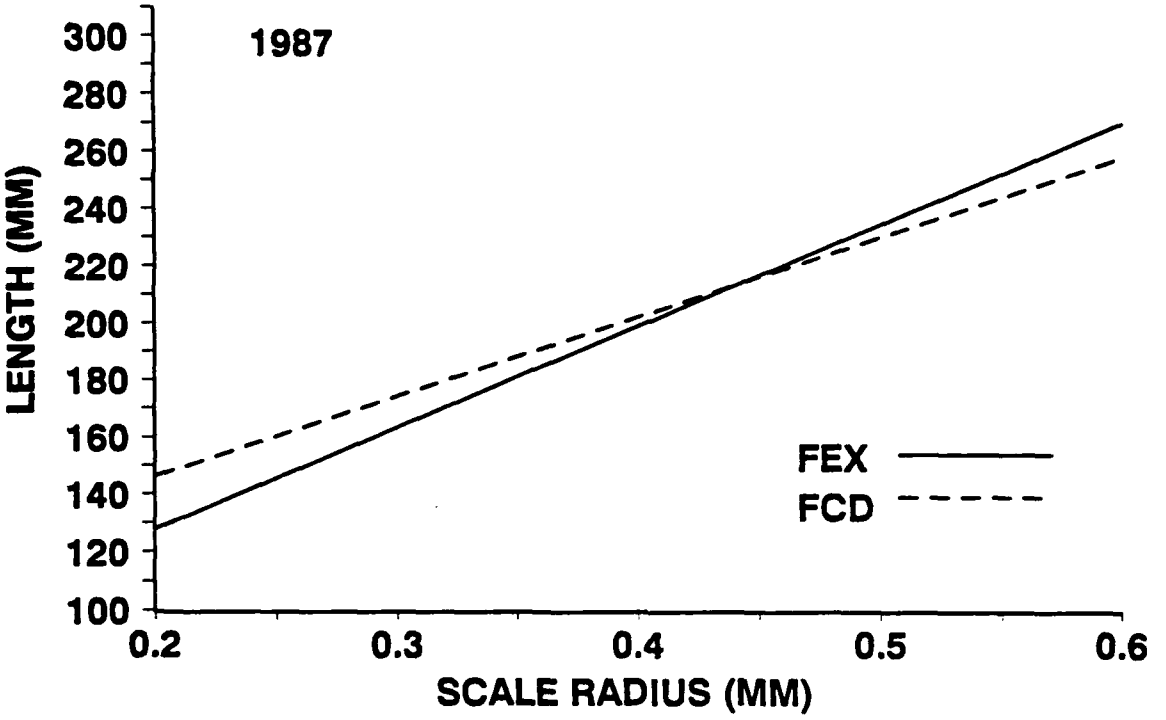


Figure 8.10b. Plots of the regression lines used in analysis of total fish length versus total scale radius between sites in 1985 and 1986.



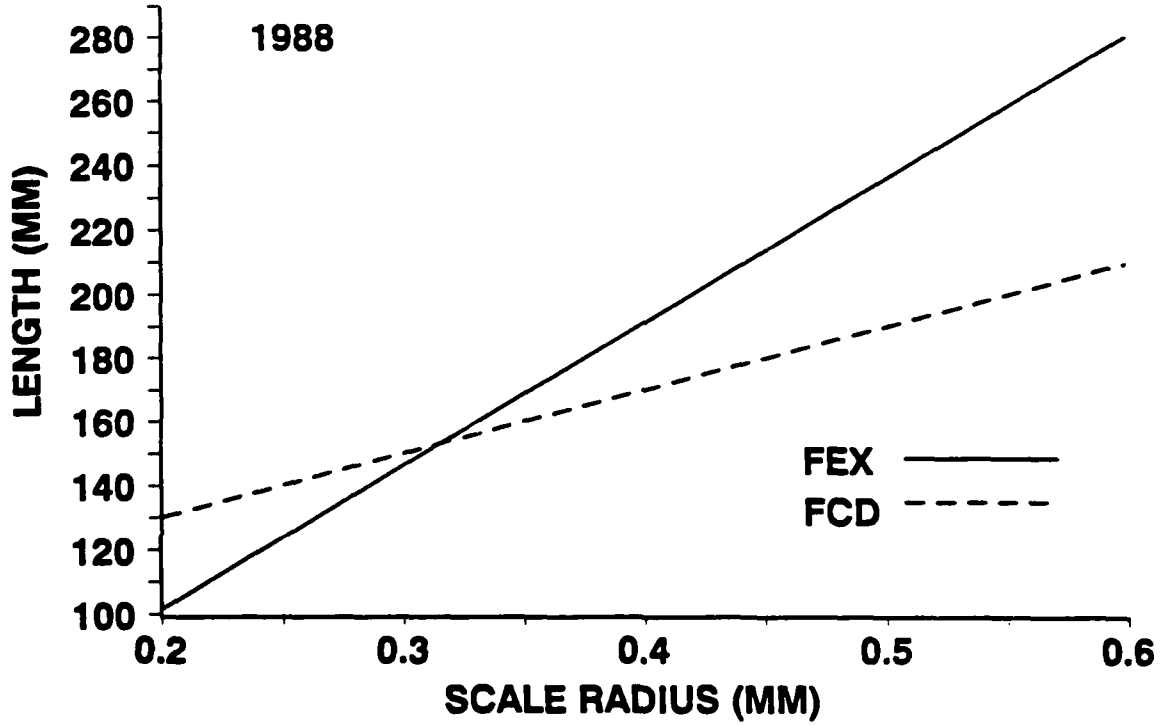


Figure 8.10c. Plots of the regression lines used in analysis of total fish length versus total scale radius between sites in 1987 and 1988.

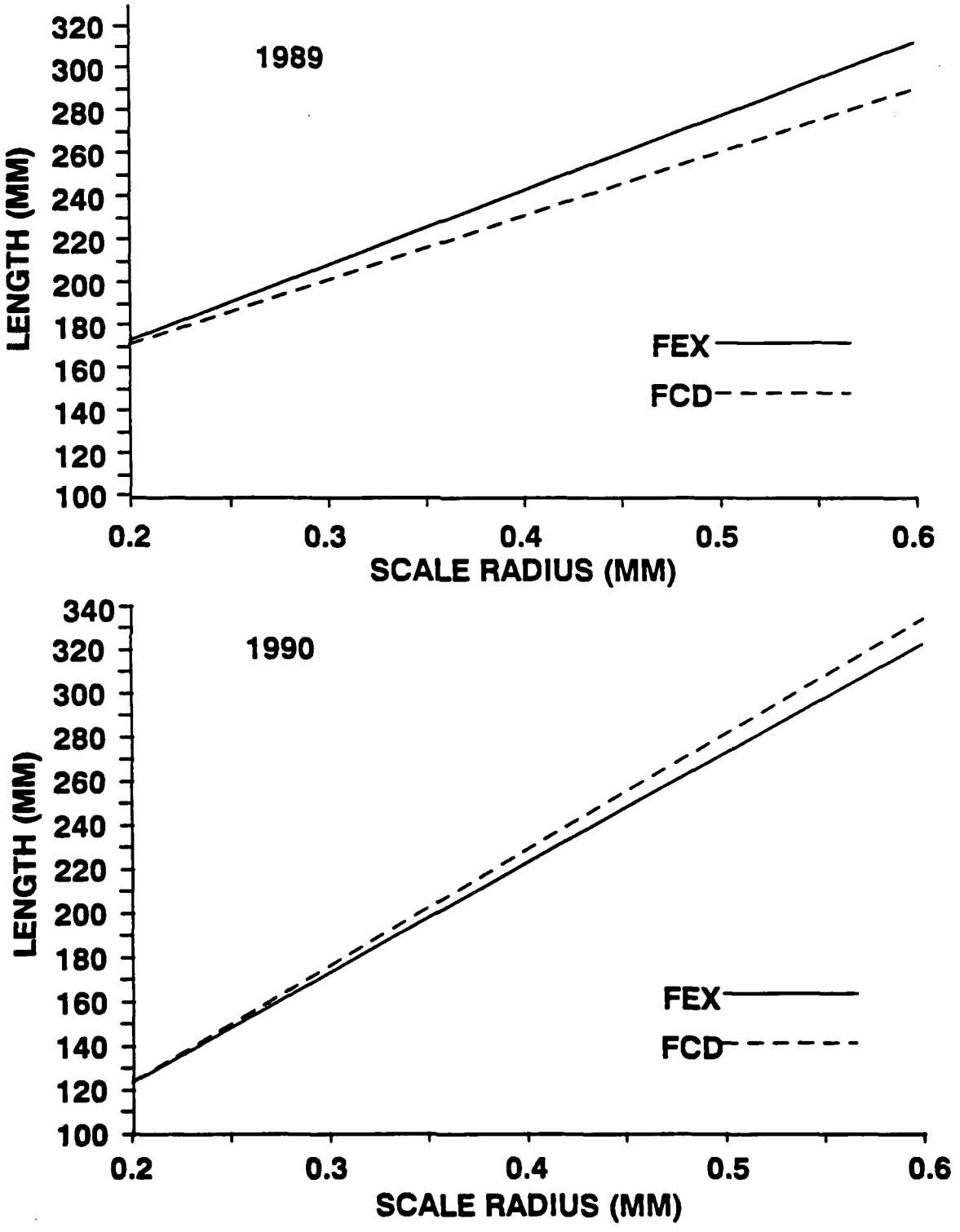


Figure 8.10d. Plots of the regression lines used in the analysis of total length versus total scale radius between sites in 1989 and 1990.

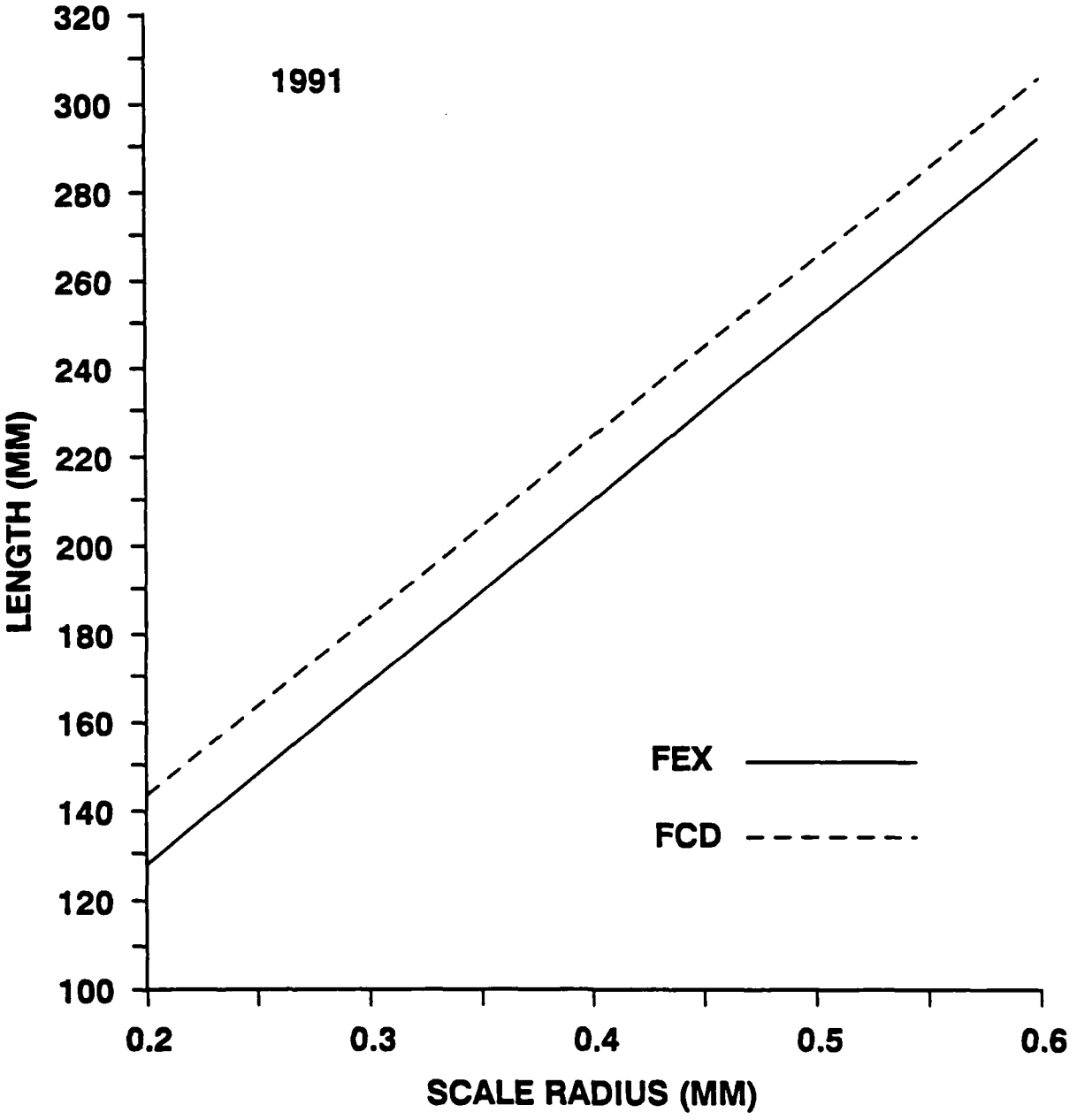


Figure 8.10e. Plots of the regression lines used in analysis of total fish length versus total scale radius between sites in 1991.

growth when compared to populations in Carlander (1969). The length frequency distribution of catches at FCD and FEX for each year are given in Figure 8.8(a-d). Growth analysis was conducted using the length versus total scale radius regression equation for 1983-1991 data. 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 8.5). The only years with significant differences between sites were 1984, 1986 and 1988. Covariance analysis was conducted to test for differences in the slopes of the regression lines between pre-operational, transitional, and fully-operational years (Table 8.6 and Figure 8.9). A significant difference was detected between the three periods ($F_{5,765}=2.35$, $p<0.05$). The slopes of the regression lines for FCD were similar during the pre-operational and transitional periods. Also, the slopes of the regression lines for FEX were similar during the pre-operational and transitional periods. However, during the fully-operational period the slopes of the regression lines at both FCD and FEX differed significantly from what they were in the previous two periods. Plots of all regression lines used in this analysis are shown on Figure 8.10(a-e).

Lee's phenomena (Ricker, 1975) was not observed in data from 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.

G. Brook Trout Condition

Brook trout condition was evaluated by use of 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.

Condition factors were not analyzed in 1993 as a result of error in the measurement of biomass data. Brook trout relative weight ranged from average to slightly below average from 1983 to 1992 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) were at levels near the literature mean. In 1991,

relative weight values decreased to levels similar to 1987 and 1988 (94.0) and remained similar (93.5) in 1992.

Length/weight regression analysis was also used to compare brook trout condition between FEX and FCD over all years from 1983-1992 (Table 8.7). No significant differences in the slopes of the regression lines were observed between sites over all years except in 1985 (ANCOVA, $p>0.05$) (Figure 8.12a-e).

Covariance analysis was conducted to test for differences in the slopes of the regression lines between pre-operational, transitional, and fully-operational years (Figure 8.13). No significant differences were found between the three periods ($F_{5,1784}=1.66$, $p>0.05$) (Table 8.8).

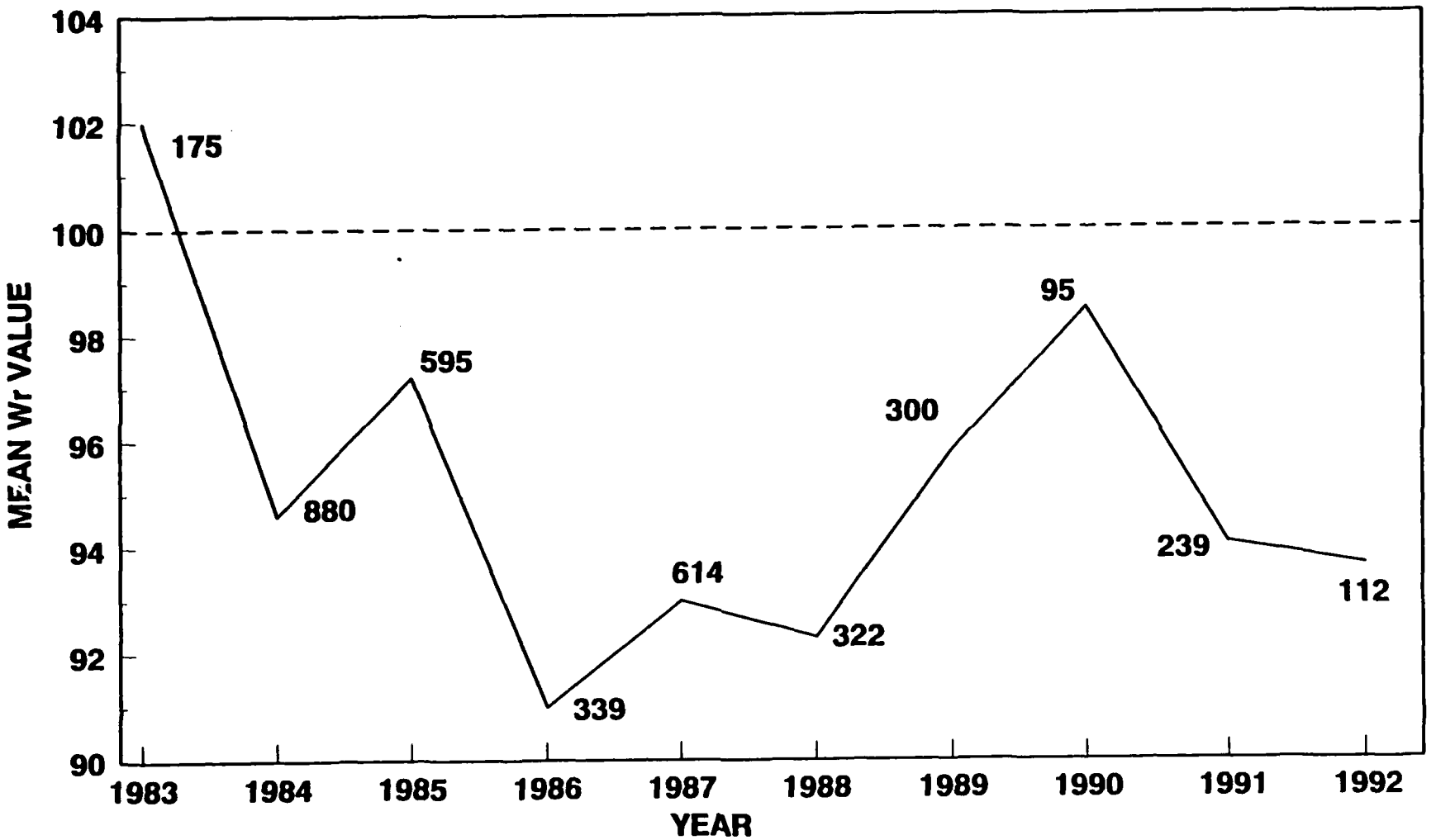


Figure 8.11. Brook trout unweighted relative weight values from the Ford River. Numbers adjacent to means refer to sample size used in calculation.

Table 8.7. Regression equations used in brook trout condition analysis between FEX and FCD in each year.

EQUATION LOG(weight) = a + bLOG(length)
y = log(weight)
x = log(length)

YEAR	FEX (n)	FCD (n)	Slope(df) (F)
1984	y=-5.358+3.143x (115)	y=-5.272+3.115x (251)	NS(1,360) (0.103)
1985	y=-5.767+3.328x (103)	y=-5.528+3.220x (134)	*(1,233) (4.930)
1986	y=-5.181+3.056x (68)	y=-5.391+3.160x (69)	NS(1,133) (0.081)
1987	y=-5.314+3.134x (252)	y=-5.434+3.185x (139)	NS(1,387) (1.030)
1988	y=-5.192+3.073x (39)	y=-5.200+3.077x (69)	NS(1,104) (0.002)
1989	y=-5.464+3.216x (56)	y=-5.510+3.225x (95)	NS(1,147) (0.020)
1990	y=-5.310+3.136x (61)	y=-5.479+3.207x (33)	NS (1,92) (0.269)
1991	y=-5.370+3.160x (103)	y=-5.330+3.150x (120)	NS (1,219) (0.005)
1992	y=-5.666+3.282x (41)	y=-5.518+3.222x (48)	NS (1,85) (0.529)

* SIGNIFICANT alpha = 0.05
NOTE - All F tests from analysis of covariance.

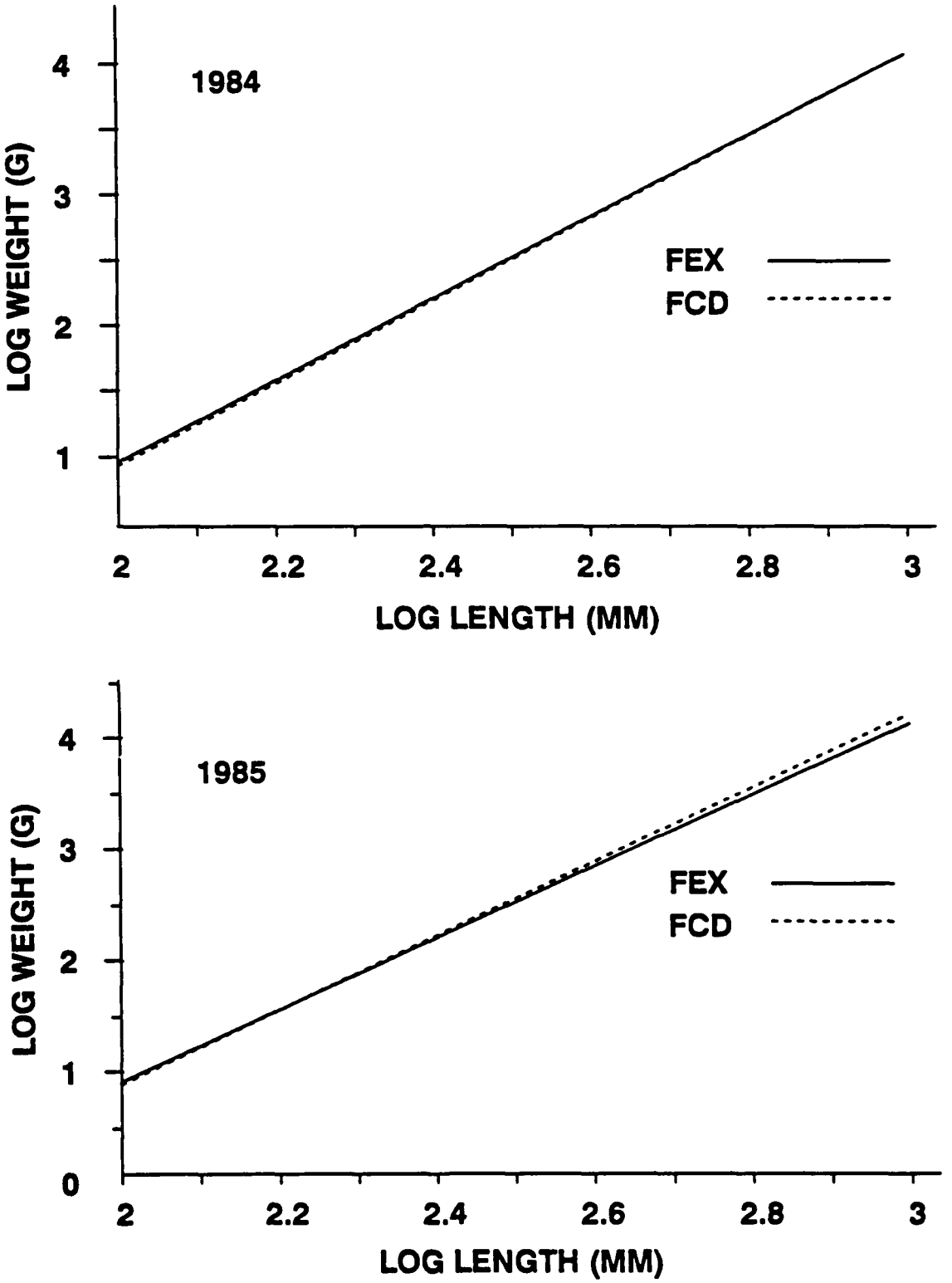


Figure 8.12a. Plot of the regression lines (log wt. vs. log ln.) used in brook trout condition analysis between FCD and FEX in 1984 and 1985.

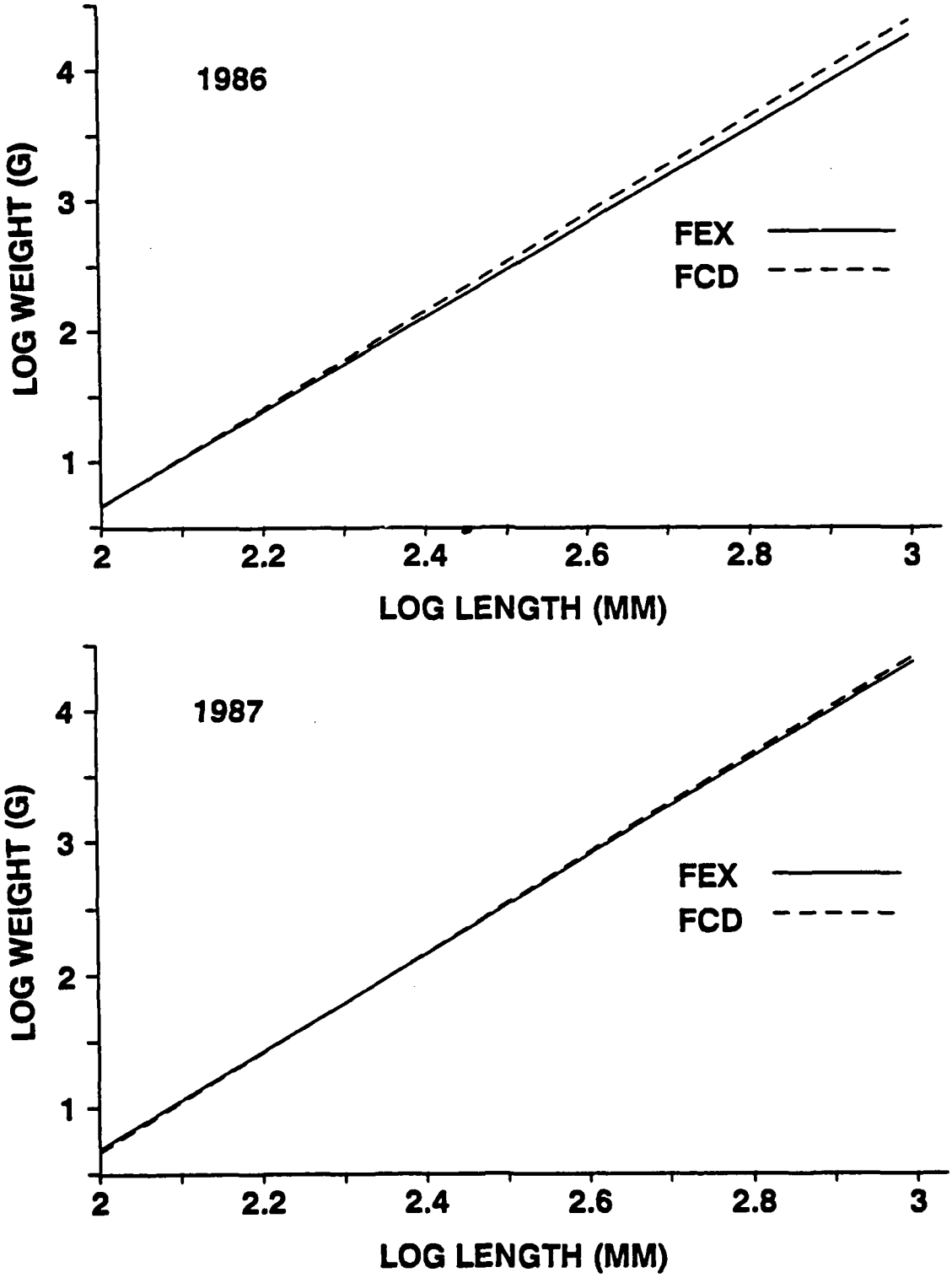


Figure 8.12b. Plot of the regression lines (log weight vs. log length) used in brook trout condition analysis between FCD and FEX in 1986 and 1987.

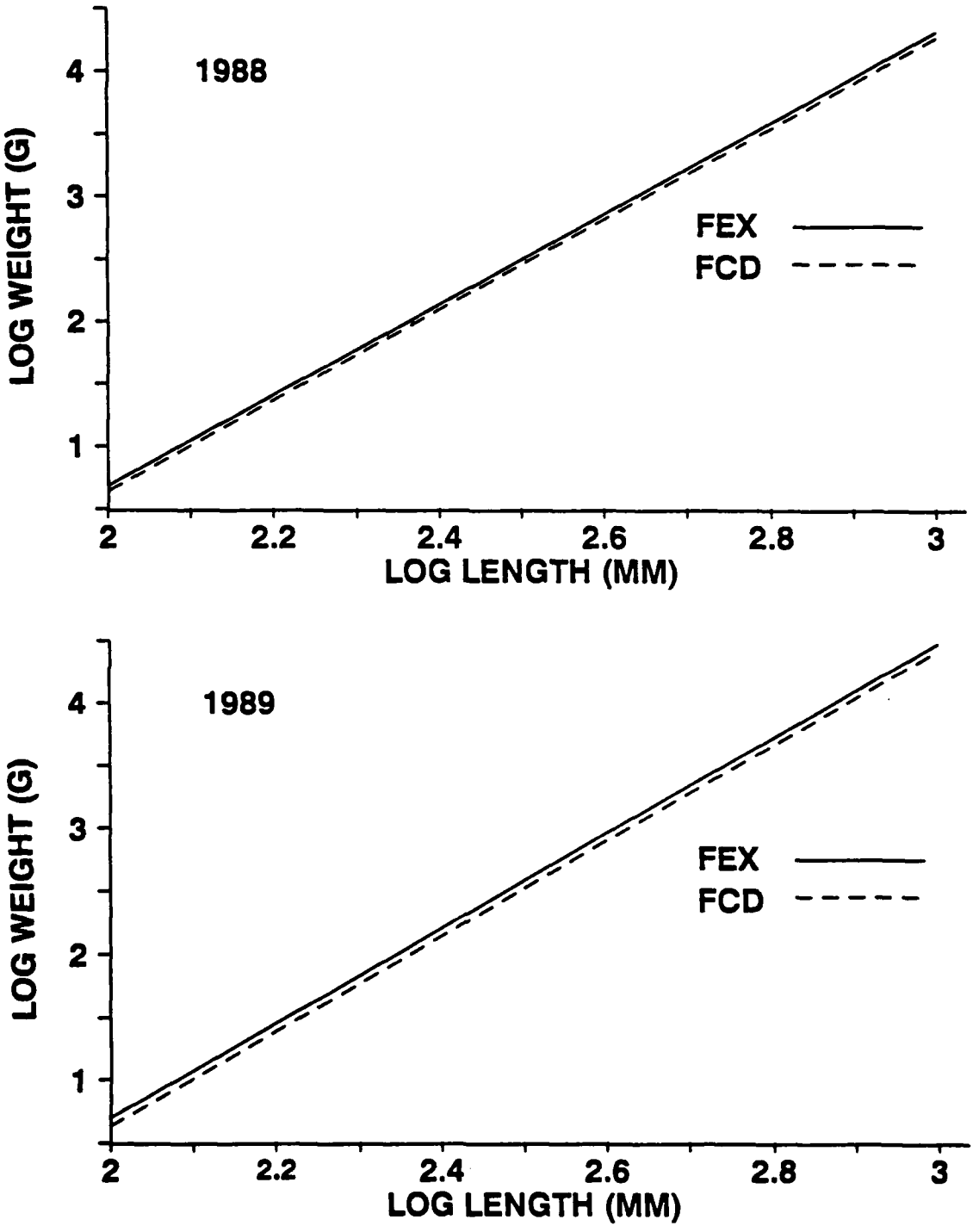
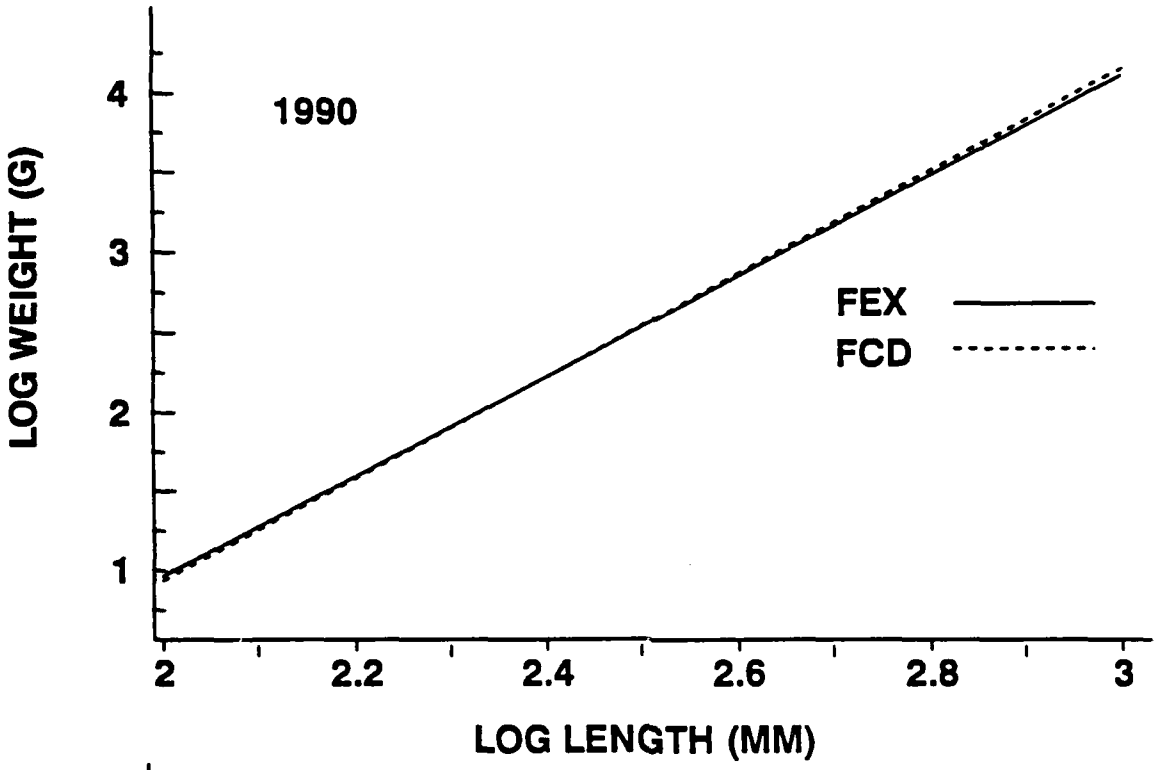


Figure 8.12c. Plot of the regression lines (log weight vs. log length) used in brook trout condition analysis between FCD and FEX in 1988 and 1989.



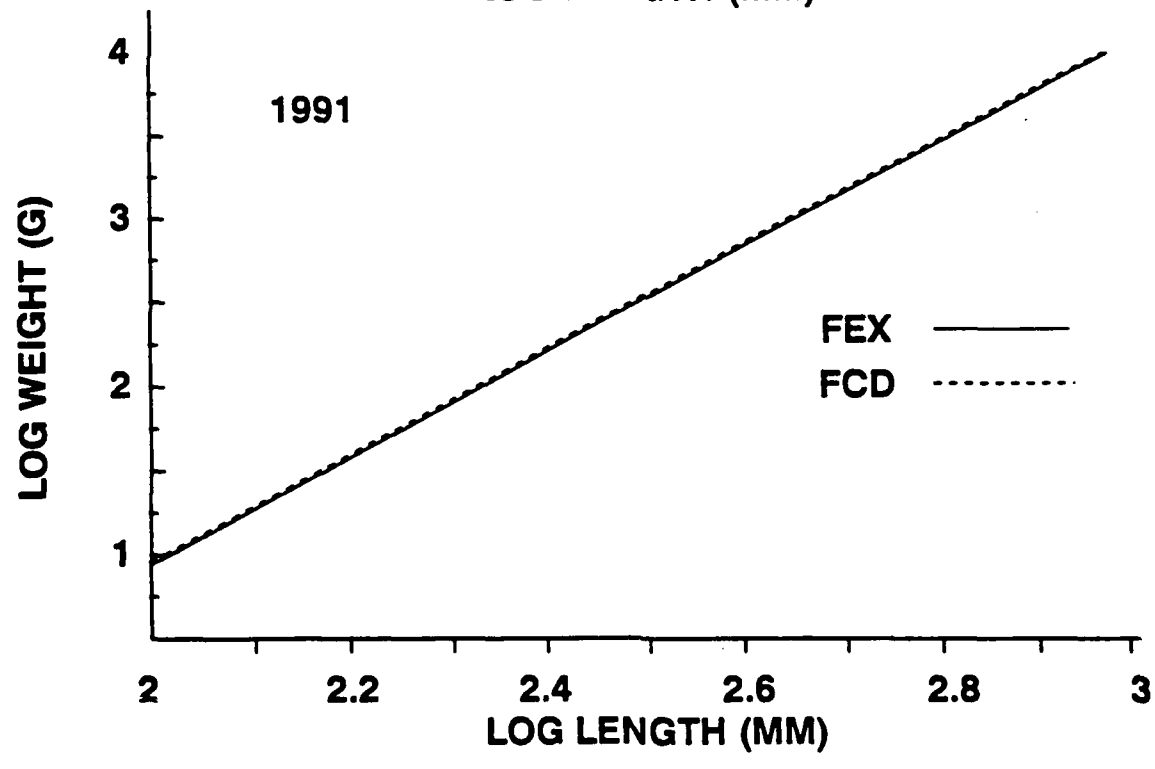


Figure 8.12d. Plot of the regression lines (log wt. vs. log in.) used in brook trout condition analysis between FCD and FEX in 1990 and 1991.

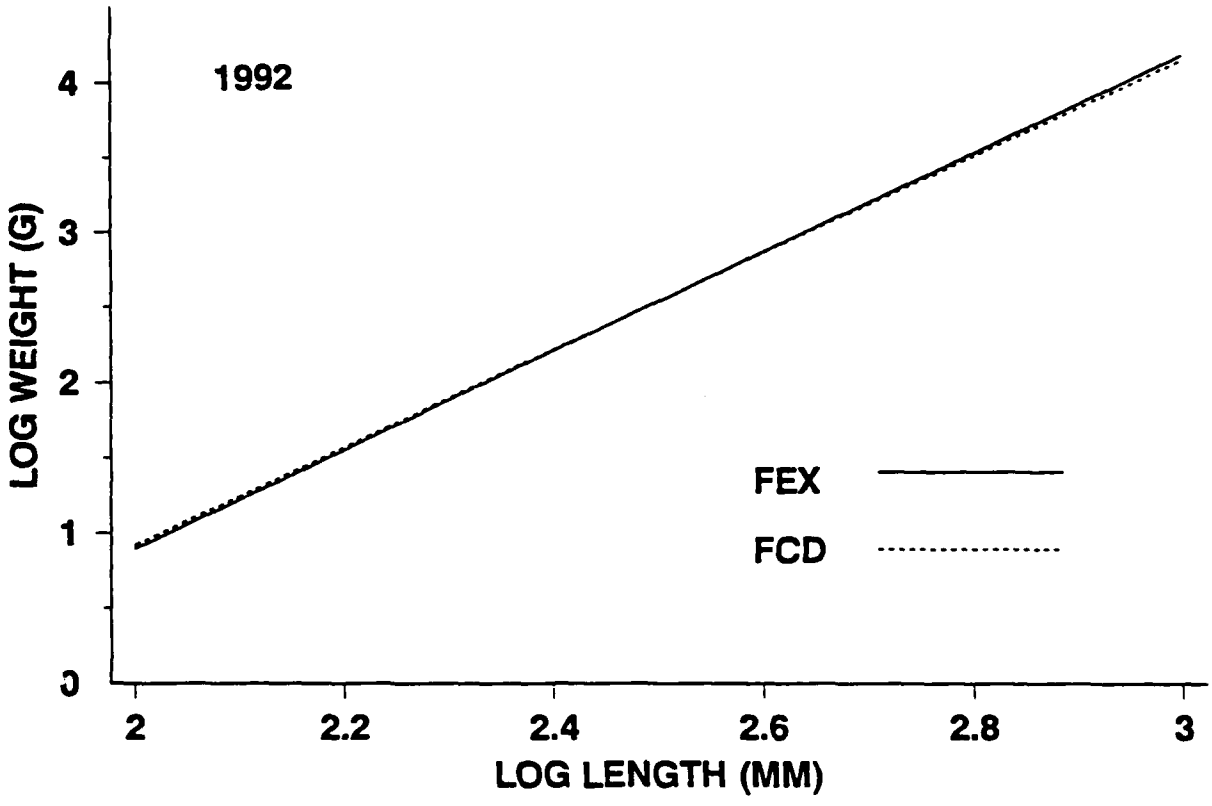


Figure 8.12e. Plot of the regression lines (log wt. vs. log ln.) used in brook trout condition analysis between FCD and FEX in 1992.

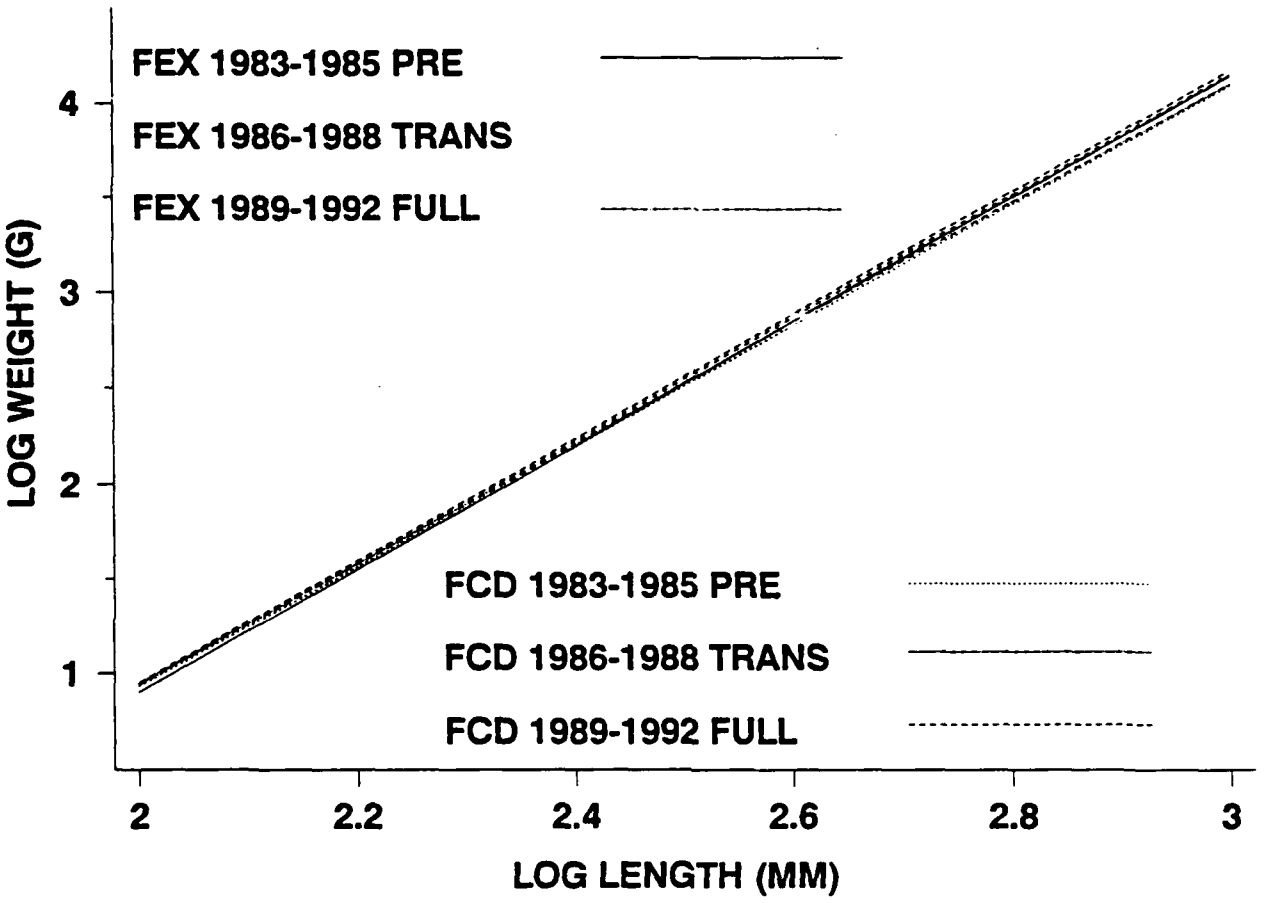


Figure 8.13. Plots of the regression lines used in the covariance analysis of log weight vs. log length.

Table 8.8. Length/weight regression equations used in the covariance analysis of brook trout condition between periods (pre-, trans-, and fully-operational) at FEX and FCD.

		n
PRE-OPERATIONAL (1983-1985)		
FCD	y=-5.39 + 3.16x	385
FEX	y=-5.58 + 3.24x	218
TRANSITIONAL (1986-1988)		
FCD	y=-5.35 + 3.15x	277
FEX	y=-5.32 + 3.13x	359
POST-OPERATIONAL (1989-1992)		
FCD	y=-5.49 + 3.22x	296
FEX	y=-5.48 + 3.21x	261

NOTE - Overall test for differences between slopes was non-significant ($F_{(5,1784)}=1.66$, $p>0.05$).

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