

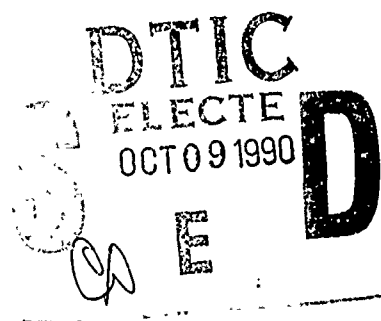
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of the Navy ELF Communications System  
Ecological Monitoring Program

Volume 3 of 3 Volumes:  
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| 19. ABSTRACT (Continue on reverse if necessary and identify by block number)<br>This is the eighth compilation of annual reports for the Navy's ELF Communications System Ecological Monitoring Program. The reports document the progress of eight studies performed during 1989 near the Naval Radio Transmitting Facility -- Republic, Michigan. The purpose of the monitoring is to determine whether electromagnetic fields produced by the ELF Communications System will affect resident biota or their ecological relationships.<br>See reverse for report titles and authors.<br>next page |       |                                                 |                                                                                                                              |                                                      |                         |
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H. Aquatic Ecosystems.  
Burton, T. M.; Stout, R. J.; Taylor, W. W.; Mullen, D.; Marod, S.;  
Eggert, S.; Repert, D.

(M)



## FOREWORD

During 1989, the U.S. Department of the Navy continued to conduct a long-term program to monitor for possible effects to resident biota and their ecological relationships from operation of the Navy's Extremely Low Frequency (ELF) Communications System. These studies were funded by the Space and Naval Warfare Systems Command (SPAWAR) through a contract to IIT Research Institute (IITRI). IITRI provided engineering support and overall program management for the ecological studies. Monitoring projects were funded as subcontract agreements between IITRI and university investigators.

The compiled reports document the technical progress and findings of monitoring projects performed near the Naval Radio Transmitting Facility--Republic, Michigan during 1989. As in the past, each report has been reviewed by four or more scientific peers, and investigators have considered and addressed peer critiques prior to providing a final document for this compilation. The reports are presented without further change or editing by SPAWAR or IITRI.

Data collection for studies at the Naval Radio Transmitting Facility--Clam Lake, Wisconsin were completed during 1989, as scheduled. The results and conclusions of studies of bird species and communities are included in this compilation; a final summary report based on data collected over the entire term of the project should be available by the end of 1990. Final summary reports for the other Wisconsin studies (wetland flora and slime molds) are available from the National Technical Information Service (NTIS).

Past compilations, executive summaries, and engineering reports are also available from NTIS. A listing of all documents prepared since the inception of the program in 1982 follows the index of 1989 annual reports.

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ECOLOGICAL MONITORING PROGRAM

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ECOLOGICAL MONITORING PROGRAM**

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1. Guntenspergen, G.; Keough, J.; Stearns, F.; Wilkum, D. ELF Communications System Ecological Monitoring Program: Wetland Studies--Final Report. IIT Research Institute, Technical Report E06620-2, 1989. 162 pp. plus appendixes.
2. Goodman, E.; Greenebaum, B. ELF Communications System Ecological Monitoring Program: Slime Mold Studies--Final Report. IIT Research Institute, Technical Report E06620-3, 1990. 43 pp. plus appendixes.

**Compilations**

3. Compilation of 1988 Annual Reports of the Navy ELF Communications System Ecological Monitoring Program. IIT Research Institute, Technical Report E06595-6, 1989. Vol. 1, 572 pp.; Vol. 2, 351 pp.; Vol. 3, 449 pp.
4. Compilation of 1987 Annual Reports of the Navy ELF Communications System Ecological Monitoring Program. IIT Research Institute, Technical Report E06595-2, 1988. Vol. 1, 706 pp.; Vol. 2, 385 pp.; Vol. 3, 491 pp.
5. Compilation of 1986 Annual Reports of the Navy ELF Communications System Ecological Monitoring Program. IIT Research Institute, Technical Report E06549-38, 1987. Vol. 1, 445 pp.; Vol. 2, 343 pp.; Vol. 3, 418 pp.
6. Compilation of 1985 Annual Reports of the Navy ELF Communications System Ecological Monitoring Program. IIT Research Institute, Technical Report E06549-26, 1986. Vol. 1, 472 pp.; Vol. 2, 402 pp.; Vol. 3, 410 pp.
7. Compilation of 1984 Annual Reports of the Navy ELF Communications System Ecological Monitoring Program. IIT Research Institute, Technical Report E06549-17, 1985. Vol. 1, 528 pp.; Vol. 2, 578 pp.
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9. Compilation of 1982 Annual Reports of the Navy ELF Communications System Ecological Monitoring Program. IIT Research Institute, Technical Report E06516-5, 1983, 402 pp.

### Electromagnetic Engineering

10. Haradem, D. P.; Gauger, J. R.; Zapotosky, J. E. ELF Communications System Ecological Monitoring Program: Electromagnetic Field Measurements and Engineering Support--1988. IIT Research Institute, Technical Report E06595-5, 1989, 69 pp. plus appendixes.
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13. Brosh, R. M.; Gauger, J. R.; Zapotosky, J. E. ELF Communications System Ecological Monitoring Program: Electromagnetic Field Measurements and Engineering Support--1985. IIT Research Institute, Technical Report E06549-24, 1986, 48 pp. plus appendixes.
14. Brosh, R. M.; Gauger, J. R.; Zapotosky, J. E. ELF Communications System Ecological Monitoring Program: Measurement of ELF Electromagnetic Fields for Site Selection and Characterization--1984. IIT Research Institute, Technical Report E06549-14, 1985, 37 pp. plus appendixes.
15. Enk, J. O.; Gauger, J. R. ELF Communications System Ecological Monitoring Program: Measurement of ELF Electromagnetic Fields for Site Selection and Characterization--1983. IIT Research Institute, Technical Report E06549-10, 1985, 19 pp. plus appendixes.

### Program Summaries

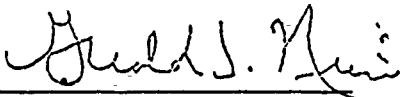
16. Zapotosky, J. E. Extremely Low Frequency (ELF) Communications System Ecological Monitoring Program: Summary of 1988 Progress. IIT Research Institute, Technical Report E06620-1, 1989, 74 pp. plus appendixes.
17. Zapotosky, J. E. Extremely Low Frequency (ELF) Communications System Ecological Monitoring Program: Summary of 1987 Progress. IIT Research Institute, Technical Report E06595-3, 1989, 64 pp. plus appendixes.
18. Zapotosky, J. E. Extremely Low Frequency (ELF) Communications System Ecological Monitoring Program: Summary of 1986 Progress. IIT Research Institute, Technical Report E06549-39, 1987, 63 pp. plus appendixes.
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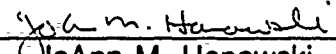
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22. Zapotosky, J. E.; Abromavage, M. M. Extremely Low Frequency (ELF) Communications System Ecological Monitoring Program: Plan and Summary of 1982 Progress. IIT Research Institute, Technical Report E06516-6, 1983, 77 pp. plus appendixes.

ELF COMMUNICATIONS SYSTEM ECOLOGICAL MONITORING PROGRAM:  
BIRD SPECIES AND COMMUNITIES

ANNUAL REPORT: 1988-89  
SUBCONTRACT NUMBER: EO6549-84-011

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Jim Loukes  
Senior Grant Administrator

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**ELF COMMUNICATIONS SYSTEM ECOLOGICAL MONITORING PROGRAM:  
BIRD SPECIES AND COMMUNITIES**

**ANNUAL REPORT: 1988-89  
SUBCONTRACT NUMBER: EO6549-84-011**

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**Report Number: NRRI/TR-89/1**

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## SUMMARY

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

No consistent patterns have yet emerged to demonstrate that birds are more or less abundant on treatment relative to control segments in either state. Few significant differences have been found at the community or species level; differences in one season or year are not always repeated in subsequent years or seasons.

## ABSTRACT

This investigation was designed to isolate effects of electromagnetic (EM) fields produced by extremely low frequency (ELF) antenna systems on bird species breeding in or migrating through Wisconsin and Michigan. Specifically, we seek to determine if bird species richness and abundance differ between areas that are close to the antenna and those that are far enough away to be unaffected by the antenna. We are pursuing this question at both the community and species level. Characteristics examined include total species richness and abundance, abundances of common bird species, and abundances of birds within selected guilds. Our monitoring program includes bird censuses over a five month period from May to September (1986-1989). Additional data were collected in June of 1985 and August-September of 1984. Here we summarize results of our 1989 research activities. The Michigan transmitter began 150 amp tuning and testing intermittently in the first part of May. On the 14th of May, the transmitter began continuous 150 amp operation for 16 hrs/day on weekdays and all day on weekends. On October 7th, the Michigan transmitter began full power continuous operation. We therefore consider May 1989 to be a transitional period, and June through September to be impact periods.

Bird abundance and species diversity were highest in June and July in Michigan and in May and June in Wisconsin. No significant differences in community level parameters (total individuals, total species) were noted in either state. Considerable annual variation in numbers of individuals and species was noted.

Particularly abundant species (all seasons included) included the Nashville Warbler, Ovenbird, White-throated Sparrow, Red-eyed Vireo, Black-capped Chickadee, Hermit Thrush and Golden-crowned Kinglet. The most abundant species present on treatment and control segments varied among seasons and between states. Among "abundant" species (>1 individual observed/500 m segment), five of 34 comparisons (over all seasons) revealed a significant difference between treatment and control

segments in Michigan; four indicated a greater abundance on control segments. Six of 31 comparisons indicated a significant difference between treatment and control segments in Wisconsin; four indicated a greater abundance on control segments.

Previous analyses of vegetation on Wisconsin and Michigan study sites (Blake et al. 1988) revealed differences between treatment and control plots. The difference most likely to influence bird populations was distribution of coniferous and deciduous habitats. Treatment segments supported more coniferous and lowland habitats than did control areas, in both states.

To account for differences in habitat between treatment and control segments in Wisconsin, we paired treatment and control segments on the basis of habitat similarity and compared bird abundances on these paired segments ( $N = 15$  pairs). (The Michigan study is designed as a "before-and-after" experiment and, thus, differences in habitat pose less of a problem for interpretation of bird distribution patterns.) Two of 31 comparisons of abundant species showed significant differences between paired segments in Wisconsin; in both cases, numbers were higher on treatment segments. The final report for Wisconsin will consider effects of vegetation on results from previous years and on distribution patterns of guilds.

Eighteen of 105 comparisons of common species (based on prominence values) between treatment and control segments (all segments) in Michigan and 20 of 100 in Wisconsin were significant. Values were higher on control segments in Michigan in 9 cases; 6 of 20 were more abundant on control than on treatment segments in Wisconsin.

Few species were consistently and significantly more abundant on either treatment or control segments among seasons within a year or within seasons between years. Differences between treatment and control segments are most likely due to habitat differences.

Species were classified into guilds on the basis of foraging behavior and preferred breeding habitat. Few significant differences in abundances of birds within different guilds were found between treatment and control segments. Differences were most consistent for habitat categories, providing further evidence that habitat differences are responsible for many of the observed differences in bird distribution patterns between treatment and control segments.

## INTRODUCTION

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

This investigation was designed to isolate effects of EM fields produced by ELF antenna systems on bird species breeding in or migrating through Wisconsin and Michigan. Specifically, we seek to determine if bird species richness and abundance differ between areas that are close to the antenna and those that are far enough away to be unaffected by the antenna. We are pursuing this question at both the community and species level. Characteristics examined include total species richness and abundance, abundances of common bird species, and abundances of birds within selected guilds.

Our study encompasses spring migration (May), early (June) and late (July) breeding, and early (August) and late (September) fall migration. In this report we summarize our research activities for 1989, our sixth year of participation in the ELF ecological monitoring program. This is the fourth year in which censuses were conducted during all seasons (above). Potential effects of the ELF antenna on birds

may vary among seasons. During migration, birds may be present on study areas for only brief periods. Conversely, breeding birds remain on territories longer (1-3 months), increasing their exposure to EM fields.

Two potential approaches are possible for assessing effects of the ELF antenna on bird communities. These are to (1) compare the affected area (treatment) with a similar control area; or (2) conduct a before-and-after study that incorporates both control and treatment plots. Because our study was initiated in Michigan before the antenna began operation, we can conduct a before-and-after investigation in that state. Our sampling was initiated before the antenna was operational. By following changes in bird numbers over time on areas affected by the antenna and on areas unaffected, we can separate effects of the antenna from effects of more regional variables (e.g., annual variation in rainfall). The Michigan transmitter began 150 amp tuning and testing intermittently in the first part of May. On the 14th of May, the transmitter began continuous 150 amp operation for 16 hrs/day on weekdays and all day on weekends. On October 7th, the Michigan transmitter began full power continuous operation. We therefore consider May 1989 to be a transitional period, and June through September to be impact periods. However, data are analysed in the same manner regardless of EM field impacts.

The antenna has been operating in Wisconsin periodically since 1969 and on a near continuous basis for the past several years. No pre-impact data on bird populations are available and, thus, we cannot assume that the antenna system has not already affected bird communities in Wisconsin. Consequently, we cannot compare transect segments based on similarities in bird species communities. We can, however, account for habitat differences in our analyses. By incorporating analyses of habitat, we will be able to more clearly isolate potential effects of the EM fields produced by the antenna. To this end, we conducted a detailed habitat assessment in 1986 and 1987 to document habitat differences and similarities between control and treatment segments in Wisconsin.



Our rationale for using habitat structure to compare areas is based on the premise that birds select breeding areas (and, to a lesser extent, migration stop-over points) largely on the basis of vegetation structure (Lack 1933; Hilden 1965; James 1971; Cody 1985). Areas of similar vegetation should also have similar bird communities. Although this study design is not as desirable as the before-and-after design in Michigan, studying potential effects in Wisconsin in concert with Michigan provides further insight into the potential long-term effects of the antenna on bird species and communities.

### EXPERIMENTAL DESIGN

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

### STUDY AREAS

Study areas were the same as in previous years and are described in Appendix 1. Three 500-m transect segments (two treatment and one control) in Michigan were partially logged; logging affected about 13, 27, and 36% of the three segments. Two treatment segments in Wisconsin were also partially logged, affecting approximately 18 and 41% of these segments. In an agreement reached with Michigan Department of Natural Resources, most logging along the Michigan study transects will be delayed until 1992. Analyses of annual variation in bird community composition revealed that slightly logged segments (< 5-20%) showed no greater difference between years than did unlogged sites. Segments that were logged over all or most of their length showed significantly greater differences in bird species composition between years than did unlogged segments. Consequently, our analyses of bird distribution patterns between years omit segments logged over more than 20% of their length.

## METHODS

Detailed methods employed in the investigation have been described previously (Hanowski et al. 1987) and are repeated in Appendix 1. Here we review the main points and describe any changes from previous years.

### BIRD CENSUSES

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

We randomly assigned censuses of control and treatment transects (eight 500 m segments/transect) to each of two observers, with the restriction that each observer census the same number of control (80) and treatment (80) segments in each month. Control and treatment transects were censused simultaneously by the two observers.

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

foraging behavior and breeding habitat. Consequently, we used those guilds in analyses of the effects of the ELF antenna during 1989.

## VEGETATION

Methods for sampling vegetation are described in Appendix 1. Habitat variables used in Wisconsin are in Appendix 3; habitat categories used in Michigan are in Appendix 4. We completed sampling of vegetation at all Wisconsin segments during 1987. Vegetation was sampled at 21 points (every 25 m) along each 500 m transect segment. Detailed results of our habitat analyses were presented in Blake et al. (1988) and are not repeated here.

## STATISTICAL ANALYSES

### COMMUNITY PARAMETERS AND ABUNDANT SPECIES

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

We used one-way ANOVA (Sokal and Rohlf 1981) to test for differences between control and treatment segments within a season. Annual differences were examined by season for number of species and individuals using a two-way ANOVA. (Separate papers will examine annual variation in abundance in more detail [e.g., for individual species] and we do not include such analyses in this report.) Because some segments were affected by logging after the initial census in 1985, we excluded logged segments in analyses of annual variation.

Variables used in parametric statistical tests were examined for normality (Wilk-Shapiro test; skewness and kurtosis) and homogeneity of variance (Bartlett's test)

prior to statistical analyses (Sokal and Rohlf 1981). Variables were transformed where necessary (e.g., logarithmic, square root) to reduce skewness, kurtosis, and heterogeneity of variances. Nonparametric tests (Kruskal-Wallis ANOVA) were used for variables that did not meet assumptions, even after transformation.

### EFFECTS OF HABITAT STRUCTURE: WISCONSIN

We used a paired sample approach to control for effects on bird populations of habitat differences that exist between treatment and control segments in Wisconsin (see Blake et al. 1988 for analyses of vegetation). We paired treatment and control segments on the basis of habitat. We used a principal components analysis to reduce the 24 original variables (15 describing structural features of the habitat and 9 describing abundance of dominant tree species) (Appendix 3A) to a smaller set of uncorrelated variables that explained a substantial amount of variation in habitat. The first 7 components had eigenvalues greater than 1.0 and explained 74% of the variation in habitat (Appendix 3b). These components were used to calculate a Euclidean distance between each possible treatment-control pair:

$$D_{ij} = \left( \sum_{k=1}^7 (X_{ik} - X_{jk})^2 \right)^{0.5}$$

where  $D_{ij}$  is the distance between segments  $i$  and  $j$  and  $X_{ik}$  and  $X_{jk}$  are weighted values for principal component  $k$  (for  $k = 7$  components) for segments  $i$  and  $j$ . Distances were calculated with each component weighted by the amount of variation it explained.

We calculated the nearest neighbor distance (i.e., most similar treatment [or control] segment to the control [or treatment] segment being compared) for each segment ( $N = 80$  nearest neighbor distances). These distances were used to determine the mean-nearest neighbor distance among all pairs. We then selected those treatment-control segment pairs that were separated by a distance that was less than the mean nearest neighbor distance among all segments. A total of 15 segment pairs met this criterion. We then used a paired sample test (t-test or Wilcoxon matched pairs

signed ranks test) to compare differences in bird abundances between treatment and control segments. Here we report results from 1989 only.

### COMMON SPECIES

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

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

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

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

### EDGE EFFECTS

Previous analyses have considered the possibility that differences between treatment and control segments were due to edge effects related to the right-of-way corridor. We found no indication that such an effect exists (Hanowski et al. 1987, Blake et al. 1988) and do not consider the question in this report.

## PROBABILITY VALUES

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

## RESULTS

### SPECIES RICHNESS AND ABUNDANCE OF INDIVIDUALS

#### 1989 results

Total number of species and individuals observed varied among seasons on control and treatment transects in both states (Tables 1, 2). Number of observations for all species are in Appendix 5. Total abundance was highest during June and July in Michigan and May and June in Wisconsin (Table 1). Abundance was low in Michigan during May as most migrants had not yet returned from wintering grounds. Part of the difference between states was due to differences in census date; censusing in Wisconsin began 7 to 10 days after the Michigan censusing was completed. Trends in abundance between treatment and control segments were not consistent (i.e., always greater on treatment or on control segments) across seasons in Michigan or Wisconsin (Table 2). No significant differences in mean number of individuals observed per segment were noted in either state (Table 2). When we based comparisons of individuals on paired treatment and control segments in Wisconsin (Table 3), mean number of individuals observed was greater on treatment segments in July, but not in any other month (Table 3).

Species' abundance patterns generally followed those for individuals (Table 2). Species richness was highly correlated with individuals per segment in Michigan ( $r = 0.95$ ) and Wisconsin ( $r = 0.96$ ). Mean number of species recorded per 500 m segment did not differ between treatment and control segments in any season (Table 2). No significant differences in number of species were noted between paired segments in Wisconsin (Table 3).

Table 1. Total numbers of individuals (indiv.) and species observed on treatment (T) and control (C) transects in Michigan and Wisconsin, 1985-1989. A combined species-total for treatment and control segments is in parentheses.

|                  |         | 1985 |   | 1986    |      | 1987    |      | 1988    |      | 1989    |      |
|------------------|---------|------|---|---------|------|---------|------|---------|------|---------|------|
|                  |         | T    | C | T       | C    | T       | C    | T       | C    | T       | C    |
| <u>MICHIGAN</u>  |         |      |   |         |      |         |      |         |      |         |      |
| May:             |         |      |   |         |      |         |      |         |      |         |      |
| indiv.           |         |      |   | 949     | 1210 | 775     | 888  | 815     | 939  | 570     | 607  |
| species          |         |      |   | 54 (76) | 69   | 50 (67) | 62   | 53 (66) | 56   | 44 (60) | 46   |
| June:            |         |      |   |         |      |         |      |         |      |         |      |
| indiv.           | 1629    | 1327 |   | 1098    | 1169 | 1131    | 1162 | 1061    | 1014 | 983     | 1020 |
| species          | 70 (81) | 72   |   | 60 (74) | 68   | 71 (81) | 73   | 70 (89) | 77   | 70 (83) | 71   |
| July:            |         |      |   |         |      |         |      |         |      |         |      |
| indiv.           |         |      |   | 938     | 978  | 1136    | 1258 | 891     | 907  | 994     | 1039 |
| species          |         |      |   | 59 (75) | 63   | 68 (81) | 73   | 69 (83) | 68   | 63 (77) | 68   |
| August:          |         |      |   |         |      |         |      |         |      |         |      |
| indiv.           |         |      |   | 380     | 478  | 682     | 610  | 564     | 469  | 791     | 551  |
| species          |         |      |   | 53 (61) | 46   | 59 (68) | 54   | 50 (66) | 51   | 62 (69) | 52   |
| September:       |         |      |   |         |      |         |      |         |      |         |      |
| indiv.           |         |      |   | 402     | 627  | 634     | 501  | 469     | 574  | 505     | 435  |
| species          |         |      |   | 36 (55) | 48   | 46 (55) | 41   | 46 (60) | 47   | 48 (60) | 45   |
| <u>WISCONSIN</u> |         |      |   |         |      |         |      |         |      |         |      |
| May:             |         |      |   |         |      |         |      |         |      |         |      |
| indiv.           |         |      |   | 1396    | 1452 | 1305    | 1302 | 1105    | 1142 | 1011    | 1065 |
| species          |         |      |   | 67 (78) | 62   | 72 (83) | 62   | 68 (82) | 69   | 68 (79) | 65   |
| June:            |         |      |   |         |      |         |      |         |      |         |      |
| indiv.           | 1548    | 1348 |   | 1207    | 1050 | 1358    | 1439 | 818     | 839  | 979     | 1016 |
| species          | 76 (81) | 66   |   | 66 (72) | 57   | 69 (76) | 65   | 68 (82) | 62   | 65 (79) | 67   |
| July:            |         |      |   |         |      |         |      |         |      |         |      |
| indiv.           |         |      |   | 858     | 808  | 861     | 761  | 644     | 693  | 805     | 690  |
| species          |         |      |   | 50 (64) | 54   | 66 (81) | 63   | 53 (67) | 55   | 49 (64) | 54   |
| August:          |         |      |   |         |      |         |      |         |      |         |      |
| indiv.           |         |      |   | 522     | 477  | 606     | 653  | 400     | 461  | 486     | 451  |
| species          |         |      |   | 40 (47) | 38   | 51 (63) | 50   | 47 (57) | 44   | 47 (56) | 40   |
| September:       |         |      |   |         |      |         |      |         |      |         |      |
| indiv.           |         |      |   | 682     | 644  | 819     | 880  | 403     | 426  | 729     | 654  |
| species          |         |      |   | 31 (48) | 39   | 46 (56) | 42   | 36 (50) | 43   | 46 (55) | 44   |

Table 2. Mean observations in a 500m segment on control (C) and treatment (T) segments, 1985-89; significance of one-way ANOVAs between treatment and control segments is shown for each year. For two-way ANOVAs, T=treatment effect, Y=year effect, and I=interaction. Two-way ANOVAs were calculated with logged segments excluded.

| Month            | 1985   |      | 1986   |      | 1987  |      | 1988   |      | 1989 |      | ANOVA |     |    |
|------------------|--------|------|--------|------|-------|------|--------|------|------|------|-------|-----|----|
|                  | T      | C    | T      | C    | T     | C    | T      | C    | T    | C    | T     | Y   | I  |
| <b>MICHIGAN</b>  |        |      |        |      |       |      |        |      |      |      |       |     |    |
| May:             |        |      |        |      |       |      |        |      |      |      |       |     |    |
| indiv.           |        |      | 23.7** | 30.3 | 19.4  | 22.2 | 20.4 * | 23.5 | 14.3 | 15.2 | ***   | *** |    |
| species          |        |      | 9.7**  | 12.9 | 8.1** | 10.8 | 9.5    | 11.0 | 7.7  | 8.2  | ***   | *** |    |
| June:            |        |      |        |      |       |      |        |      |      |      |       |     |    |
| indiv.           | 40.8** | 33.3 | 27.5   | 29.2 | 28.3  | 29.1 | 26.5   | 25.4 | 24.6 | 25.5 |       | *** | ** |
| species          | 14.2   | 14.0 | 11.1   | 12.5 | 12.5  | 12.9 | 12.4   | 13.1 | 11.7 | 12.9 | .     | *** |    |
| July:            |        |      |        |      |       |      |        |      |      |      |       |     |    |
| indiv.           |        |      | 23.5   | 24.5 | 28.4  | 31.5 | 22.1   | 22.7 | 24.9 | 26.0 |       | *** |    |
| species          |        |      | 9.6    | 10.4 | 11.8  | 14.4 | 11.1   | 11.0 | 10.8 | 11.8 | **    | *** |    |
| August:          |        |      |        |      |       |      |        |      |      |      |       |     |    |
| indiv.           |        |      | 9.6    | 12.0 | 17.1  | 15.3 | 14.1   | 11.7 | 19.8 | 13.8 |       | *** |    |
| species          |        |      | 4.6    | 5.2  | 7.3   | 6.7  | 6.1    | 5.8  | 7.7  | 6.5  |       | *** |    |
| September:       |        |      |        |      |       |      |        |      |      |      |       |     |    |
| indiv.           |        |      | 10.1 * | 15.7 | 15.9  | 12.5 | 11.7   | 14.4 | 12.6 | 10.9 |       |     | .  |
| species          |        |      | 4.0    | 5.6  | 5.4   | 5.1  | 5.0    | 5.6  | 5.0  | 4.7  |       |     | .  |
| <b>WISCONSIN</b> |        |      |        |      |       |      |        |      |      |      |       |     |    |
| May:             |        |      |        |      |       |      |        |      |      |      |       |     |    |
| indiv.           |        |      | 34.9   | 36.3 | 32.6  | 32.5 | 27.6   | 28.6 | 25.3 | 26.6 |       | *** |    |
| species          |        |      | 13.4   | 12.8 | 13.1  | 12.2 | 13.3   | 13.6 | 11.5 | 12.3 |       | .   |    |
| June:            |        |      |        |      |       |      |        |      |      |      |       |     |    |
| indiv.           | 38.7** | 33.8 | 30.2 * | 26.3 | 34.0  | 36.0 | 20.5   | 21.0 | 24.5 | 25.4 |       | *** | .  |
| species          | 15.0 * | 13.0 | 12.3   | 11.3 | 14.3  | 14.4 | 11.4   | 10.6 | 12.0 | 11.2 | .     | *** |    |
| July:            |        |      |        |      |       |      |        |      |      |      |       |     |    |
| indiv.           |        |      | 21.5   | 20.2 | 21.5  | 19.0 | 16.1   | 17.3 | 20.1 | 17.3 |       | **  |    |
| species          |        |      | 8.4    | 7.8  | 9.7   | 8.8  | 7.7    | 7.9  | 8.8  | 7.8  | .     | .   |    |
| August:          |        |      |        |      |       |      |        |      |      |      |       |     |    |
| indiv.           |        |      | 13.1   | 12.2 | 15.2  | 16.3 | 10.0   | 11.5 | 12.2 | 11.3 |       | *** |    |
| species          |        |      | 5.3    | 4.8  | 5.8   | 6.5  | 4.6    | 4.6  | 5.1  | 5.0  |       | **  |    |
| September:       |        |      |        |      |       |      |        |      |      |      |       |     |    |
| indiv.           |        |      | 17.1   | 16.0 | 20.5  | 22.0 | 10.1   | 10.7 | 18.2 | 16.4 |       | *** |    |
| species          |        |      | 5.3    | 5.3  | 6.1   | 6.8  | 4.1    | 4.2  | 5.9  | 5.8  |       | *** |    |

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



Table 3. Mean number of observations in Wisconsin in 1989 on all treatment (T) and control (C) segments and on paired segments; Segments were paired (N = 15 pairs) on the basis of similarities in vegetation. Differences between paired segments were tested with paired t-tests. Mean values are given for species only if they showed a significant difference between paired segments. See Tables 2 and 4 for results based on all segments.

| Species                      | All Segments |      | Paired Segments |      |
|------------------------------|--------------|------|-----------------|------|
|                              | T            | C    | T               | C    |
| <u>MAY<sup>1</sup></u>       |              |      |                 |      |
| Total species                | 11.5         | 12.3 | 12.9            | 11.5 |
| Total individuals            | 25.3         | 26.6 | 24.5            | 24.4 |
| <u>JUNE<sup>2</sup></u>      |              |      |                 |      |
| Total species                | 12.0         | 11.2 | 12.7            | 11.3 |
| Total individuals            | 24.5         | 25.4 | 22.1            | 24.3 |
| <u>JULY<sup>3</sup></u>      |              |      |                 |      |
| Total species                | 8.8          | 7.8  | 9.1             | 7.9  |
| Total individuals            | 20.1         | 17.3 | 20.3 *          | 15.5 |
| Black-throated Green Warbler | 0.9          | 1.0  | 1.2 *           | 0.2  |
| Golden-crowned Kinglet       | 1.0          | 0.5  | 1.7 *           | 0.4  |
| <u>AUGUST<sup>4</sup></u>    |              |      |                 |      |
| Total species                | 5.1          | 5.0  | 5.3             | 5.3  |
| Total individuals            | 12.2         | 11.3 | 12.3            | 12.5 |
| <u>SEPTEMBER<sup>5</sup></u> |              |      |                 |      |
| Total species                | 5.9          | 5.8  | 6.6             | 5.5  |
| Total individuals            | 18.2         | 16.4 | 14.5            | 14.5 |

<sup>1</sup> 7 species tested.

<sup>2</sup> 6 species tested.

<sup>3</sup> 7 species tested.

<sup>4</sup> 4 species tested.

<sup>5</sup> 7 species tested.

\*  $P < 0.05$

### Annual variation and treatment effects on species and individuals

Considerable annual variation in abundance of individuals and species was noted in both states (Tables 2, 4). Abundance tended to be lowest in 1988, reflecting the severe drought that affected much of the region (see Blake et al., in review; Table 4). Treatment effects were noted in Michigan during May (individuals and species), June (species only), and July (species only; Table 2); individuals and species were more abundant on controls. A treatment effect was noted for species in Wisconsin during June and July, but no other treatment effects were noted when results from all years were included in the analyses (Table 2). The significance of these results is considered in the discussion section (see pages 19 and 22).

### **DISTRIBUTION OF ABUNDANT SPECIES**

#### Spring migration

The Black-capped Chickadee was the most abundant species on treatment and control segments in Michigan (Appendix 5a). Seven species were recorded with an average abundance of at least one bird per segment (treatment or control) in Michigan, but only Yellow-bellied Sapsuckers showed a significant difference (more abundant on controls) between controls and treatments (Table 5). The Ovenbird was the most abundant species in Wisconsin on both control and treatment segments (Appendix 5b). Four of eight abundant species differed in abundance between control and treatment segments in Wisconsin (Table 5); all four were more abundant on controls. When comparisons were based on paired treatment and control segments, however, no species differed in abundance between treatment and control segments (Table 3).

#### Early breeding

The Ovenbird was the most abundant species in June in both states and on both control and treatment segments (Appendices 5a, 5b). Nashville Warblers were more abundant on treatment segments and Black-throated Green Warblers and Rose-breasted

Table 4. Summary of differences among years and among treatment (T) and control (C) segments, by season and year (85, 86, 87, 88, 89). (See Table 2 for ANOVA results.) Year and segment combination (e.g., C86 = control segments in 1986) are arranged from left to right in decreasing order of abundance. Year-segment combination not underlined by the same line are significantly different ( $P < 0.05$ ). For example, for individuals in Michigan in June, abundance was higher on treatment segments in 1985 than at any other time.

| Month            | Abundance of Individuals                       | Abundance of Species                               |
|------------------|------------------------------------------------|----------------------------------------------------|
| <u>Michigan</u>  |                                                |                                                    |
| May              | <u>C86 T86 C88 C87 T88 T87 C89 T89</u>         | <u>C86 C88 C87 T86 T88 C89 T87 T89</u>             |
| June             | <u>T85 C85 C87 C86 T87 T86 T88 C89 C88 T89</u> | <u>T85 C85 C88 C87 C89 C86 T87 T88 T86 T89</u>     |
| July             | <u>C87 T87 C89 T89 C86 T86 C88 T88</u>         | <u>C87 T87 C89 C88 T88 T89 C86 T86</u>             |
| August           | <u>T89 T87 C87 C89 T88 C88 C86 T86</u>         | <u>T89 C87 T87 C89 C88 T88 C86 T86</u>             |
| September        | <u>C86 T87 C88 T89 C87 C89 T88 T86</u>         | <u>C86 T87 C88 T89 C87 C89 T88 T86</u>             |
| <u>Wisconsin</u> |                                                |                                                    |
| May              | <u>C86 T86 C87 T87 C88 T88 C89 T89</u>         | <u>C88 T86 T88 T87 C86 C89 C87 T89</u>             |
| June             | <u>T85 C87 C85 T87 T86 C86 C89 T89 C88 T88</u> | <u>T85 C87 T87 C85 T86 T88 T89 T88 C86 C89 C88</u> |
| July             | <u>T86 T87 C86 T89 C87 C88 C89 T88</u>         | <u>T87 C87 T89 T86 C88 C86 C89 T88</u>             |
| August           | <u>C87 T87 T86 C86 T89 C88 C89 T88</u>         | <u>C87 T87 T86 C88 T89 C89 T88 C86</u>             |
| September        | <u>C87 T87 T89 T86 C89 C86 C88 T88</u>         | <u>C87 T87 T89 T86 C89 C86 C88 T88</u>             |

Table 5. Mean number of individuals per segment for abundant species (those with an average of at least one individual per treatment or control segment) that showed a significant difference (one-way ANOVA) in abundance between treatment (T) and control (C) segments in 1989.

| Species                      | Michigan |    | Wisconsin |     |
|------------------------------|----------|----|-----------|-----|
|                              | T        | C  | T         | C   |
| <u>MAY<sup>1</sup></u>       |          |    |           |     |
| Yellow-bellied Sapsucker     | 0.3      | ** | 1.1       |     |
| Winter Wren                  |          |    | 0.5       | **  |
| Black-throated Green Warbler |          |    | 1.2       | *   |
| Black-and-white Warbler      |          |    | 0.8       | *   |
| Ovenbird                     |          |    | 3.6       | *   |
| <u>JUNE<sup>2</sup></u>      |          |    |           |     |
| Nashville Warbler            | 2.8      | *  | 1.8       |     |
| Black-throated Green Warbler | 0.8      | *  | 1.5       |     |
| Rose-breasted Grosbeak       | 0.5      | *  | 1.0       |     |
| <u>JULY<sup>3</sup></u>      |          |    |           |     |
| Black-capped Chickadee       |          |    | 2.1       | *   |
| Ovenbird                     | 2.2      | *  | 3.5       | 1.1 |
| <u>AUGUST<sup>4</sup></u>    |          |    |           |     |
| <u>SEPTEMBER<sup>5</sup></u> |          |    |           |     |
| Yellow-rumped Warbler        |          |    | 1.0       | **  |

|   |                 |                |                 |
|---|-----------------|----------------|-----------------|
| 1 | Species tested: | 7 in Michigan; | 8 in Wisconsin. |
| 2 | " "             | 9 " "          | 7 " "           |
| 3 | " "             | 9 " "          | 8 " "           |
| 4 | " "             | 6 " "          | 3 " "           |
| 5 | " "             | 3 " "          | 5 " "           |

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

Grosbeaks were more abundant on control segments in Michigan (Table 5). No species differed in abundance between treatment and control segments in Wisconsin either when comparisons were based on all segments or on matched segments (Tables 3, 5).

#### Late breeding

The Ovenbird was the most abundant species in Michigan and the Hermit Thrush and Red-eyed Vireo were most abundant in Wisconsin (Appendices 5a, 5b). The Ovenbird was more abundant on control segments in Michigan and the Black-capped Chickadee was more abundant on treatment segments in Wisconsin (Table 5), but no other abundant species showed a significant difference between treatment and control segments in July when comparisons were based on all segments. Black-throated Green Warblers and Golden-crowned Kinglets were more abundant on treatment segments in Wisconsin when comparisons were based on paired segments (Table 3). Black-capped Chickadee abundance did not differ between paired treatment and control segments.

#### Early fall migration

Bird communities in both states were dominated by Black-capped Chickadees during early fall migration (Appendices 5a, 5b). No abundant species in either state showed a significant difference in abundance between control and treatment segments (Tables 3, 5).

#### Late fall migration

Bird communities during late fall migration were dominated by Red-breasted Nuthatches (particularly in Wisconsin) and Black-capped Chickadees (particularly in Michigan) (Appendices 5a, 5b). No abundant species showed a significant difference in abundance between control and treatment segments in Michigan (Table 5). Yellow-rumped Warblers were more abundant on treatment segments in Wisconsin when comparisons were based on all transects (Table 5) but not when based on paired transects (Table 3).

## DISTRIBUTION PATTERNS OF COMMON SPECIES

Abundances of common species (as indexed by prominence values) differed between treatment and control transects in 18 of 105 comparisons (17%) during 1989 in Michigan (Table 6). In 9 cases, prominence values were higher on control than on treatment segments. Winter Wren was more common (higher prominence value) on control segments in both May and June, but no other species showed a significant difference in more than one season in Michigan.

Twenty of 100 comparisons of common species showed significant differences between control and treatment transects during 1989 in Wisconsin (Table 6). In 14 comparisons, prominence values were higher on treatment segments. Three species showed a significant difference in more than one season (Golden-crowned Kinglet, Chipping Sparrow, Indigo Bunting); all were more common on treatment segments. The biological significance of these results, and those for abundant species, are discussed later (see page 24).

## GUILD COMPOSITION

Few significant differences [4 of 50 tests (8%)] between treatment and control segments existed in abundance of members in different foraging guilds (Table 7). No foraging guild showed a significant difference in more than one season in either state (Table 7).

Differences were more pronounced among habitat guilds (14 of 60 tests 23%; Table 7). Birds preferring deciduous forest habitats were more common on control segments in Michigan and Wisconsin; the reverse was true for birds preferring coniferous habitat, particularly in Wisconsin (Table 7). Birds preferring early successional and open habitats were more abundant on treatment segments in Michigan (Table 7).

Table 6. Prominence values (see text) for species showing significant differences (G-test) between treatment (T) and control (C) segments in 1989.

| Species                      | Michigan |    | Wisconsin |     |      |
|------------------------------|----------|----|-----------|-----|------|
|                              | T        | C  | T         | C   |      |
| <u>MAY<sup>1</sup></u>       |          |    |           |     |      |
| Yellow-bellied Sapsucker     |          |    | 5.2       | *   | 13.9 |
| Northern Flicker             | 16.8     | *  | 6.3       |     |      |
| Brown Creeper                | 8.0      | ** | 22.8      |     |      |
| Winter Wren                  | 6.8      | *  | 16.3      |     |      |
| Golden-crowned Kinglet       |          |    | 28.3      | *** | 7.1  |
| Red-eyed Vireo               |          |    | 15.3      | *   | 28.3 |
| Common Yellowthroat          |          |    | 16.5      | *   | 7.1  |
| Chipping Sparrow             |          |    | 14.3      | *** | 0.7  |
| Dark-eyed Junco              | 5.0      | *  | 0.2       |     |      |
| Brown-headed Cowbird         |          |    | 0.8       | *   | 6.3  |
| <u>JUNE<sup>2</sup></u>      |          |    |           |     |      |
| Yellow-bellied Sapsucker     | 2.1      | *  | 9.7       |     |      |
| Great Crested Flycatcher     | 0.4      | ** | 10.1      |     |      |
| Black-capped Chickadee       | 5.4      | *  | 16.0      |     |      |
| Winter Wren                  | 4.5      | ** | 16.3      |     |      |
| Golden-crowned Kinglet       | 26.1     | *  | 13.1      |     |      |
| Cedar Waxwing                |          |    | 19.3      | **  | 6.3  |
| Yellow-rumped Warbler        |          |    | 0.2       | *   | 4.3  |
| Mourning Warbler             |          |    | 11.8      | **  | 1.3  |
| Common Yellowthroat          |          |    | 24.0      | *   | 11.0 |
| Indigo Bunting               | 1.1      | ** | 10.0      |     |      |
| Chipping Sparrow             |          |    | 4.2       | *   | 0.2  |
| Red-winged Blackbird         |          |    | 5.7       | *   | 0.2  |
| <u>JULY<sup>3</sup></u>      |          |    |           |     |      |
| Great Crested Flycatcher     | 0.4      | ** | 7.1       |     |      |
| Golden-crowned Kinglet       |          |    | 23.7      | *   | 10.0 |
| Chestnut-sided Warbler       |          |    | 8.9       | *   | 2.1  |
| Mourning Warbler             | 14.0     | *  | 4.2       |     |      |
| Indigo Bunting               |          |    | 5.9       | *   | 0.2  |
| Chipping Sparrow             | 9.0      | *  | 1.6       |     |      |
| Swamp Sparrow                |          |    | 7.1       | **  | 0.3  |
| <u>AUGUST<sup>4</sup></u>    |          |    |           |     |      |
| Eastern Wood Pewee           | 3.3      | ** | 16.4      |     |      |
| Blue Jay                     |          |    | 3.8       | *   | 12.4 |
| American Robin               | 11.2     | *  | 2.5       |     |      |
| Cedar Waxwing                | 20.5     | ** | 4.6       |     |      |
| Rufous-sided Towhee          | 4.6      | *  | 0.2       |     |      |
| <u>SEPTEMBER<sup>5</sup></u> |          |    |           |     |      |
| Downy Woodpecker             |          |    | 0.3       | **  | 8.4  |
| Golden-crowned Kinglet       |          |    | 19.7      | *   | 8.5  |
| Nashville Warbler            |          |    | 5.4       | *   | 0.4  |

<sup>1</sup> Species tested: 16 in MI; 27 in WI.

<sup>3</sup> Species tested: 28 in MI; 19 in WI.

<sup>5</sup> Species tested: 10 in MI; 12 in WI.

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

<sup>2</sup> Species tested: 33 in MI; 28 in WI.

<sup>4</sup> Species tested: 18 in MI; 12 in WI.

Table 7. Mean number of individuals in foraging and habitat guilds that showed a significant difference (One-way ANOVA) between control (C) and treatment (T) in Michigan and Wisconsin in 1989.

| Guild                        | Month     | Michigan |         | Wisconsin |        |
|------------------------------|-----------|----------|---------|-----------|--------|
|                              |           | T        | C       | T         | C      |
| <u>FORAGING GUILDS</u>       |           |          |         |           |        |
| Foliage insects              | July      |          |         | 9.7       | * 7.5  |
| Ground invertebrates & seeds | July      |          |         | 2.7       | * 1.4  |
|                              | August    | 2.9      | * 0.7   |           |        |
| Flycatchers                  | August    | 0.7      | * 1.2   |           |        |
| <u>HABITAT GUILDS</u>        |           |          |         |           |        |
| Deciduous forest             | May       | 3.7      | * 5.0   | 8.1       | * 10.5 |
|                              | June      | 7.7      | * 10.5  |           |        |
|                              | July      | 7.2      | ** 11.1 |           |        |
|                              | September |          |         | 5.5       | * 7.0  |
| Coniferous forest            | May       |          |         | 3.0       | * 1.6  |
|                              | June      |          |         | 2.2       | * 1.3  |
|                              | September |          |         | 7.7       | * 5.5  |
| Lowland coniferous           | May       | 0.5      | * 0.0   |           |        |
| Mixed deciduous & coniferous | May       |          |         | 6.2       | * 7.7  |
| Early successional           | June      | 4.1      | * 2.6   |           |        |
|                              | July      | 4.6      | * 2.3   |           |        |
|                              | August    | 3.3      | * 0.8   |           |        |
| Fields, meadows              | August    | 2.2      | * 0.9   |           |        |



## DISCUSSION

### SPECIES DISTRIBUTION AND ABUNDANCE PATTERNS

No consistent patterns have yet emerged during this study (1985-1989) to demonstrate that birds are more or less abundant on treatment relative to control segments in either state. Few significant differences have been found at the community or species level; differences in one season or year are not always repeated in subsequent years or seasons. Differences between treatment and control segments are most noticeable in Michigan during May; four of the six significant differences found for individuals (Fig. 1) and species (Fig. 2) are in Michigan during May. Patterns are less consistent in subsequent months, however. Individuals were significantly more abundant on treatment segments in June 1985 and on control segments in September 1986, but no other significant differences have been demonstrated at the community level (Table 2; Figs. 1, 2).

The Michigan facility was operated well below full strength in 1987 and half of 1988 (15 amperes, 8 hr/day, weekdays, starting June 1 1987 through 2 July 1988) and at 75 amperes (8 hr/day, weekdays) for the remainder of 1988. It was operated at 150 amperes for 16-24 hr/day during most of the 1989 sampling period. There has been, however, little noticeable change in bird populations on treatment relative to control segments. Populations were lower overall in 1988 relative to 1987, and remained low or increased slightly in 1989. As this pattern in abundance was observed on both treatment and control segments, it is most likely attributable to some factor other than the antenna operation. 1988 was extremely dry and hot (National Oceanic and Atmospheric Administration) and the weather conditions may have had an adverse impact on birds (e.g., reduced reproductive success; early emmigration from study areas; see Blake et al., in review). The drought was not as severe in 1989 (pers. obs.) and further declines were not noted for most species; some species increased slightly in abundance from 1988 to 1989.

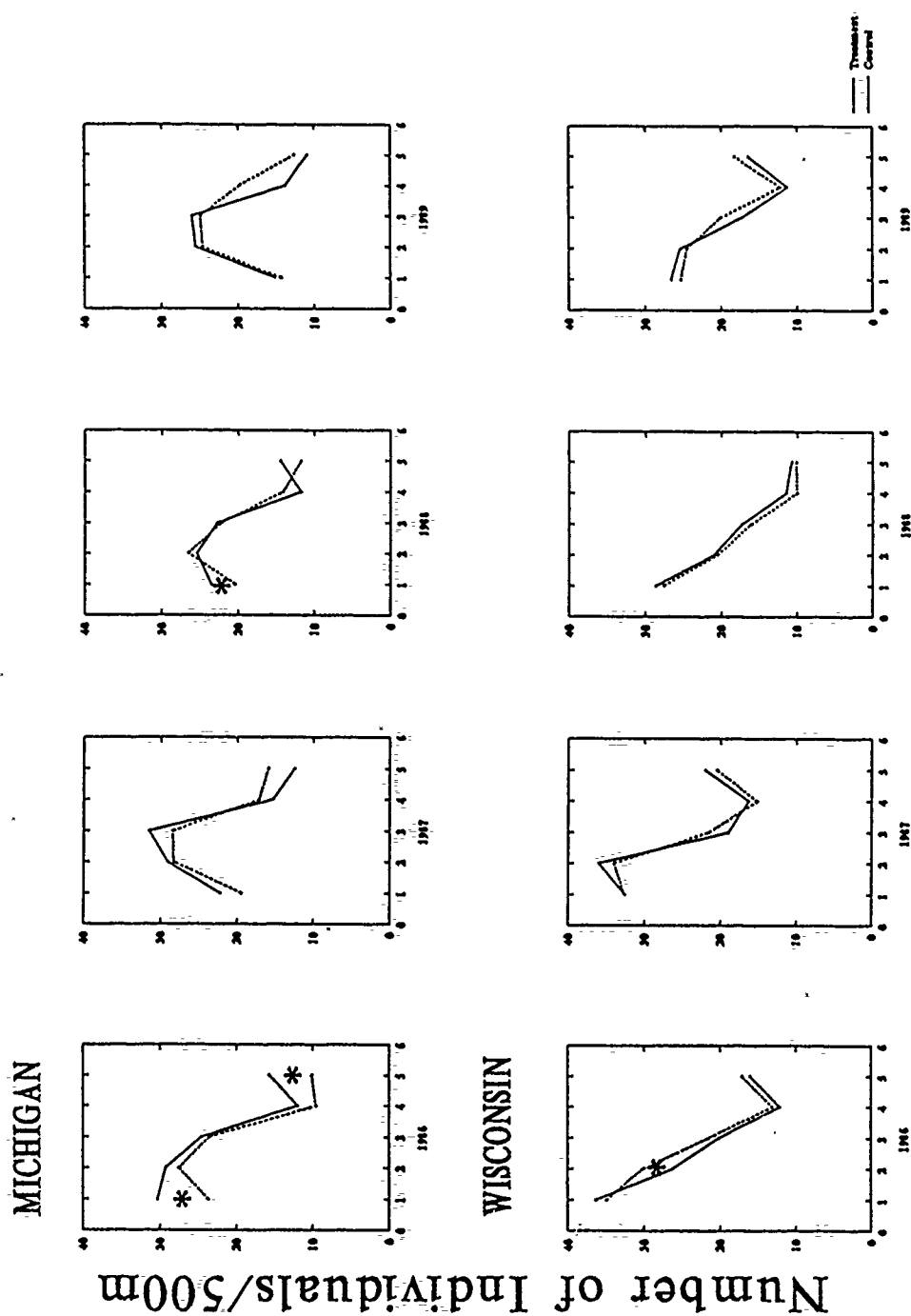


Figure 1. Mean number of individuals recorded per 500m segment on treatment and control segments, May (1) to September (5), 1986-1989.

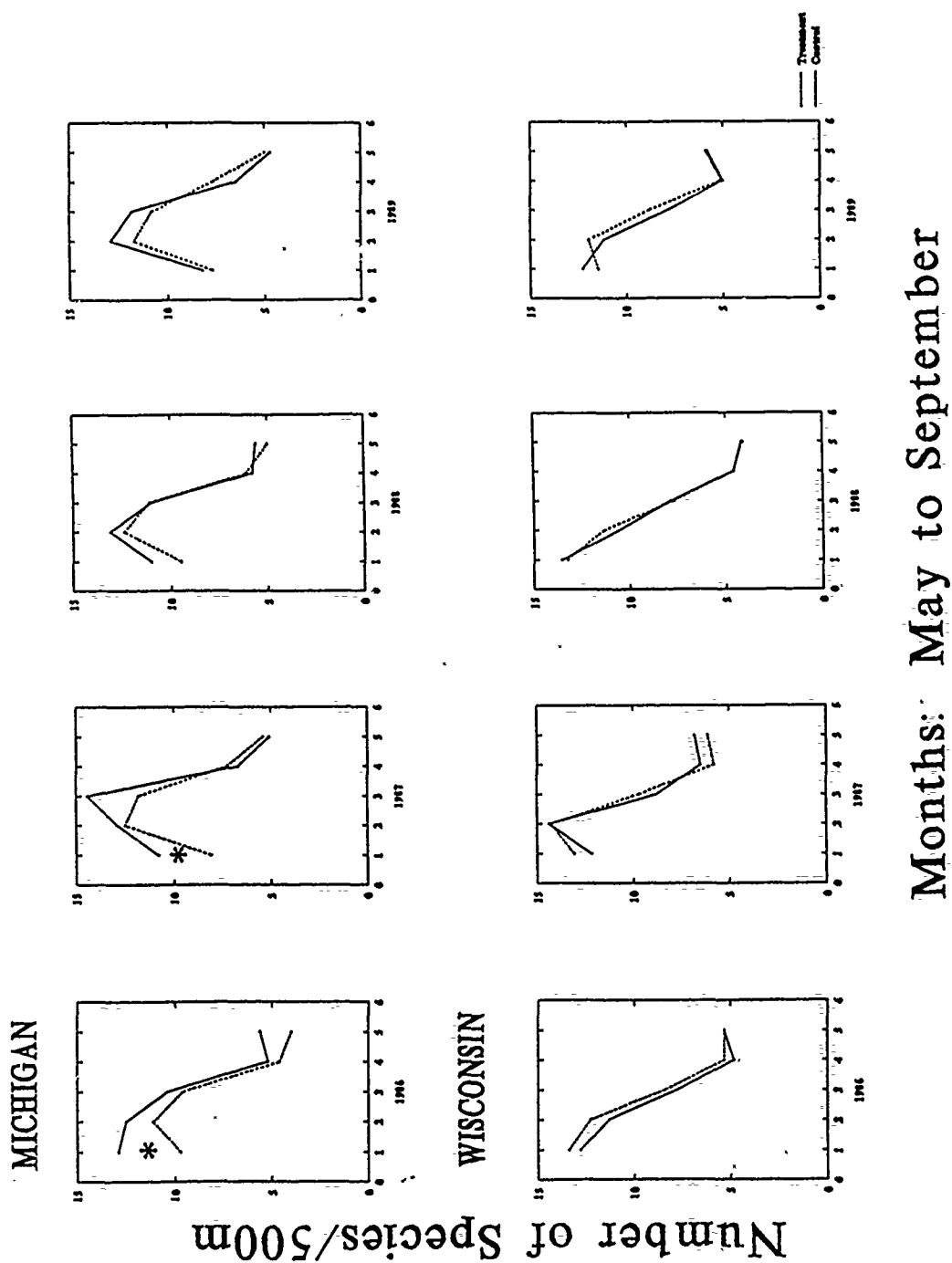


Figure 2. Mean number of species recorded per 500m segment on treatment and control segments, May (1) to September (5), 1986-1989.

Results from Wisconsin showed little consistency between years or among seasons in species richness or number of individuals. If the ELF transmitter was strongly influencing bird distribution patterns, one might expect that relative abundance of birds on treatment and control segments would remain the same from one year to the next, particularly during the breeding season, and from one season to the next. There was, however, little evidence for such an effect (Table 2, Figs. 1, 2). Species and individuals were more abundant on treatment segments in 1985 and individuals in 1986, but no other significant difference at the community level has been noted. In fact, throughout 1986-1989, species richness and abundance of individuals have been remarkably similar on treatments and controls (Figs. 1, 2).

The effect of the drought in 1988 also was seen in the generally lower values for 1988 relative to 1987 in Wisconsin. Rainfall during 1989 in Wisconsin, particularly during the breeding season, was closer to normal and abundances of several species increased. The fact that bird populations were lower in both states in 1988 provides further support for the suggestion that operation of the Michigan facility had little immediate effect on bird populations in that state.

#### Annual variation in abundance

Substantial variation occurred among years in abundance of many bird species. Overall, abundance has tended to decline from 1985 to 1988; a slight rebound was noted in 1989 in Wisconsin. Although the precise causes of such variation largely are unknown, they are likely related to the severe drought in 1988; the drought followed by two relatively dry years (1986-1987). An analysis of annual variation in bird populations (June data, 1985-1989) was completed and is under review (Blake et al., in review). By the completion of this project we will be able to analyze such variation in greater detail in Michigan, where seven years of data will be available for analysis.

A potentially confounding factor in examination of annual variation in bird communities relates to sampling. Particularly during spring migration, changes in

weather may profoundly influence the abundance of birds in a particular area (Richardson 1978). Differences in weather from one year to the next may produce apparent (as well as real) differences in abundance of birds. We attempt to minimize this problem by sampling over a five to six day period each season. Thus, weather patterns may not be as likely to strongly influence results of that sample. Similarly, we attempt to sample each season during the same calendar time period each year. It is likely, however, that differences of as much as a week from one year to the next have a considerably smaller influence on abundance than differences that may occur as a consequence of weather. This was particularly noticeable during the May sample in Michigan, where cold weather, including snow, probably delayed arrival of many migrants. Overall abundances were much lower in May 1989 than in previous years.

#### Guild distribution patterns

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

Relatively few differences in abundance of birds in different guilds were noted between treatment and control segments in either state in 1989 or previous years (Blake et al. 1989). Differences that did exist likely reflected differences in habitat that occur between treatment and control segments. Treatment segments in Michigan had more early successional habitats than did control areas and birds breeding in such habitats showed the strongest treatment effect, being more abundant in treatment segments. A similar result was noted for earlier years (Blake et al. 1989). Deciduous forest habitat is more common in control areas and coniferous habitats more common in treatment segments in both states (Blake et al. 1988); distribution of birds preferring deciduous or coniferous habitat followed a similar trend.

### Individual species

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

There have been relatively few cases where differences in abundance of a species between treatment and control segments have remained consistently significant among seasons and years (Tables 8, 9; Fig 3). A total of 41 species in each state have shown a significant difference in abundance between treatment and control segments in at least one season and year. Somewhat more species (21) were more abundant on control than on treatment segments (13) in Michigan (Table 8). The number of species showing a difference in Wisconsin was equally split between treatment (17 species) and control (20 species) segments (Table 9). However, many species have shown a significant difference in only one season in one year (Fig. 3). Moreover, seven species in Michigan and four in Wisconsin have been more abundant on treatment segments in one season and on control segments in another (Tables 8, 9). For example, the Yellow-rumped Warbler was more abundant on treatment segments in June 1985 and 1986 in Michigan but was more common on control segments during September 1986 (Table 8). Such reversals may reflect seasonal changes in habitat selection. For example, a species may breed in one habitat but then move into a different habitat following breeding. If distribution of breeding and nonbreeding habitats differ between treatments and controls, a switch in abundance between treatment and controls also may occur.

Several species have shown a consistent pattern of distribution between treatment and control segments. Yellow-bellied Flycatchers in Michigan, for example, have been

Table 8. Summary by year and month\* of species that were significantly more abundant on treatment or control segments in Michigan. Underlined months indicate that differences were tested by ANOVA (i.e., "abundant" species; see text). Differences for common species (not underlined) were based on goodness-of-fit G-tests.

| Species                      | More abundant on treatment |             |              |              |           | More abundant on control |       |             |            |           |
|------------------------------|----------------------------|-------------|--------------|--------------|-----------|--------------------------|-------|-------------|------------|-----------|
|                              | 1985                       | 1986        | 1987         | 1988         | 1989      | 1985                     | 1986  | 1987        | 1988       | 1989      |
| Northern Flicker             |                            |             |              |              | M         |                          |       |             |            |           |
| Yellow-bellied Flycatcher    | Ju                         | Ju          | Ju           | Jy           | Ju        |                          |       |             |            |           |
| Golden-crowned Kinglet       | Ju                         | Jy          | <u>S</u>     | <u>Jy</u>    |           |                          |       |             |            |           |
| Hermit Thrush                |                            |             |              |              |           |                          |       |             |            |           |
| American Robin               | Ju                         |             |              | JyA          | A         |                          |       |             |            |           |
| Cedar Waxwing                |                            |             |              | A            | A         |                          |       |             |            |           |
| Golden-winged Warbler        |                            |             | Ju           |              |           |                          |       |             |            |           |
| Nashville Warbler            | <u>Ju</u>                  | <u>JuJy</u> | <u>Jy</u>    |              | <u>Ju</u> |                          |       |             |            |           |
| Chestnut-sided Warbler       | <u>Ju</u>                  |             |              | <u>JuJy</u>  |           |                          |       |             |            |           |
| Mourning Warbler             | <u>Ju</u>                  |             |              |              | Jy        |                          |       |             |            |           |
| Rufous-sided Towhee          |                            |             |              |              | A         |                          |       |             |            |           |
| White-throated Sparrow       | <u>Ju</u>                  | S           | <u>JuJyA</u> | <u>JuJyS</u> |           |                          |       |             |            |           |
| Dark-eyed Junco              |                            |             |              |              | M         |                          |       |             |            |           |
| Blue Jay                     |                            | Ju          |              |              |           |                          | S     |             | M          |           |
| Black-capped Chickadee       |                            |             |              | Jy           |           |                          |       | <u>MJu</u>  |            | Ju        |
| Winter Wren                  |                            |             |              | M            |           | Ju                       | M     |             | Ju         | MJu       |
| Yellow-rumped Warbler        | Ju                         | Ju          |              |              |           |                          | S     |             |            |           |
| Rose-breasted Grosbeak       | <u>Ju</u>                  | M           |              |              |           |                          |       |             |            | Ju        |
| Chipping Sparrow             | <u>Ju</u>                  |             |              | Ju           | Jy        |                          | M     |             |            |           |
| Song Sparrow                 |                            |             |              | MJu          |           | Ju                       |       |             |            |           |
| American Woodcock            |                            |             |              |              |           |                          |       | Jy          |            |           |
| Ruffed Grouse                |                            |             |              |              |           | Jy                       | Jy    |             | Jy         |           |
| Yellow-bellied Sapsucker     |                            |             |              |              |           | M                        | MJyA  | <u>MJyS</u> | <u>MJu</u> |           |
| Downy Woodpecker             |                            |             |              |              |           | A                        |       |             |            |           |
| Eastern Wood-Pewee           |                            |             |              |              |           |                          | A     |             |            | A         |
| Least Flycatcher             |                            |             |              |              |           | Jy                       |       |             |            |           |
| Great Crested Flycatcher     |                            |             |              |              |           |                          | Ju    |             |            | JuJy      |
| Brown Creeper                |                            |             |              |              |           |                          | Jy    |             | MJy        | M         |
| Red-breasted Nuthatch        |                            |             |              |              |           |                          |       |             | S          |           |
| Veery                        |                            |             |              |              |           |                          |       | Jy          |            |           |
| Northern Parula              |                            |             |              |              |           |                          |       |             | Jy         |           |
| Black-throated Green Warbler |                            |             |              |              |           |                          |       | <u>M</u>    | <u>M</u>   | <u>Ju</u> |
| Blackburnian Warbler         |                            |             |              |              |           |                          |       | <u>Ju</u>   |            |           |
| Black-and-white Warbler      |                            |             |              |              |           |                          |       | M           |            |           |
| American Redstart            |                            |             |              |              |           | M                        |       |             |            |           |
| Ovenbird                     |                            |             |              |              |           | S                        |       |             |            |           |
| Common Yellowthroat          |                            |             |              |              |           | MS                       | M     | MS          | Jy         |           |
| Swamp Sparrow                |                            |             |              |              |           | <u>JuJy</u>              | Jy    | Jy          | <u>Ju</u>  |           |
| Red-winged Blackbird         |                            |             |              |              |           |                          | MJy   |             |            |           |
| Brown-headed Cowbird         |                            |             |              |              |           | MJu                      | MJuJy | M           |            | Ju        |
| Purple Finch                 |                            |             |              |              |           | MJu                      |       | Ju          |            |           |
|                              |                            |             |              |              |           |                          |       | M           |            |           |

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

Table 9. Summary by year and month\* of species that were significantly more abundant on treatment or control segments in Wisconsin. Differences in habitat structure between treatment and control segments have not been incorporated in these results. Underlined months indicate that differences were tested by ANOVA (i.e., "abundant" species; see text). Differences for common species (not underlined) were based on goodness-of-fit G-tests.

| Species                      | More abundant on treatment |      |           |              |           | More abundant on control |          |          |      |          |
|------------------------------|----------------------------|------|-----------|--------------|-----------|--------------------------|----------|----------|------|----------|
|                              | 1985                       | 1986 | 1987      | 1988         | 1989      | 1985                     | 1986     | 1987     | 1988 | 1989     |
| Alder Flycatcher             | Ju                         |      |           |              |           |                          |          |          |      |          |
| Black-capped Chickadee       |                            |      |           |              | <u>Jy</u> |                          |          |          |      |          |
| Red-breasted Nuthatch        |                            |      | <u>Jy</u> | Ju           |           |                          |          |          |      |          |
| Golden-crowned Kinglet       |                            | Ju   | <u>Jy</u> |              | MJuJyS    |                          |          |          |      |          |
| Nashville Warbler            |                            | A    |           |              | S         |                          |          |          |      |          |
| Chestnut-sided Warbler       | <u>Ju</u>                  |      | <u>Ju</u> | <u>MJuJy</u> | Jy        |                          |          |          |      |          |
| Magnolia Warbler             |                            | M    | <u>M</u>  |              |           |                          |          |          |      |          |
| Cape May Warbler             |                            | M    |           |              |           |                          |          |          |      |          |
| Yellow-rumped Warbler        | Ju                         |      |           |              | JuS       |                          |          |          |      |          |
| Mourning Warbler             |                            |      |           |              | Ju        |                          |          |          |      |          |
| Common Yellowthroat          |                            | M    |           |              | M         |                          |          |          |      |          |
| Indigo Bunting               |                            | Ju   |           |              | JuJy      |                          |          |          |      |          |
| Chipping Sparrow             | Ju                         | Ju   | Ju        | MJu          | MJu       |                          |          |          |      |          |
| Song Sparrow                 |                            | M    |           | Ju           |           |                          |          |          |      |          |
| Swamp Sparrow                | Ju                         | Ju   | Jy        |              | Jy        |                          |          |          |      |          |
| White-winged Crossbill       |                            |      | Jy        |              |           |                          |          |          |      |          |
| Evening Grosbeak             | Ju                         |      |           |              |           |                          |          |          |      |          |
| Blue Jay                     |                            |      | <u>M</u>  |              |           | Jy                       |          |          | Jy   | A        |
| Ruby-crowned Kinglet         |                            |      |           | S            |           |                          |          | A        |      |          |
| Hermit Thrush                |                            | A    |           |              |           |                          |          |          | Ju   |          |
| American Robin               | Ju                         |      |           |              |           |                          |          | Ju       |      | .        |
| Ruffed Grouse                |                            |      |           |              |           | Ju                       | S        |          | S    |          |
| Yellow-bellied Sapsucker     |                            |      |           |              |           |                          |          |          |      | M        |
| Downy Woodpecker             |                            |      |           |              |           |                          |          |          |      | A        |
| Eastern Wood-Pewee           |                            |      |           |              |           |                          |          | Ju       | Ju   |          |
| Yellow-bellied Flycatcher    | <u>Ju</u>                  |      |           |              |           | <u>Ju</u>                |          |          |      |          |
| Least Flycatcher             | <u>Ju</u>                  |      |           |              |           | <u>Ju</u>                |          | M        | Ju   |          |
| Great Crested Flycatcher     | <u>Ju</u>                  |      |           |              |           | <u>Ju</u>                | Ju       | M        |      |          |
| Brown Creeper                |                            |      |           |              |           |                          |          |          | A    |          |
| Winter Wren                  | Ju                         |      |           |              |           |                          |          | Jy       |      | <u>M</u> |
| Veery                        |                            |      |           |              |           |                          | Ju       |          |      |          |
| Cedar Waxwing                |                            |      |           |              |           |                          |          |          | A    | Ju       |
| Red-eyed Vireo               |                            |      |           |              |           |                          |          | A        |      | M        |
| Northern Parula              |                            |      |           |              |           |                          | <u>M</u> |          |      |          |
| Black-throated Green Warbler |                            |      |           |              |           |                          |          |          |      | <u>M</u> |
| Blackburnian Warbler         |                            |      |           |              |           |                          |          |          | Ju   | <u>M</u> |
| Black-and-white Warbler      |                            |      |           |              |           | M                        |          |          |      | <u>M</u> |
| Ovenbird                     |                            |      |           |              |           | <u>Jy</u>                |          | JuJy     |      | <u>M</u> |
| Canada Warbler               |                            |      |           |              |           | Ju                       |          | <u>M</u> |      |          |
| Rose-breasted Grosbeak       |                            |      |           |              |           | MJu                      |          | M        |      |          |
| Brown-headed Cowbird         |                            |      |           |              |           |                          |          |          |      | M        |

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



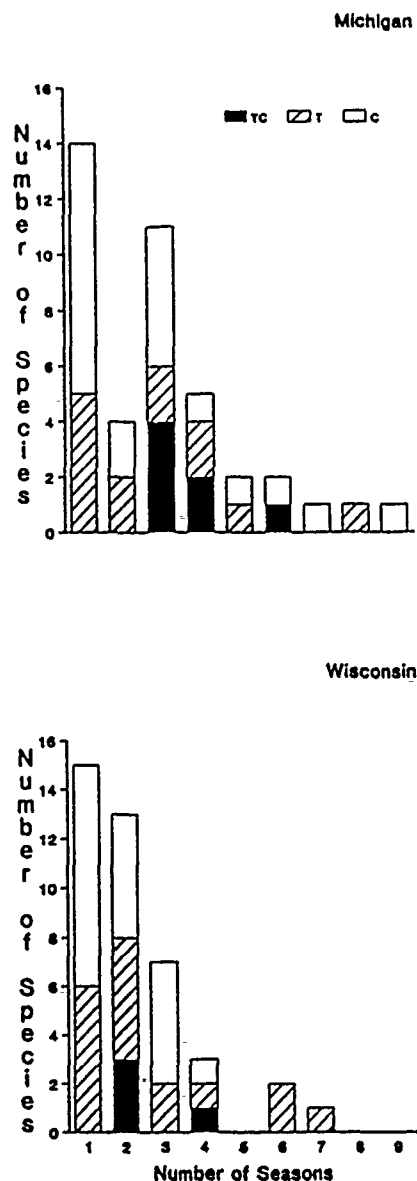


Figure 3. Number of species more abundant on treatment or control segments during 1 or more seasons, all years combined (i.e., a possible maximum of 21 "seasons" if a significant difference occurred in every season in each year). T = always more abundant on treatment; C = always more abundant on control; TC = more abundant on treatment in 1 (or more) season(s) and more abundant on control in another season.

more abundant on treatment segments in three of five Junes sampled (Table 8). White-throated Sparrows and Nashville Warblers also have been consistently more abundant on treatment segments. Several species (e.g., Yellow-bellied Sapsucker, Common Yellowthroat, Red-winged Blackbird) consistently have been more abundant on control segments in Michigan. Similarly, in Wisconsin, several species were consistently more abundant on treatment segments (e.g., Chestnut-sided Warbler, Chipping Sparrow, Golden-crowned Kinglet) (Table 9).

Differences in abundance of species that showed a consistent difference between treatment and control segments likely are related to habitat in many cases. White-throated Sparrows, for example, favor early successional habitats. Such habitats were more common on treatment segments than on controls in Michigan. In contrast, deciduous woods are more common on control segments in Michigan (and Wisconsin) and Yellow-bellied Sapsuckers were more frequently observed on control segments.

#### **HABITAT STRUCTURE ON TREATMENT AND CONTROL SEGMENTS**

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

Placement of treatment segments was constrained by the location of the ELF transmission lines. Thus, our sampling is not strictly random with respect to habitats in the study regions. In both states for example, treatment areas support more coniferous

habitat, particularly lowland coniferous habitats, whereas control areas support more deciduous habitats (Blake et al. 1988). Differences in a variety of other habitat features also occur, but the deciduous-coniferous difference was most pronounced and, as has been discussed above, likely influenced composition of related bird communities. Several differences in bird community characteristics observed between treatment and control segments likely were due to differences in habitat and we are accounting for many of these differences with our analyses.

#### Habitat structure on Wisconsin segments

The experimental design in Michigan (before-and-after) will allow us to detect changes due to EM fields, apart from those due to habitat differences, if such changes occur. Because the antenna has been operating in Wisconsin since before this project started, we may not be able to detect effects of the EM fields without accounting for differences in habitat structure. To account for such habitat effects, we paired treatment and control segments on the basis of vegetation. We reasoned that if habitat structure on treatment and control segments being compared was similar, then differences in bird populations, if they occur, might be due to factors other than habitat.

No comparisons based on paired segments revealed a significant difference between treatment and control segments for total species or individuals. Only two significant differences were noted among abundant species; in both cases, correcting for habitat increased abundances on treatment segments. No difference in abundance that was significant when all segments were included also was significant when segments were paired on the basis of habitat. Thus, when habitat differences are accounted for, there is even less evidence to indicate a significant treatment effect in Wisconsin.

These analyses were done for 1989 only; results for 1988 were treated in last year's report (Blake et al. 1989). The significance of observed patterns may be more apparent when results from all years are examined, as will be done for the final report

for Wisconsin (Hanowski et al., in prep.). Similarly, we will reexamine distribution patterns of different guilds (e.g., species preferring deciduous habitat).

## OBJECTIVES

Our major objective for 1989 was to complete bird censuses during all seasons in both states; that objective was met. Our objectives for 1990 and beyond are to continue our sampling of bird communities in Michigan, following our established procedures. We also will complete a thorough analysis of all Wisconsin data for incorporation into a final report for that state.

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

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### EXPERIMENTAL DESIGN

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

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

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

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

<sup>1</sup> Estimates are for all species observed during 10 min count period.

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

<sup>3</sup> Estimates are for the total territorial males mapped in a 12.5 ha area.

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

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

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

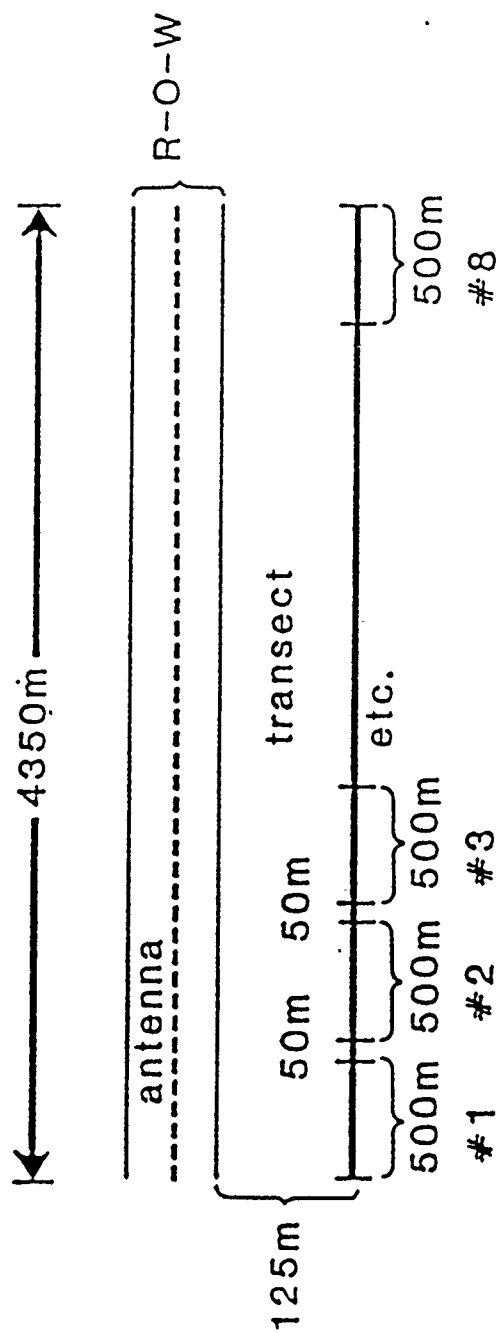


Figure A1. Schematic of a treatment transect layout. ROW = right-of-way.

## STUDY AREAS

Starting locations for 10 control and 10 treatment transects were randomly selected in Michigan and Wisconsin (Figures A2 and A3) with methods described previously (Niemi and Hanowski 1986). Electromagnetic fields were measured to insure that 76 Hz EM fields at a treatment site were significantly larger than: (1) 76 Hz EM fields at control sites, (2) 60 Hz fields at treatment sites, and (3) 60 Hz fields at control sites. In addition, exposure criteria required that there was no substantial difference in the ambient 60 Hz EM fields between control and treatment transects (Brosh et al. 1986). Electromagnetic fields were measured at the beginning and ending points for each transect; they were not completed for each transect segment because most were not easily reached (e.g., most are 1-4 km from a road). However, in 1988 and 1989 EM fields were measured along three entire transects in Wisconsin and at various perpendicular distances from the antenna (Haradem et al. 1989). These measurements will provide a measure of how EM fields vary both along and perpendicular to the antennna.

All transect pairs (control versus treatment) in Wisconsin fall within the "acceptable" category for EM field ratios established by IITRI. Eight of 25 transect pairs in Michigan were determined to be "conditionally acceptable" based on data collected in 1986. Previous data placed all pairs in the "acceptable" category (Haradem et al. 1987). All transects still satisfy the EM exposure criteria and will be used for the remainder of the monitoring period.

Information regarding proposed logging along the transects was obtained from Department of Natural Resources in Michigan and the U.S. Forest Service in Wisconsin. Five control and five treatment transect segments were scheduled for

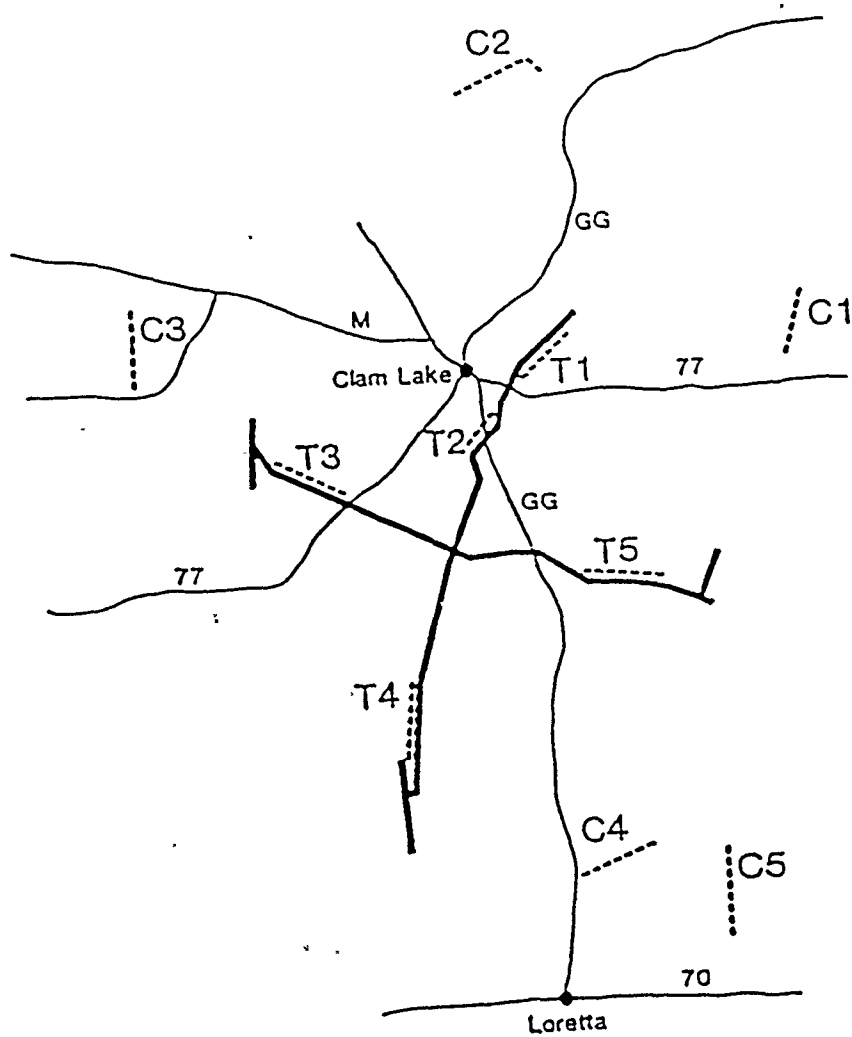


Figure A2. Location of Wisconsin antenna and study transects.

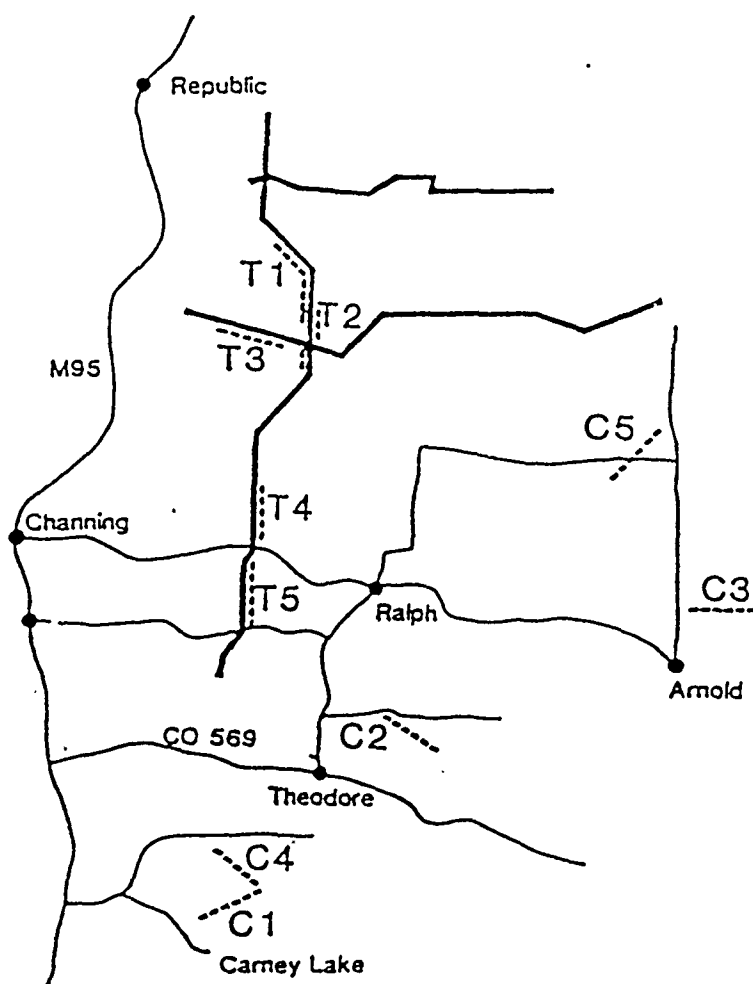


Figure A3. Location of Michigan antenna and study transects.



logging in Michigan effective through 1990 (Table A2). However, in an agreement reached with Michigan DNR (September 1988), logging on Carney Lake and Skunk Creek will not be completed until 1992 (Table A2). In 1989 three Michigan segments were affected by logging (Heart Lake, Leemans Road, and Arnold Road)(Table A2). In Wisconsin, two control and eight treatment transect segments will be affected; however, all of these sites will be selectively cut or thinned (Table A2). In 1989 two Wisconsin segments were affected by logging activity (both in Moose River)(Table A2). Because of the length of our transects, it is probably impossible to avoid areas affected by logging. We will be sensitive to disturbances along transects in subsequent analyses and if necessary, affected transect segments can be removed from analyses. This will allow us to assess potential affect of logging or other disturbances on results of the investigation.

## METHODS

### Bird censuses

We used the line-transect method to census all transects (Emlen 1971, 1977; Jarvinen and Vaisanen 1975). Census data were gathered during morning hours (one half hour to four and one half hours after sunrise) on days when wind speed was < 15 km/hr and when there was little or no precipitation. Control and treatment transect segments were censused simultaneously by two observers to eliminate differences that could occur by censusing at different times. Censuses of control and treatment transects were randomly assigned to each of two observers with the restriction that each observer census the same number of control (80) and treatment (80) segments in each census period. This was done to control for potential differences in observers.

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

| Number and Name     | Township | Range | Sections       | Number of 500 m segments affected |
|---------------------|----------|-------|----------------|-----------------------------------|
| <b>MICHIGAN</b>     |          |       |                |                                   |
| C1 Carney Lake      | 41N      | 29W   | 33,34,35,36    | 2 (1992)                          |
| C2 Skunk Creek      | 42N      | 28W   | 14,23,24       | 2 (1992)                          |
|                     | 42N      | 27W   | 19,30          |                                   |
| C3 Arnold           | 43N      | 25W   | 31,32,33,34    | 1 *                               |
|                     | 43N      | 25W   | 32             | 1 ***                             |
| C4 Lost Lake        | 41N      | 29W   | 21,26,27,28,35 | 2 **                              |
| C5 Bob's Creek      | 44N      | 26W   | 13,23,24,26    | 1 (1989)                          |
| T1 Heart Lake       | 45N      | 28W   | 7,18           | 1                                 |
|                     | 45N      | 28W   | 19             | 1 ***                             |
| T2 Flat Rock Creek  | 44N      | 28W   | 6              | 3 *                               |
|                     | 45N      | 28W   | 19,30,31       |                                   |
| T3 Schwartz Creek   | 45N      | 28W   | 31             | 2 **                              |
|                     | 45N      | 29W   | 26,27,35,36    |                                   |
| T4 Turner Road      | 43N      | 29W   | 1,11,12        | 0                                 |
|                     | 44N      | 29W   | 36             |                                   |
| T5 Leeman's Road    | 43N      | 29W   | 14,23,26,35    | 0                                 |
| <b>WISCONSIN</b>    |          |       |                |                                   |
| C1 Spillerberg Lake | 43N      | 3W    | 23,26,35       | 0                                 |
| C2 Mineral Lake     | 44N      | 4W    | 15,16,17,18    | 0                                 |

Table A2 continued

| Number and Name     | Township   | Range    | Sections          | Number of 500 m segments affected          |
|---------------------|------------|----------|-------------------|--------------------------------------------|
| C3 Rock Lake        | 42N<br>43N | 6W<br>6W | 6<br>19,30,31     | 1 (thinning)                               |
| C4 Blaisdell Lake   | 40N<br>40N | 4W<br>3W | 13,14,22,23<br>18 | 0                                          |
| C5 Brunette River   | 40N        | 3W       | 16,21,28          | 1 (thinning)                               |
| T1 Woodtick Lake    | 43N        | 4W       | 22,23,27,28,33    | 0                                          |
| T2 Little Clam Lake | 42N        | 4W       | 5,8,17            | 3 (thinning)                               |
| T3 Christy Lake     | 42N        | 5W       | 7,8,15,16,17      | 1 (thin part) *<br>1 (thin all) *          |
| T4 Black Lake       | 41N        | 5W       | 24,25,36          | 0                                          |
| T5 Moose River      | 42N<br>42N | 3W<br>4W | 31<br>35,36       | 1 (thin part) *<br>2 (thin all) *<br>2 *** |

Eight transect segments were censused daily by each observer. Each observer walked the designated transect segment at a rate of approximately 16.7 m/min and recorded the following for each bird observed: (1) species; (2) sex when possible; (3) behavior (e.g., singing or calling); (4) estimated perpendicular distance from the segment center line, in meters; (4) position relative to the segment center line (e.g., right or left side); and (5) distance, in meters, from the start of the segment. Information for each individual bird observed was recorded on microcomputer files. Birds flying over (i.e., above the canopy) were not included. Data were checked for accuracy after entry.

We used the number of individuals observed up to 100 m from the segment center line in all data analyses instead of attempting to calculate a density value. Relative density could be calculated with a variety of formulae (Emlen 1971, 1977; Jarvinen and Vaisanen 1975; Burnham et al. 1981) but at the present we have no basis for using one formula over another. We only assume that the number of birds recorded is related to the density of birds in an area. A disadvantage to using a density formula (e.g., LINETRAN; Burnham et al. 1981) is the number of observations required to obtain a reliable density estimate. For example, at least 30 observations/species are recommended to calculate densities with the Fourier series estimator. Such a sample size is prohibitive for this study because we do not observe this many individuals of one species on a 500 m segment. To obtain the specified sample, our segments would have to be about five times longer (about 2500 m) than they are now. This design is not feasible because of the large sample size (number of segments) needed to detect the desired difference between control and treatment

areas. It may be possible to use this technique at a later date if we pool data among years or among different experimental units.

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

#### Bird guilds

We listed all bird species observed in Michigan and Wisconsin and all species that could potentially occur in our study areas. Each species was classified by 1) nesting area, 2) food or foraging type, 3) breeding habitat preference, and 4) migration type (Appendix 2). Classifications were based on published sources (e.g., Martin et. al. 1951; Bent 1963, 1964; Green and Niemi 1978; Terres 1982; AOU 1983, 1985) and personal observations. A hierarchical classification scheme was used if a species occurred in more than one category. When this occurred, we identified primary, secondary, and tertiary areas of use for these species; primary being the predominant category of use. We use this information in analyses to address any differential effects of the ELF antenna on species that use particular feeding strategies, specific nesting areas, or different migration patterns (see Verner 1984). These analyses allow us to test for differences between control and treatment transects for species that have similar life history characteristics and therefore, similar exposures to ELF EM fields.

### Wisconsin vegetation

Vegetation on all 80 control and treatment segments was measured over a two year period (1986 and 1987). A two year period was selected to more efficiently use personnel and to better control for seasonal variation in vegetation growth. A representative portion of segments measured in 1986 were remeasured in 1987 to quantify annual differences in vegetation growth and/or variation in sampling efficiency.

Vegetation samples were collected at 25 m intervals to describe changes that occur within each segment. Sample points were positioned two meters from the transect line to avoid biases in where flag markers for transects were placed. We used methods that we have successfully used in past investigations to assess habitat characteristics (Niemi and Hanowski 1984; Niemi 1985); methods were modified from Wiens (1969) and Wiens and Rotenberry (1981). Densities of trees, shrubs, forbs, and graminoids were calculated with the point-centered quarter method (Cottam and Curtis 1956). Vegetation variables measured and their description are in Appendix 3A. All vegetation data were entered onto microcomputer files and checked for accuracy by someone other than the original data entry person.

### Michigan vegetation

We classified habitats of the Michigan study areas at 25 m intervals along each segment. Nineteen habitat types were used for classification (Appendix 4) and percentage of occurrence of each type on control and treatment areas was calculated. We did this to identify gross habitat differences between control and treatment segments that might potentially explain differences in bird populations. For example, before the antenna is turned on in Michigan we would expect that any differences between control and treatment transects would be due to some other source of

difference between these areas (i.e., habitat). We collected 1750 vegetation samples in Michigan and entered these data onto microcomputer files. A goodness-of-fit G-test was used to test for differences between control and treatment transects using the frequencies of the 19 habitat types observed.

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



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

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

## Appendix 2 (continued)

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

## Appendix 2 (continued)

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

## Appendix 2 (continued)

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

## Appendix 2 (continued)

| Species                      | Nesting | Food  | Habitat  | Migration |
|------------------------------|---------|-------|----------|-----------|
| Northern Parula              | 2       | 10    | 11,3,2   | 3         |
| Yellow Warbler               | 3       | 10    | 6,5,7    | 3         |
| Chestnut-sided Warbler       | 3       | 10    | 4,3      | 3         |
| Magnolia Warbler             | 2,3     | 10    | 4,2,3    | 3         |
| Cape May Warbler             | 2       | 10    | 2,3      | 3         |
| Black-throated Blue Warbler  | 3       | 10    | 1,3,4    | 3         |
| Yellow-rumped Warbler        | 2       | 13    | 2,3,11,4 | 2,3       |
| Black-throated Green Warbler | 2       | 10    | 3,1      | 3         |
| Blackburnian Warbler         | 2       | 10    | 2,3      | 3         |
| Pine Warbler                 | 2       | 10    | 2        | 2         |
| Palm Warbler                 | 1       | 6     | 11,10    | 2,3       |
| Bay-breasted Warbler         | 2       | 10    | 2,3      | 3         |
| Blackpoll Warbler            | 2       | 10    | 2,4,3    | 3         |
| Black-and-white Warbler      | 1       | 16    | 3,4,6,1  | 3         |
| American Redstart            | 2,3     | 12,10 | 4,1,6    | 3         |
| Ovenbird                     | 1       | 6     | 1,3,2,4  | 3         |
| Northern Waterthrush         | 1,6     | 6     | 9        | 3         |
| Connecticut Warbler          | 1       | 10    | 11       | 3         |
| Mourning Warbler             | 1,3     | 10    | 4,3      | 3         |
| Common Yellowthroat          | 3       | 10    | 6,8,4    | 2,3       |
| Wilson's Warbler             | 3       | 10    | 6        | 3         |
| Canada Warbler               | 3       | 10    | 3,4      | 3         |

## Appendix 2 (continued)

| Species                 | Nesting | Food  | Habitat    | Migration |
|-------------------------|---------|-------|------------|-----------|
| Scarlet Tanager         | 3       | 10    | 1,3        | 3         |
| Rose-breasted Grosbeak  | 3,2 13  | 1,4,3 | 3          |           |
| Indigo Bunting          | 3       | 15    | 5,4        | 3         |
| Rufous-sided Towhee     | 1,2,3   | 8     | 4          | 2         |
| American Tree Sparrow   | 3       | 7     | 5          | 4,2       |
| Chipping Sparrow        | 2       | 8     | 2,3,4,11   | 2         |
| Clay-colored Sparrow    | 3       | 8     | 5,6        | 2,3       |
| Field Sparrow           | 1,3     | 8     | 5          | 2         |
| Savannah Sparrow        | 1       | 8     | 5,8,10     | 2         |
| Fox Sparrow             | 1,3     | 8     | 4,5        | 2         |
| Song Sparrow            | 3       | 8     | 5,4,6      | 2         |
| Lincoln's Sparrow       | 1       | 8     | 10,8,4     | 2         |
| Swamp Sparrow           | 3       | 8     | 6,8        | 2         |
| White-throated Sparrow  | 1       | 8     | 4,3,2,11,1 | 2         |
| White-crowned Sparrow   | 1,3     | 8     | 4,6,5      | 2         |
| Dark-eyed Junco         | 1       | 8     | 11,2,3,4   | 2,1       |
| Snow Bunting            | 5       | 7     | 5          | 4         |
| Bobolink                | 1       | 8     | 5,8        | 3         |
| Red-winged Blackbird    | 3       | 8     | 8          | 2         |
| Eastern Meadowlark      | 1       | 6     | 5          | 2         |
| Western Meadowlark      | 1       | 6     | 5          | 2         |
| Yellow-headed Blackbird | 3       | 8     | 8          | 2         |

## Appendix 2 (continued)

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

## A. Nesting

- 1 Ground
- 2 Canopy or canopy vegetation (tree but not necessarily tree top)
- 3 Subcanopy or shrub
- 4 Cavity, hole or bank

## Appendix 2 (continued)

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



## Appendix 2 (continued)

- 18 Aquatic vegetation
- 19 Aquatic invertebrates

**C. Habitat**

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

**D. Migration**

- 1 Permanent resident; populations may be augmented during winter or during summer
- 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 3A. Description of habitat variables used to quantify habitat characteristics of Wisconsin study areas.

Appendix 3A. Description of habitat variables used to quantify habitat characteristics of Wisconsin study areas.

| Habitat Variable | Description                                                                                                                                                                                                                                                          |
|------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Ground Cover     | Estimate of percent of green vegetation less than 10 cm high in m <sup>2</sup> surrounding the center point                                                                                                                                                          |
| Water Cover      | Estimate of percent of standing water in m <sup>2</sup> surrounding the center point                                                                                                                                                                                 |
| Water Depth      | Depth at center point                                                                                                                                                                                                                                                |
| Overall Height   | Estimate of the average height of vegetation in 25 m <sup>2</sup> surrounding center point                                                                                                                                                                           |
| Tree Density     | Density of trees greater than 2.5 cm diameter breast height (dbh) measured by the point-centered quarter method                                                                                                                                                      |
| Tree Height      | Height of four trees measured for tree density; measured with a clinometer                                                                                                                                                                                           |
| Tree Species     | Identification of four trees measured for tree density                                                                                                                                                                                                               |
| Tree Diameter    | Measured dbh of four trees measured for tree density                                                                                                                                                                                                                 |
| Canopy Cover     | Average of four readings taken with a spherical densiometer in NE quarter of point-centered plot                                                                                                                                                                     |
| Log Density      | Density of fallen logs greater than 2.5 cm diameter measured by the point-centered quarter method                                                                                                                                                                    |
| Log Species      | Identification of four logs measured for log density                                                                                                                                                                                                                 |
| Log Diameter     | Measured diameter of four logs measured for log density. Diameter was measured at point where log was closest to center point.                                                                                                                                       |
| Shrub Density    | Density of shrubs greater than 30 cm high and less than 2.5 cm dbh measured by the point-centered method. Shrubs were defined as any plant species that was persistent in the environment year round at a height of at least 30 cm (e.g., woody shrubs and cattails) |
| Shrub Height     | Height of four shrubs measured for shrub density                                                                                                                                                                                                                     |

## Appendix 3A (continued)

| Habitat Variable    | Description                                                                              |
|---------------------|------------------------------------------------------------------------------------------|
| Shrub Species       | Species of four shrubs measured for shrub density                                        |
| Forb Density        | Density of forbs > 10 cm high measured by the point-centered method                      |
| Forb Species        | Species of four forbs measured for forb density                                          |
| Grass-Sedge Density | Density of grasses and sedges > 10 cm high measured by the point-centered quarter method |

Appendix 3B. Proportion of variation explained and important variables (in order of importance) for seven factors calculated with principal components analysis of vegetation data from Wisconsin. Weighted factor scores for each transect segment were used to pair control and treatment transects (see text for detail).

Appendix 3B. Proportion of variation explained and important variables (in order of importance) for seven factors calculated with principal components analysis of vegetation data from Wisconsin. Weighted factor scores for each transect segment were used to pair control and treatment transects (see text for detail).

| Factor | Proportion of Variation | Important Variables                                                                                                                    |
|--------|-------------------------|----------------------------------------------------------------------------------------------------------------------------------------|
| 1      | .2588                   | Tree Height, overall height, deciduous basal area, sugar maple ( <u>Acer saccharum</u> ) importance value                              |
| 2      | .1262                   | Black ash ( <u>Fraxinus nigra</u> ) importance value, water cover, northern white cedar ( <u>Thuja occidentalis</u> ) importance value |
| 3      | .1065                   | Coniferous basal area, tree density                                                                                                    |
| 4      | .0707                   | Number of shrub species, number of tree species                                                                                        |
| 5      | .0673                   | Balsam fir ( <u>Abies balsamea</u> ) importance value, density of trees 15-23 cm dbh, coniferous basal area                            |
| 6      | .0570                   | Density of trees 15-23 cm dbh                                                                                                          |
| 7      | .0489                   | Shrub density                                                                                                                          |

Appendix 4. Description of habitat types used to classify Michigan study areas.

## Appendix 4. Description of habitat types used to classify Michigan study areas.

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



Appendix 5A. Total number of individuals and species observed on control (C) and treatment (T) transects in Michigan during five census periods in 1987. English and scientific names follow AOU (1983, 1985).



## Appendix 5A (continued)

|                                                          | May |    | June |    | July |    | August |    | September |   |
|----------------------------------------------------------|-----|----|------|----|------|----|--------|----|-----------|---|
|                                                          | T   | C  | T    | C  | T    | C  | T      | C  | T         | C |
| Ruffed Grouse<br><u>Bonasa umbellus</u>                  | 23  | 13 | 7    | 2  | 6    | 14 | 21     | 7  | 4         | 0 |
| American Woodcock<br><u>Scolopax minor</u>               | 1   | 1  | 3    | 0  | 4    | 3  | 1      | 5  | 7         | 0 |
| Black-billed Cuckoo<br><u>Coccyzus erythrophthalmus</u>  | 0   | 0  | 0    | 0  | 1    | 0  | 0      | 0  | 0         | 0 |
| Yellow-billed Cuckoo<br><u>Coccyzus americanus</u>       | 0   | 0  | 1    | 4  | 0    | 0  | 0      | 0  | 0         | 0 |
| Barred Owl<br><u>Strix varia</u>                         | 0   | 0  | 0    | 0  | 0    | 0  | 0      | 1  | 0         | 0 |
| Whip-poor-will<br><u>Caprimulgus vociferus</u>           | 0   | 1  | 0    | 0  | 0    | 0  | 1      | 0  | 0         | 0 |
| Chimney Swift<br><u>Chaetura pelagica</u>                | 0   | 0  | 0    | 0  | 0    | 2  | 0      | 0  | 0         | 0 |
| Ruby-throated Hummingbird<br><u>Archilochus colubris</u> | 0   | 0  | 1    | 0  | 0    | 2  | 2      | 2  | 0         | 2 |
| Belted Kingfisher<br><u>Ceryle alcyon</u>                | 0   | 1  | 0    | 0  | 0    | 1  | 0      | 0  | 0         | 0 |
| Yellow-bellied Sapsucker<br><u>Sphyrapicus varius</u>    | 13  | 46 | 6    | 17 | 9    | 18 | 5      | 11 | 0         | 4 |
| Downy Woodpecker<br><u>Picoides pubescens</u>            | 7   | 7  | 4    | 0  | 3    | 3  | 4      | 2  | 0         | 5 |
| Hairy Woodpecker<br><u>Picoides villosus</u>             | 2   | 4  | 3    | 3  | 3    | 1  | 2      | 6  | 4         | 4 |
| Black-backed Woodpecker<br><u>Picoides arcticus</u>      | 1   | 0  | 0    | 0  | 0    | 3  | 1      | 2  | 1         | 0 |
| Northern Flicker<br><u>Colaptes auratus</u>              | 25  | 14 | 8    | 7  | 12   | 12 | 21     | 8  | 6         | 6 |
| Pileated Woodpecker<br><u>Dryocopus pileatus</u>         | 1   | 0  | 0    | 1  | 2    | 3  | 1      | 0  | 3         | 0 |

## Appendix 5A (continued)

|                                                            | May |    | June |    | July |    | August |    | September |    |
|------------------------------------------------------------|-----|----|------|----|------|----|--------|----|-----------|----|
|                                                            | T   | C  | T    | C  | T    | C  | T      | C  | T         | C  |
| Olive-sided Flycatcher<br><u>Contopus borealis</u>         | 0   | 0  | 2    | 1  | 1    | 1  | 1      | 1  | 2         | 1  |
| Eastern Wood-Pewee<br><u>Contopus virens</u>               | 0   | 0  | 7    | 18 | 5    | 11 | 8      | 26 | 5         | 6  |
| Yellow-bellied Flycatcher<br><u>Empidonax flaviventris</u> | 0   | 0  | 17   | 9  | 11   | 8  | 1      | 0  | 0         | 0  |
| Alder Flycatcher<br><u>Empidonax alnorum</u>               | 0   | 0  | 9    | 12 | 2    | 2  | 6      | 6  | 0         | 0  |
| Least Flycatcher<br><u>Empidonax minimus</u>               | 0   | 0  | 29   | 31 | 20   | 37 | 2      | 4  | 0         | 1  |
| Eastern Phoebe<br><u>Sayornis phoebe</u>                   | 1   | 2  | 0    | 0  | 0    | 0  | 1      | 1  | 0         | 0  |
| Great Crested Flycatcher<br><u>Myiarchus crinitus</u>      | 0   | 2  | 2    | 17 | 2    | 19 | 1      | 2  | 0         | 1  |
| Eastern Kingbird<br><u>Tyrannus tyrannus</u>               | 0   | 0  | 2    | 2  | 4    | 1  | 6      | 8  | 0         | 0  |
| Tree Swallow<br><u>Tachycineta bicolor</u>                 | 1   | 0  | 0    | 0  | 0    | 0  | 0      | 0  | 0         | 0  |
| Gray Jay<br><u>Perisoreus canadensis</u>                   | 2   | 0  | 2    | 1  | 7    | 1  | 7      | 5  | 8         | 4  |
| Blue Jay<br><u>Cyanocitta cristata</u>                     | 16  | 11 | 16   | 17 | 20   | 14 | 14     | 19 | 36        | 24 |
| American Crow<br><u>Corvus brachyrhynchos</u>              | 1   | 0  | 1    | 0  | 1    | 0  | 0      | 1  | 0         | 0  |
| Common Raven<br><u>Corvus corax</u> Linnaeus               | 2   | 2  | 1    | 4  | 1    | 1  | 1      | 3  | 1         | 1  |
| Black-capped Chickadee<br><u>Parus atricapillus</u>        | 68  | 75 | 13   | 28 | 29   | 52 | 96     | 97 | 97        | 99 |
| Boreal Chickadee<br><u>Parus hudsonicus</u>                | 5   | 0  | 4    | 0  | 2    | 1  | 10     | 2  | 2         | 1  |

## Appendix 5A (continued)

|                                                      | May |    | June |    | July |    | August |    | September |    |
|------------------------------------------------------|-----|----|------|----|------|----|--------|----|-----------|----|
|                                                      | T   | C  | T    | C  | T    | C  | T      | C  | T         | C  |
| Red-breasted Nuthatch<br><u>Sitta canadensis</u>     | 10  | 10 | 5    | 14 | 18   | 23 | 54     | 42 | 77        | 61 |
| White-breasted Nuthatch<br><u>Sitta carolinensis</u> | 1   | 4  | 0    | 0  | 0    | 1  | 3      | 7  | 0         | 3  |
| Brown Creeper<br><u>Certhia americana</u>            | 16  | 35 | 3    | 8  | 5    | 14 | 13     | 21 | 1         | 7  |
| Winter Wren<br><u>Troglodytes troglodytes</u>        | 13  | 25 | 10   | 25 | 17   | 24 | 11     | 10 | 4         | 3  |
| Sedge Wren<br><u>Cistothorus platensis</u>           | 0   | 0  | 1    | 3  | 5    | 1  | 0      | 0  | 2         | 0  |
| Marsh Wren<br><u>Cistothorus palustris</u>           | 0   | 2  | 0    | 0  | 0    | 0  | 0      | 1  | 0         | 0  |
| Golden-crowned Kinglet<br><u>Regulus satrapa</u>     | 59  | 39 | 40   | 24 | 40   | 24 | 67     | 17 | 46        | 44 |
| Ruby-crowned Kinglet<br><u>Regulus calendula</u>     | 24  | 35 | 6    | 1  | 3    | 1  | 7      | 1  | 2         | 0  |
| Eastern Bluebird<br><u>Sialia sialis</u>             | 1   | 0  | 2    | 1  | 0    | 0  | 0      | 0  | 0         | 0  |
| Veery<br><u>Catharus fuscescens</u>                  | 0   | 0  | 20   | 18 | 17   | 25 | 1      | 0  | 2         | 0  |
| Swainson's Thrush<br><u>Catharus ustulatus</u>       | 0   | 0  | 0    | 2  | 0    | 0  | 0      | 0  | 0         | 0  |
| Hermit Thrush<br><u>Catharus guttatus</u>            | 41  | 31 | 26   | 41 | 91   | 81 | 46     | 45 | 16        | 14 |
| Wood Thrush<br><u>Hylocichla mustelina</u>           | 0   | 0  | 2    | 0  | 0    | 1  | 0      | 0  | 0         | 0  |
| American Robin<br><u>Turdus migratorius</u>          | 29  | 39 | 22   | 18 | 17   | 25 | 19     | 7  | 9         | 6  |
| Gray Catbird<br><u>Dumetella carolinensis</u>        | 0   | 0  | 0    | 1  | 2    | 0  | 2      | 0  | 0         | 0  |

## Appendix 5A (continued)

|                                                              | May |   | June |    | July |    | August |    | September |    |
|--------------------------------------------------------------|-----|---|------|----|------|----|--------|----|-----------|----|
|                                                              | T   | C | T    | C  | T    | C  | T      | C  | T         | C  |
| Brown Thrasher<br><u>Toxostoma rufum</u>                     | 4   | 0 | 6    | 2  | 3    | 0  | 2      | 0  | 1         | 0  |
| Cedar Waxwing<br><u>Bombycilla cedrorum</u>                  | 0   | 0 | 7    | 3  | 26   | 14 | 36     |    |           |    |
| European Starling<br><u>Sturnus vulgaris</u>                 | 1   | 4 | 2    | 0  | 0    | 0  | 5      | 0  | 0         | 0  |
| Solitary Vireo<br><u>Vireo solitarius</u>                    | 0   | 2 | 9    | 2  | 3    | 1  | 2      | 1  | 0         | 1  |
| Yellow-throated Vireo<br><u>Vireo flavifrons</u>             | 0   | 0 | 0    | 1  | 1    | 1  | 0      | 0  | 0         | 0  |
| Philadelphia Vireo<br><u>Vireo philadelphicus</u>            | 0   | 0 | 1    | 0  | 0    | 0  | 0      | 0  | 0         | 0  |
| Red-eyed Vireo<br><u>Vireo olivaceus</u>                     | 0   | 0 | 51   | 62 | 61   | 82 | 34     | 43 | 7         | 16 |
| Golden-winged Warbler<br><u>Vermivora chrysoptera</u>        | 0   | 0 | 6    | 11 | 1    | 0  | 0      | 0  | 0         | 0  |
| Tennessee Warbler<br><u>Vermivora peregrina</u>              | 0   | 0 | 0    | 2  | 0    | 0  | 0      | 0  | 2         | 0  |
| Nashville Warbler<br><u>Vermivora ruficapilla</u>            | 0   | 1 | 111  | 72 | 94   | 49 | 18     | 11 | 3         | 3  |
| Northern Parula<br><u>Parula americana</u>                   | 0   | 0 | 5    | 8  | 4    | 8  | 0      | 0  | 1         | 1  |
| Yellow Warbler<br><u>Dendroica petechia</u>                  | 0   | 0 | 0    | 0  | 0    | 1  | 1      | 0  | 0         | 0  |
| Chestnut-sided Warbler<br><u>Dendroica pensylvanica</u>      | 0   | 0 | 51   | 30 | 41   | 25 | 6      | 4  | 2         | 1  |
| Magnolia Warbler<br><u>Dendroica magnolia</u>                | 0   | 0 | 3    | 0  | 0    | 0  | 1      | 0  | 0         | 0  |
| Black-throated Blue Warbler<br><u>Dendroica caerulescens</u> | 0   | 0 | 0    | 2  | 0    | 0  | 0      | 0  | 1         | 0  |

## Appendix 5A (continued)

|                                                           | May |    | June |     | July |     | August |    | September |   |
|-----------------------------------------------------------|-----|----|------|-----|------|-----|--------|----|-----------|---|
|                                                           | T   | C  | T    | C   | T    | C   | T      | C  | T         | C |
| Yellow-rumped Warbler<br><u>Dendroica coronata</u>        | 43  | 39 | 17   | 14  | 19   | 16  | 0      | 1  | 0         | 4 |
| Black-throated Green Warbler<br><u>Dendroica virens</u>   | 0   | 1  | 32   | 59  | 31   | 47  | 11     | 14 | 2         | 2 |
| Blackburnian Warbler<br><u>Dendroica fusca</u>            | 0   | 0  | 11   | 8   | 1    | 6   | 2      | 0  | 0         | 0 |
| Pine Warbler<br><u>Dendroica pinus</u>                    | 0   | 0  | 4    | 1   | 0    | 0   | 0      | 0  | 0         | 0 |
| Palm Warbler<br><u>Dendroica palmarum</u>                 | 1   | 0  | 0    | 0   | 1    | 0   | 0      | 0  | 0         | 0 |
| Black-and-white Warbler<br><u>Mniotilta varia</u>         | 0   | 0  | 15   | 17  | 9    | 14  | 4      | 1  | 2         | 4 |
| American Redstart<br><u>Setophaga ruticilla</u>           | 0   | 0  | 0    | 1   | 0    | 0   | 0      | 0  | 1         | 1 |
| Ovenbird<br><u>Seiurus aurocapillus</u>                   | 0   | 0  | 120  | 153 | 87   | 140 | 7      | 11 | 17        | 8 |
| Northern Waterthrush<br><u>Seiurus noveboracensis</u>     | 0   | 2  | 0    | 7   | 0    | 4   | 0      | 0  | 0         | 0 |
| Connecticut Warbler<br><u>Oporornis agilis</u>            | 0   | 0  | 1    | 0   | 2    | 0   | 0      | 0  | 0         | 0 |
| Mourning Warbler<br><u>Oporornis philadelphia</u>         | 0   | 0  | 23   | 11  | 28   | 10  | 0      | 0  | 0         | 0 |
| Common Yellowthroat<br><u>Geothlypis trichas</u>          | 0   | 0  | 4    | 21  | 11   | 22  | 6      | 1  | 5         | 5 |
| Canada Warbler<br><u>Wilsonia canadensis</u>              | 0   | 0  | 1    | 7   | 3    | 4   | 1      | 1  | 2         | 3 |
| Scarlet Tanager<br><u>Piranga olivacea</u>                | 0   | 0  | 9    | 14  | 8    | 8   | 0      | 0  | 1         | 1 |
| Rose-breasted Grosbeak<br><u>Phoebastria ludovicianus</u> | 0   | 0  | 18   | 39  | 12   | 10  | 4      | 1  | 1         | 4 |

## Appendix 5A (continued)

[illegible]



## Appendix 5A (continued)

|                                                           | May |     | June |      | July |      | August |     | September |     |
|-----------------------------------------------------------|-----|-----|------|------|------|------|--------|-----|-----------|-----|
|                                                           | T   | C   | T    | C    | T    | C    | T      | C   | T         | C   |
| White-winged Crossbill<br><u>Loxia leucoptera</u>         | 0   | 0   | 37   | 0    | 0    | 0    | 23     | 0   | 9         | 7   |
| Pine Siskin<br><u>Carduelis pinus</u>                     | 0   | 4   | 0    | 0    | 0    | 0    | 0      | 0   | 0         | 0   |
| American Goldfinch<br><u>Carduelis tristis</u>            | 1   | 0   | 6    | 2    | 1    | 1    | 9      | 4   | 8         | 1   |
| Evening Grosbeak<br><u>Coccothraustes vespertinus</u>     | 4   | 1   | 0    | 1    | 0    | 3    | 1      | 0   | 0         | 1   |
| Unidentified passerine<br><u>Unidentified passerine</u>   | 7   | 5   | 23   | 18   | 23   | 14   | 42     | 39  | 59        | 51  |
| Unidentified woodpecker<br><u>Unidentified woodpecker</u> | 1   | 0   | 1    | 2    | 6    | 5    | 5      | 6   | 3         | 1   |
| Unidentified raptor<br><u>Unidentified raptor</u>         | 0   | 0   | 0    | 0    | 0    | 0    | 0      | 0   | 1         | 0   |
| Total individuals                                         | 570 | 607 | 983  | 1020 | 994  | 1039 | 791    | 551 | 505       | 435 |
| Total species                                             | 44  | 46  | 70   | 71   | 63   | 68   | 62     | 52  | 48        | 45  |

Appendix 5B. Total number of individuals and species observed on control (C) and treatment (T) transects in Wisconsin during five census periods in 1989. English and scientific names follow AOU (1983, 1985).



## Appendix 5B (continued)

|                                                            | May |    | June |    | July |    | August |    | September |    |
|------------------------------------------------------------|-----|----|------|----|------|----|--------|----|-----------|----|
|                                                            | T   | C  | T    | C  | T    | C  | T      | C  | T         | C  |
| Barred Owl<br><u>Strix varia</u>                           | 1   | 1  | 0    | 0  | 0    | 0  | 1      | 0  | 0         | 2  |
| Chimney Swift<br><u>Chaetura pelagica</u>                  | 1   | 0  | 1    | 2  | 0    | 0  | 0      | 0  | 0         | 0  |
| Ruby-throated Hummingbird<br><u>Archilochus colubris</u>   | 0   | 0  | 1    | 0  | 0    | 0  | 0      | 0  | 0         | 0  |
| Belted Kingfisher<br><u>Ceryle alcyon</u>                  | 0   | 1  | 0    | 1  | 0    | 1  | 1      | 3  | 1         | 0  |
| Yellow-bellied Sapsucker<br><u>Sphyrapicus varius</u>      | 11  | 22 | 15   | 14 | 1    | 2  | 3      | 1  | 5         | 11 |
| Downy Woodpecker<br><u>Picoides pubescens</u>              | 0   | 2  | 0    | 1  | 0    | 2  | 2      | 0  | 2         | 16 |
| Hairy Woodpecker<br><u>Picoides villosus</u>               | 3   | 2  | 3    | 2  | 0    | 2  | 3      | 7  | 5         | 4  |
| Black-backed Woodpecker<br><u>Picoides arcticus</u>        | 1   | 3  | 0    | 1  | 0    | 0  | 1      | 0  | 0         | 1  |
| Northern Flicker<br><u>Colaptes auratus</u>                | 1   | 3  | 5    | 7  | 5    | 2  | 2      | 2  | 6         | 5  |
| Pileated Woodpecker<br><u>Dryocopus pileatus</u>           | 3   | 1  | 0    | 1  | 1    | 2  | 1      | 1  | 2         | 1  |
| Olive-sided Flycatcher<br><u>Contopus borealis</u>         | 1   | 1  | 4    | 1  | 2    | 5  | 0      | 1  | 0         | 0  |
| Eastern Wood-Pewee<br><u>Contopus virens</u>               | 0   | 3  | 5    | 10 | 2    | 8  | 3      | 11 | 1         | 6  |
| Yellow-bellied Flycatcher<br><u>Empidonax flaviventris</u> | 10  | 11 | 28   | 31 | 21   | 20 | 4      | 1  | 0         | 0  |
| Alder Flycatcher<br><u>Empidonax alnorum</u>               | 2   | 0  | 3    | 3  | 3    | 0  | 1      | 0  | 0         | 0  |
| Least Flycatcher<br><u>Empidonax minimus</u>               | 21  | 31 | 32   | 23 | 3    | 1  | 0      | 1  | 0         | 0  |

## Appendix 5B (continued)

|                                                       | May |    | June |    | July |    | August |    | September |     |
|-------------------------------------------------------|-----|----|------|----|------|----|--------|----|-----------|-----|
|                                                       | T   | C  | T    | C  | T    | C  | T      | C  | T         | C   |
| Eastern Phoebe<br><u>Sayornis phoebe</u>              | 1   | 0  | 0    | 0  | 0    | 0  | 0      | 0  | 0         | 0   |
| Great Crested Flycatcher<br><u>Myiarchus crinitus</u> | 6   | 12 | 5    | 4  | 0    | 1  | 0      | 0  | 0         | 0   |
| Eastern Kingbird<br><u>Tyrannus tyrannus</u>          | 0   | 0  | 0    | 1  | 2    | 3  | 0      | 0  | 0         | 0   |
| Tree Swallow<br><u>Tachycineta bicolor</u>            | 0   | 5  | 0    | 0  | 0    | 3  | 0      | 0  | 0         | 0   |
| Gray Jay<br><u>Perisoreus canadensis</u>              | 3   | 1  | 1    | 0  | 1    | 0  | 3      | 4  | 3         | 5   |
| Blue Jay<br><u>Cyanocitta cristata</u>                | 34  | 25 | 21   | 19 | 9    | 14 | 9      | 21 | 32        | 48  |
| American Crow<br><u>Corvus brachyrhynchos</u>         | 0   | 2  | 1    | 0  | 0    | 0  | 0      | 0  | 0         | 0   |
| Common Raven<br><u>Corvus corax</u> Linnaeus          | 0   | 0  | 0    | 3  | 0    | 1  | 0      | 0  | 0         | 0   |
| Black-capped Chickadee<br><u>Parus atricapillus</u>   | 26  | 24 | 18   | 28 | 84   | 44 | 93     | 91 | 104       | 98  |
| Boreal Chickadee<br><u>Parus hudsonicus</u>           | 0   | 0  | 0    | 0  | 0    | 1  | 1      | 0  | 2         | 0   |
| Red-breasted Nuthatch<br><u>Sitta canadensis</u>      | 14  | 7  | 14   | 9  | 13   | 8  | 30     | 28 | 196       | 184 |
| White-breasted Nuthatch<br><u>Sitta carolinensis</u>  | 2   | 1  | 0    | 3  | 0    | 1  | 1      | 5  | 2         | 6   |
| Brown Creeper<br><u>Certhia americana</u>             | 6   | 12 | 12   | 18 | 6    | 12 | 10     | 13 | 21        | 25  |
| Winter Wren<br><u>Troglodytes troglodytes</u>         | 20  | 47 | 29   | 35 | 24   | 32 | 10     | 7  | 4         | 3   |
| Sedge Wren<br><u>Cistothorus platensis</u>            | 5   | 0  | 0    | 0  | 3    | 0  | 0      | 0  | 0         | 0   |

## Appendix 5B (continued)

|                                                       | May |    | June |     | July |    | August |    | September |    |
|-------------------------------------------------------|-----|----|------|-----|------|----|--------|----|-----------|----|
|                                                       | T   | C  | T    | C   | T    | C  | T      | C  | T         | C  |
| Marsh Wren<br><u>Cistothorus palustris</u>            | 0   | 0  | 2    | 0   | 0    | 0  | 0      | 0  | 0         | 0  |
| Golden-crowned Kinglet<br><u>Regulus satrapa</u>      | 40  | 17 | 28   | 14  | 40   | 21 | 45     | 38 | 36        | 22 |
| Ruby-crowned Kinglet<br><u>Regulus calendula</u>      | 1   | 0  | 2    | 1   | 0    | 0  | 0      | 0  | 3         | 0  |
| Veery<br><u>Catharus fuscescens</u>                   | 1   | 0  | 12   | 4   | 2    | 2  | 0      | 3  | 0         | 0  |
| Swainson's Thrush<br><u>Catharus ustulatus</u>        | 0   | 0  | 0    | 0   | 0    | 0  | 0      | 0  | 4         | 4  |
| Hermit thrush<br><u>Catharus guttatus</u>             | 40  | 30 | 55   | 58  | 91   | 76 | 9      | 10 | 11        | 14 |
| Wood Thrush<br><u>Hylocichla mustelina</u>            | 0   | 0  | 0    | 1   | 0    | 0  | 0      | 0  | 0         | 0  |
| American Robin<br><u>Turdus migratorius</u>           | 10  | 10 | 6    | 12  | 4    | 6  | 7      | 4  | 0         | 0  |
| Gray Catbird<br><u>Dumetella carolinensis</u>         | 0   | 0  | 0    | 0   | 0    | 1  | 2      | 0  | 0         | 0  |
| Brown Thrasher<br><u>Toxostoma rufum</u>              | 1   | 0  | 0    | 1   | 0    | 0  | 1      | 0  | 0         | 0  |
| Cedar Waxwing<br><u>Bombycilla cedrorum</u>           | 0   | 0  | 1    | 11  | 14   | 13 | 43     | 23 | 7         | 4  |
| Solitary Vireo<br><u>Vireo solitarius</u>             | 4   | 11 | 5    | 1   | 0    | 3  | 2      | 0  | 1         | 2  |
| Philadelphia Vireo<br><u>Vireo philadelphicus</u>     | 2   | 1  | 0    | 0   | 0    | 0  | 0      | 0  | 0         | 0  |
| Red-eyed Vireo<br><u>Vireo olivaceus</u>              | 28  | 39 | 78   | 108 | 73   | 92 | 30     | 37 | 10        | 6  |
| Golden-winged Warbler<br><u>Vermivora chrysoptera</u> | 14  | 6  | 6    | 6   | 0    | 1  | 0      | 0  | 0         | 0  |

## Appendix 5B (continued)

|                                                         | May |    | June |    | July |    | August |   | September |   |
|---------------------------------------------------------|-----|----|------|----|------|----|--------|---|-----------|---|
|                                                         | T   | C  | T    | C  | T    | C  | T      | C | T         | C |
| Tennessee Warbler<br><u>Vermivora peregrina</u>         | 2   | 1  | 1    | 1  | 0    | 0  | 3      | 0 | 6         | 0 |
| Nashville Warbler<br><u>Vermivora ruficapilla</u>       | 92  | 68 | 56   | 75 | 53   | 25 | 5      | 3 | 13        | 2 |
| Northern Parula<br><u>Parula americana</u>              | 13  | 21 | 12   | 17 | 2    | 3  | 0      | 2 | 0         | 0 |
| Yellow Warbler<br><u>Dendroica petechia</u>             | 4   | 1  | 3    | 0  | 0    | 0  | 1      | 0 | 0         | 0 |
| Chestnut-sided Warbler<br><u>Dendroica pensylvanica</u> | 77  | 56 | 70   | 50 | 17   | 6  | 0      | 3 | 6         | 3 |
| Magnolia Warbler<br><u>Dendroica magnolia</u>           | 4   | 1  | 4    | 4  | 6    | 2  | 0      | 0 | 0         | 1 |
| Cape May Warbler<br><u>Dendroica tigrina</u>            | 0   | 0  | 1    | 0  | 0    | 0  | 0      | 0 | 0         | 0 |
| Yellow-rumped Warbler<br><u>Dendroica coronata</u>      | 30  | 18 | 20   | 4  | 9    | 2  | 0      | 2 | 41        | 7 |
| Black-throated Green Warbler<br><u>Dendroica virens</u> | 47  | 77 | 47   | 57 | 34   | 38 | 3      | 4 | 5         | 8 |
| Blackburnian Warbler<br><u>Dendroica fusca</u>          | 7   | 16 | 13   | 18 | 0    | 0  | 1      | 0 | 1         | 1 |
| Pine Warbler<br><u>Dendroica pinus</u>                  | 0   | 0  | 0    | 1  | 0    | 0  | 0      | 0 | 0         | 0 |
| Palm Warbler<br><u>Dendroica palmarum</u>               | 3   | 1  | 2    | 0  | 0    | 1  | 0      | 0 | 9         | 0 |
| Bay-breasted Warbler<br><u>Dendroica castanea</u>       | 1   | 0  | 0    | 0  | 0    | 0  | 0      | 0 | 1         | 0 |
| Black-and-white Warbler<br><u>Mniotilta varia</u>       | 30  | 48 | 21   | 23 | 6    | 2  | 3      | 4 | 2         | 3 |
| American Redstart<br><u>Setophaga ruticilla</u>         | 0   | 1  | 4    | 1  | 1    | 0  | 0      | 1 | 1         | 0 |

## Appendix 5B (continued)

|                                                          | May |     | June |     | July |    | August |    | September |    |
|----------------------------------------------------------|-----|-----|------|-----|------|----|--------|----|-----------|----|
|                                                          | T   | C   | T    | C   | T    | C  | T      | C  | T         | C  |
| Ovenbird<br><u>Seiurus aurocapillus</u>                  | 144 | 199 | 119  | 162 | 47   | 61 | 18     | 23 | 20        | 46 |
| Northern Waterthrush<br><u>Seiurus noveboracensis</u>    | 2   | 1   | 2    | 0   | 0    | 0  | 0      | 0  | 1         | 1  |
| Connecticut Warbler<br><u>Oporornis agilis</u>           | 0   | 0   | 2    | 2   | 1    | 0  | 0      | 0  | 0         | 0  |
| Mourning Warbler<br><u>Oporornis philadelphia</u>        | 5   | 9   | 34   | 20  | 11   | 4  | 3      | 0  | 0         | 0  |
| Common Yellowthroat<br><u>Geothlypis trichas</u>         | 29  | 15  | 14   | 7   | 24   | 14 | 9      | 2  | 9         | 2  |
| Canada Warbler<br><u>Wilsonia canadensis</u>             | 4   | 8   | 10   | 10  | 0    | 1  | 2      | 4  | 0         | 1  |
| Scarlet Tanager<br><u>Piranga olivacea</u>               | 2   | 8   | 4    | 3   | 2    | 4  | 0      | 0  | 0         | 0  |
| Rose-breasted Grosbeak<br><u>Pheucticus ludovicianus</u> | 21  | 22  | 8    | 14  | 4    | 7  | 5      | 1  | 4         | 1  |
| Indigo Bunting<br><u>Passerina cyanea</u>                | 0   | 0   | 10   | 1   | 14   | 1  | 4      | 0  | 0         | 0  |
| Rufous-sided Towhee<br><u>Pipilo erythrophthalmus</u>    | 0   | 0   | 1    | 0   | 0    | 0  | 0      | 0  | 0         | 0  |
| Chipping Sparrow<br><u>Spizella passerina</u>            | 25  | 3   | 12   | 1   | 7    | 0  | 0      | 0  | 2         | 0  |
| Lark Sparrow<br><u>Chondestes grammacus</u>              | 3   | 0   | 0    | 0   | 0    | 0  | 0      | 0  | 0         | 0  |
| Song Sparrow<br><u>Melospiza melodia</u>                 | 10  | 4   | 12   | 11  | 17   | 9  | 7      | 1  | 1         | 4  |
| Lincoln's Sparrow<br><u>Melospiza lincolni</u>           | 1   | 0   | 0    | 0   | 2    | 0  | 0      | 0  | 0         | 0  |
| Swamp Sparrow<br><u>Melospiza georgianna</u>             | 13  | 1   | 7    | 1   | 20   | 2  | 0      | 0  | 3         | 0  |



## Appendix 5B (continued)

|                                                           | May |     | June |    | July |    | August |    | September |    |
|-----------------------------------------------------------|-----|-----|------|----|------|----|--------|----|-----------|----|
|                                                           | T   | C   | T    | C  | T    | C  | T      | C  | T         | C  |
| White-throated Sparrow<br><u>Zonotrichia albicollis</u>   | 63  | 64  | 53   | 47 | 62   | 45 | 23     | 13 | 37        | 28 |
| Dark-eyed Junco<br><u>Junco hyemalis</u>                  | 0   | 1   | 0    | 6  | 0    | 0  | 0      | 0  | 0         | 0  |
| Red-winged Blackbird<br><u>Agelaius phoeniceus</u>        | 3   | 4   | 6    | 5  | 0    | 0  | 0      | 0  | 0         | 0  |
| Common Grackle<br><u>Quiscalus quiscula</u>               | 0   | 5   | 0    | 5  | 2    | 0  | 0      | 0  | 0         | 0  |
| Brown-headed Cowbird<br><u>Molothrus ater</u>             | 3   | 14  | 1    | 2  | 0    | 0  | 0      | 0  | 0         | 0  |
| Northern Oriole<br><u>Icterus galbula</u>                 | 1   | 0   | 0    | 0  | 1    | 1  | 2      | 0  | 0         | 0  |
| Purple Finch<br><u>Carpodacus purpureus</u>               | 8   | 5   | 2    | 2  | 1    | 0  | 1      | 0  | 0         | 0  |
| White-winged Crossbill<br><u>Loxia leucoptera</u>         | 0   | 0   | 0    | 0  | 10   | 19 | 6      | 8  | 14        | 6  |
| Pine Siskin<br><u>Carduelis pinus</u>                     | 1   | 0   | 0    | 0  | 0    | 0  | 0      | 4  | 14        | 0  |
| American Goldfinch<br><u>Carduelis tristis</u>            | 2   | 1   | 5    | 8  | 1    | 3  | 7      | 4  | 1         | 1  |
| Evening Grosbeak<br><u>Coccothraustes vespertinus</u>     | 1   | 7   | 0    | 2  | 0    | 0  | 0      | 0  | 2         | 3  |
| Unidentified passerine<br><u>Unidentified passerine</u>   | 30  | 21  | 16   | 7  | 36   | 30 | 59     | 53 | 61        | 46 |
| Unidentified woodpecker<br><u>Unidentified woodpecker</u> | 0   | 4   | 4    | 5  | 4    | 8  | 3      | 5  | 5         | 0  |
| Total individuals                                         | 101 | 106 | 5    | 10 | 16   | 80 | 5      | 69 | 48        | 6  |
| Total species                                             | 68  | 65  | 65   | 67 | 49   | 54 | 47     | 40 | 46        | 44 |

Appendix 6. Presentations 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.

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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.

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#### IV. GLOSSARY AND ACRONYMS

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

H' - taxon diversity (after Shannon-Weiner). An information theory index which weights the number of

taxa and the apportionment of numbers of individuals among the taxa.

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

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

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

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

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

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

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

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

Mann-Whitney U test - non-parametric statistical test of two samples which gives rise to a t-test or ANOVA. Null hypothesis is that two samples come from populations having the same distribution.

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

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

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

ammonium-N: ammonium-Nitrogen

nitrate-N: nitrate-Nitrogen

nitrite-N: nitrite-Nitrogen

inorganic-N: inorganic-Nitrogen; the sum of the three N species above.

organic-N: organic-Nitrogen; total Kjeldahl nitrogen minus ammonium nitrogen.

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

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

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

P - predators; animals that ingest other animals.

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

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

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

Periphyton - algae, bacteria and fungi attached to the substrate, rocks, twigs or any other debris in the stream. Our studies emphasize periphytic algae attached to bottom substrates.

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

Predators - animals that ingest other animals.

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

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

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

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

Shredder - see S (first definition) above.

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

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

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

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

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

Univoltine - one emergence per year.

Weir - semi-permanent traps used to capture fish. Made of hardware cloth held in place with metal rods. Installed at beginning of study season and removed at

the end of the season; installation is similar to that described for fyke nets above. Weirs intercept fish moving up or downstream. Fish are captured in removeable weir boxes when these boxes are in place. When boxes are removed, weir is negotiable by all fish.

Wr - relative weight condition factors used in fish studies.

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

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



## V. ABSTRACT

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

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

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

Data collected on the aquatic insect communities include: (1) data on species richness and biomass of stream insects associated with bottom materials (sand, gravel, pebble, cobble); (2) data on leaf processing rates derived from studies of leaf packs placed on the leading edge of bricks in the streams, and (3) studies of movement by the immatures of a species of dragonfly (Ophiogomphus colubrinus). The insect communities associated with bottom materials show distinct seasonal patterns, but no difference in taxon diversity, evenness, or species richness can be related to ELF effects either for the entire community or for individual functional feeding groups. The leaf pack studies include separate studies of freshly picked green leaves and leaves collected after leaf fall in the autumn from speckled (tag) alder (Alnus rugosa) leaves. These studies also include studies of the insect communities associated with these leaf packs with special emphasis on three species of mayflies (Ephemeroptera) and a species of stonefly (Plecoptera). None of the parameters monitored as part of the leaf pack studies show any differences that can be related to ELF effects. Results from the dragonfly movement studies showed no site differences for most years. When sites were

significantly different, no particular pattern emerged, either before or after ELF activation. It seems likely that the low discharge and high temperatures characteristic of some years may have had differential effects at the two sites causing differences unrelated to ELF effects.

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 1989 while nineteen species were collected at the control site (FCD). Overall, the species composition and diversity were similar at the two sites with only changes seen in the seldom caught species. There was no significant difference in either numbers or biomass of fish caught between the two sites. 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 within the fish community.

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

## VI. SUMMARY

This research project is directed at determining the effects of low-level, long-term, electromagnetic fields (ELF) on natural stream ecosystems and their associated plant and animal life. Detailed ecological sampling and analyses are being conducted simultaneously at two sites: (1) a control site, FCD, and (2) an experimental site, FEX, at the corridor of the ELF antenna. These sites have been studied since 1983 with additional sites monitored for studies of fish movements. The N-S leg of the ELF antenna crosses the FEX site and was tested at 4-6 amps for several hours on several days from July 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. Thus, data collected to date represent data collected prior to any exposure from the operation of the antenna (June 1983 through June 1986) or represent transitional data with variable operations and exposures to electromagnetic radiation (July 1986 to present). These transitional period data have only included exposure during daytime for short time periods with exposure at half the final proposed operating amps (150) or less. Even so, some initial analyses on the effects of these exposures to the biota have been included in this report.

### 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 had been true for hardness, nitrate, and organic nitrogen in most years. The differences observed for hardness and for nitrate and organic-N could 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.

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

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

Chemical and physical parameters for FEX and FCD demonstrated that these two sites were very similar with significant differences between sites showing up for less than one-third of the parameters monitored prior to 1989. The differences that did occur were slight and should have little impact on site productivity. Most of these differences were not present in 1988 with the exception of water temperature and hardness.

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

1. Chlorophyll a

Annual patterns for chlorophyll a standing crop and accrual were characterized by large year to year variability. The only consistent trend was for July-August peaks in most years and winter lows. The magnitudes of peaks also varied between years. Paired t-tests for 1988-89 data showed no differences between our control (FCD) and experimental sites (FEX), nor were there any differences for all data collected since 1983. "Before" (6/83-4/86) and "after" (5/86-9/89), control (FCD) and impact (FEX) (BACI) analyses indicate that the between-site relationship in chlorophyll a has changed since May 1986 when the testing of the antenna began. However, the lack of differences between sites for the after years coupled with significant positive correlations between water temperature and chlorophyll a, the importance of water temperature as a predictor of chlorophyll a in stepwise regression models, and the increasing water temperatures during the drought periods in the spring and summer in 1986, 87, 88, and 89 lead us to believe that this change is related to weather variables and not to ELF exposure.

## 2. Organic Matter

Organic matter (AFDW-biomass) standing crop and accrual rates showed considerable year to year variability similar to chlorophyll a. These parameters have been consistently characterized as having no significant differences between sites since 1983. BACI analyses also showed that no difference has occurred in AFDW-organic matter accumulation since the testing of the antenna began in 1986. The only overall trend has been for a July-August peak in standing crop and accrual rates and winter time lows for both standing crop and accrual. Stepwise regression analysis failed to indicate any variable or set of variables that consistently predict standing crop. In last year's correlation matrix organic matter standing crop was correlated with water temperature (positively) and discharge and dissolved oxygen (negatively).

## 3. Diatom Cell Density

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

## 4. Total Biovolume and Individual Cell Volume

Individual cell volume comparisons of diatoms between sites showed no significant differences according to paired t-tests. Differences in the BACI analysis of biovolume are attributed to differences in the data set for the winters of 1984, 85, 86 and 88. In general, average cell volume was high in winter and low in summer, whereas total biovolume tended to be highest in summer since it is the product of average volume times density. Stepwise regression analysis indicates that water temperature is the most consistent predictor of cell volume and silica is the most consistent predictor of total biovolume. Average cell volume was negatively correlated ( $p < 0.05$ ) with water temperature and total biovolume was not correlated with any of the physical/chemical variables.

## 5. Species Diversity and Evenness

Diatom species diversity and evenness were not significantly different in 1989 or for all data collected to date according to paired t-tests. Annual trends show a high diversity and evenness during winter (except winter of 1986-87) and lower values during the summer periods. In 1989, we calculated percent abundance for all species of diatoms and presented data for those species that achieved dominance greater than 10 % for any season. Three species, Achnanthes minutissima, Cocconeis placentula, and Fragilaria vaucheriae were found to dominate during the 1989 summer period. The dominance of Fragilaria in the summer season was atypical, caused by extremely high abundances at both sites during May 1989. Three typical species achieved dominance during the winter of 1988. BACI analyses were presented for four dominant and two non-dominant species of diatoms and showed that few differences have occurred before and after antenna testing began. Even so, overall diversity and evenness have changed significantly over that time period according to the BACI analyses. Because of the pattern of year to year differences, we suggest that these changes may be related to environmental rather than ELF effects.

## 6. Correlation with Environmental Variables

Stepwise multiple regression analysis was conducted for each biological parameter on selected physical/chemical variables (chosen from last year's correlation matrix). In many cases the regression models agreed with the results of the correlation matrix, yet a large amount of variance was left unexplained. In some cases the regression models pointed out relationships that did not show up in the correlation matrix. Next year these models will be expanded to include more variables in an attempt to explain more of the variance.

## 7. Photosynthesis-Respiration Studies

Net production, respiration, and gross production of the community on rock surfaces did not differ greatly between sites. BACI analyses indicate that there has been no significant differences between FEX and FCD sites for gross primary production rates for "before" and "after" data. This parameter may offer a sensitive means of detecting ELF effects on community metabolism.

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

Grazing macroinvertebrates can change the composition of the diatom community at densities equal to or greater than densities found in the Ford River. Specifically, Glossoma nigrior, a grazing caddisfly, caused a shift in dominance within the diatom community in 1985 and 1986 with Cocconeis decreasing in abundance and Achnanthes increasing in abundance as grazing pressure increased. Such shifts in community structure occurred at both FEX and FCD despite no significant changes in community based parameters such as chlorophyll a or AFDW-organic matter biomass accumulation. Results from 1985 were somewhat different from results from 1986. In 1986, the trend towards decreased abundance of Cocconeis and increased abundance of Achnanthes occurred at both sites but was not as significant as in 1985. In 1987, there was no measurable impact of grazers on any aspect of the periphyton community with the possible exception of shifts in dominance of a couple of minor taxa at FEX. In 1988, there was a grazer impact on the dominance of Achnanthes but this impact resulted in a decrease in dominance (opposite the results of 1985 and 86). Between year differences in the impact of grazers on the periphyton communities in our streamside channels may be due to variation in the silt load encountered during the course of the studies. We made some minor modifications in our procedures to avoid such potential confounding problems in 1989 and await final analyses of these data before deciding whether, or how, to proceed with this element.

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

Taxon diversity ( $H'$ ) and taxon evenness ( $J'$ ) did not show differences between sites during the summer months; however, there were significant yearly differences. In the spring and fall seasons, there were significant site and year effects. The only season where there were significant interactions between sites and years was in the fall. The yearly significant differences for  $H'$  and  $J'$  were not related to ELF effects, as determined by graphical analysis. Taxon richness ( $S'$ ) showed no site effects in the spring seasons. This was not the case for summer and fall seasons. Then, richness was higher at FEX than at FCD. Substrates at FEX are more heterogeneous and this probably contributed to the higher taxon richness at that site. Numbers of individuals were also greater at FEX over the years.

Cumulative degree days (using water temperatures taken from EPROM readings) were higher at FEX than at FCD. This was especially true in 1989. It appears that there was a



datapod error at FCD in 1989. In the next Annual Report, adjustments will be made to this dataset. Cumulative degree data represents physiological time rather than chronological time, and is therefore, being used in growth rate studies. Growth rate studies (MDW/IND) values for six species has not been updated for 1989. Those results will appear in the next Annual Report.

Total insect biomass, analyzed season by season, showed no site nor site x year interaction effects in the spring and summer. Only during the fall were there significant interactions between site and year. It appears that the spring and summer seasons are the most reliable seasons for analysis, as the fall season shows very high variability in many parameters, including total insect biomass. Predator/prey biomass ratios showed no significant interactions between site and year for any of the three seasons. However, there were significant site effects in the spring and summer months. In 1986 when the weather was dry and hot and the fall was mild, the predator/prey ratio differed from other years, as seen from graphical analysis. When that year was excluded, there were no site nor year effects during the summers.

Discharge was linearly related to total insect mass. ANCOVA analyses, with mean discharge as the covariate, showed that in the spring months the negative relationship between insect mass and discharge was very strong at the FEX site. The mean values of insect mass, adjusted to the mean discharge value, were not significantly different during that season. Both the summer and fall seasons had a significantly higher mass of insects at FEX than at FCD; however, the patterns of responses to increasing velocities were similar at the two sites.

A theoretical dose-response curve for potential ELF effects was presented, along with cautions for using this method of analysis. Even though ELF effects, if they occur, may not operate in a dose-response manner, we do not know this. After we receive daily data on intensities and duration of ELF fields, we will analyze the data by this method. We will also look at the BACI method for looking at before versus after impact analyses.

#### Element 5 - Movement Patterns of Ophiogomphus colubrinus

Movement patterns of naiads of Ophiogomphus colubrinus were studied by marking and releasing them, and recapturing them after they had been at FEX and FCD for 24 or 48 hrs. Chi Square analyses showed highly significant differences among and between years for distances moved at both sites. When sites were compared with one another for those moved versus those remaining stationary, many years showed no site

differences for either the 24 or 48 hr experiments. When sites were significantly different, no particular pattern emerged, either before or after ELF activation. In some years, more moved at the FEX and in other years more moved at the FCD site. Additional statistical analyses (unpaired t-tests for each pair of experiments each year) will be performed before the decision as to whether to delete this element will be made.

#### Element 6 - Leaf Litter Processing

Each year, fresh leaves were processed faster than autumn leaves at each site. Although processing rates varied from year to year, FEX and FCD were not significantly different with respect to fresh leaves. There were site differences for autumn leaves over the years; autumn leaves were always processed faster, before and after ELF activation, at FEX. The site differences for autumn leaves may be caused by the usually higher biomass and numbers of aquatic insects at that site, determined both from substrate and leafpack samples. Taxon diversity, richness, numbers of individuals, and mean total biomass (adjusted for leaf mass) on autumn leaves showed significant yearly variation, but no site variation. On the other hand, those variables for insects on fresh leaves showed yearly differences as well. For some variables, there were site differences ( $H'$ , mean total biomass) and year x site differences ( $H'$ ,  $S'$ , number of individuals). These results illustrate, once again, that fresh and autumn leaves are "seen" differently by the aquatic insects who consume them, directly or indirectly. Growth rates and patterns of three species of aquatic insects were shown not to differ with respect to leaf treatment or site. Physiological time (cumulative degree days) revealed these similarities in growth rates much better than did chronological time.

Appendix II presents results of a theoretical paper on the effects of condensed tannins on leaf processing rates in tropical and temperate biomes (Can. Jour. Fish. & Aquat. Sci., 46:1097-1106) and results of a cooperative study on testing the hypothesis in the paper. It was found that leaves high in condensed tannins were processed more slowly than leaves low in condensed tannins at each of three sites (Alaska, Michigan, Costa Rica). Further, if cumulative degree-days (physiological time) rather than days (chronological time) was used in computing processing rates, leaves lacking or low in condensed tannins were processed much faster; whereas, no strong differences in processing rates occurred for leaves high in condensed tannins when they were in warm water. The difference between physiological and chronological time for those latter species of leaves was minimal.

## Element 7 - Fish Community and Abundance

### 1. Species Composition

Fourteen species from five orders and ten families were collected at FEX in 1989. This represents a net decrease of one order, one family and four species from previous years. Nineteen species from eleven families and six orders were collected at FCD in 1989 with a decrease of three species from previous years. Overall, the species composition was similar at the two sites with the only changes seen in rare species.

### 2. Species Abundance

Numerically and by biomass, the catch was dominated by five species. Numerically, common shiners and creek chubs made up over 80% of the catch at both sites. Burbot and creek chub catch was the least variable, and white sucker and common shiner catches were most variable. By biomass, common shiners, white suckers and brook trout were the dominant species at both FEX and FCD, making up over 75% of the catch. At FCD, common shiners, white suckers and brook trout comprised 83.1% of the catch. Brook trout and white sucker catch in biomass was the most variable. Catch in biomass was more variable from year to year than catch in number. Overall, the fish species composition was similar from site to site and from year to year.

Shannon-Wiener species diversity decreased at both sites in 1989 from previous values. No significant differences were found between sites, however, diversity values ranged between 1.46 to 2.2 over all years.

### 3. Catch Statistics

Catch rates (catch per day) were variable for all species and were seasonally dependent. At FEX, catch rates for common shiners was much higher than normal. Brook trout and burbot catches decreased and white sucker catch rates at FEX were about average for all years. Brook trout and burbot continued negative trends in catch rates at FCD. Common shiner catch was extremely high at FCD as it was at FEX. Creek chub and white sucker catch was average when compared to previous years. Brook trout, burbot and white suckers all demonstrated similar catch rates at both sites and the differences can be attributed to increased habitat heterogeneity at FCD.

The mean length of most species in 1989 showed no consistent year to year trends at either FCD or FEX, and brook trout, creek chubs and white suckers at FCD were significantly larger than their FEX counterparts.

#### 4. Fish Community Mobility

Most non-salmonid fish species with adequate sample sizes demonstrated site to site movement with most species showing a non-marking site recapture rate of 20.0%. Recapture percentages for 1989 were similar to 1983 through 1985. Site to site movements were lower in 1986, 1987 and 1988 due to significant discharge changes in these years.

#### 5. Individual Species Analyses

Age, growth and condition factor analysis using common shiners, creek chubs and white suckers was initiated as a section of this element in 1986 with the premise that these factors are good indicators of fish stress. Growth analysis using scales indicated that common shiners and creek chubs show better than average growth when compared to values in the literature. White suckers and northern pike both displayed poor growth when compared to literature values. Fish condition was examined using relative condition factors. Standard weight formulas were derived for common shiners, creek chubs and white suckers from literature data. Common shiner condition was above the species average in each year. Creek chubs and white suckers demonstrated below species average condition ( $Wr=87-92$ ). Creek chub condition factors declined from 1983-1987 and then increased slightly in 1988 and 1989. Common shiner condition showed a cyclic trend from 1983 - 1986 and maintained a lower condition above the species mean for 1986 - 1988. The 1989 condition factor for common shiners was very high. White sucker condition declined from 1983 through 1986 then improved from 1987 through 1989, however, all values were below the species mean.

#### 6. Fixed Gear Calibration

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

### Element 8 - Brook Trout Movement

#### 1. Movement Patterns and Rates

Brook trout catches peaked in spring-early summer at all sites. The peak occurred in June in 1984, 1987, 1988 and

1989 and in July in 1985 with the movement in an upstream direction. Peak catches of 1984, 1985, 1987 and 1988 were not seen in 1986 or 1989. Brook trout movement appeared to be initiated by mean daily water temperatures exceeding the optimal growth temperature (16 C). Movement rates are probably controlled by how quickly temperatures increase past optimal in spring. Low groundwater discharge and river flow volumes also may create thermal barriers to movement. Ground water recharge through spring snowmelt and precipitation are also important variables. Brook trout (>190 mm) move from FEX and FCD upstream to the TM site based on a total of 680 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 and 1988. Movement was again observed in 1989 although not at 1984-1985 levels. Movement rates were found to range between 0.67 to 6.7 km/day. Rates from FEX to TM were similar between 1984, 1985, 1987 and 1989 with no catches between these sites in 1986 and 1988. Brook trout movement rates were greater in 1989 than 1984 and 1985 from FCD to TM with no movement detected in 1986 and 1988 and little in 1987. Angler tag return data verified the above movement rates indicating the fish move at a fairly constant measurable rate upstream.

## 2. Population Analysis

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

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

## 3. Brook Trout Age, Growth and Condition

Age and growth analysis using scales indicated that the brook trout in the Ford River exhibit average or better growth when compared to literature values. Brook trout

length at age 1 was approximately 90 mm, at age 2 was approximately 188 mm and at age 3 was approximately 285 mm. Statistical analysis of this data is in progress and will be reported in the next report. 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 in 1987, 1988 and 1989. Statistical analysis of this data is in progress and will be reported in the next report.

## VII. PROJECT RATIONALE AND APPROACH

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

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

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

The effects of ELF on stream ecosystems will be tested using a paired plot design of selected sections of the chosen stream, the Ford River. Plots were selected to afford one area of study away from the antenna corridor for use as a control site (FCD), and another area directly under the antenna cable for use as the experimental site (FEX) (Fig. VII.1). These two stream sections constitute our paired plot design. We have intensively studied and sampled the river at these sites since June of 1983, when the final site selections were made. We also monitor fish movement using the other sites indicated on Fig. VII.1 (FS1, FCU, and TM).

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

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



## VIII. 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 changes in upstream-downstream movements of selected aquatic insects that might occur as a result of ELF; and
- (4) 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 the last annual report).

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

### Materials and Methods

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

The 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 and data are again available for both sites.

(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 comes from the twice weekly samples taken in the field at both sites. The 28 day mean dissolved oxygen at FEX using this field data is not significantly different (paired-t = -0.117, P = 0.913) than the 28 day means calculated using the ambient monitoring equipment at that site. Thus, we feel that there is no serious loss of data resulting from the temporary loss of the meter. Since the ambient monitoring equipment provides more detailed data (every 30 minutes throughout the season) than the manual field sampling we are replacing the D.O. meter before the start of the 1990 field season.

(3) pH was measured using the Altex (Beckman) Monitor II System with specially built long term, gel-filled submersible pH probes from Fisher Scientific. These meters have given us problems in the past. The meters were repaired over the winter of 1987-88 and new probes were ordered. We think that much of our past problems were associated with using the submersed probes for too long a period of time. These probes only have a submersed expected life of 3 or 4 months according to the chemist at Fisher Scientific. By changing the probes as needed over the summer, we were able to obtain consistent data during 1988 and 1989.

(4) Air and water temperature were monitored using thermistors.

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

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

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

In addition to the manual determinations of pH, dissolved oxygen, water and air temperature as described above, samples were taken once per week for determination of turbidity, alkalinity, hardness, and specific conductance. These samples were chilled on ice, returned to the field laboratory, and the above parameters were determined within three hours of collection. Twice per week, samples were taken and frozen for later determination of total phosphorus, soluble reactive phosphorus (samples filtered within three hours of collection), nitrate-N, nitrite-N, ammonium-N, organic-N (total Kjeldahl N minus ammonium), chloride, and dissolved silicate-Si (Si samples were refrigerated instead of being frozen since freezing can cause interference with this procedure). The N, P, Si, and Cl samples were analyzed during the winter months after preparation of the annual report. Thus, there is a one year lag time in reporting these data. During winter months, samples were taken at one month intervals for all of the parameters discussed above through the winter of 1986-87. This interval was decreased to once every other month in 1987-88 and once every 6 weeks in 1988-89 since the expense of taking the samples is prohibitive given the minimal amount of biological data collected during the winter months.

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

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

Statistical comparisons included paired t-tests between the two sites for each parameter, correlations between the two sites. In response to reviewers suggestions we did not include the large correlation matrix reported in previous years. This matrix was so large that it is reasonable for some significant correlations to appear due solely to chance. When necessary we will refer to correlations from the 1988 report. Unless otherwise indicated, we accepted as significant  $p < 0.05$ .

## Results and Discussion

### A. Field Chemistry

The dissolved oxygen (DO) data for 1989 (Table 1.1) corroborated the highly predictable pattern observed at both sites for all previous years of the project with winter highs and summer lows (Fig. 1.1). In general, winter values were 11 mg/L or higher and summer values never dropped below 7 mg/L (Fig. 1.1). Since cold water contains more dissolved oxygen at saturation than does warm water, one would expect this type of pattern if the water in the river is near saturation throughout the year. The Ford River was typically 5-15 % undersaturated at each site, and DO has shown high negative correlations with temperature at each site ( $r = -0.93$  and  $-0.95$  at FCD and FEX respectively,  $p < 0.01$  at both sites). There was a significant ( $p < 0.01$ ) correlation ( $r = 0.99$ ) in dissolved oxygen values between the two sites for 1989 (Table 1.2) as illustrated by Fig 1.1 and Table 1.1. We also reported this high degree of correlation for all data collected prior to 1989 ( $r = 0.98$ ) (Table 1.3). In 1989, there were significant differences between the two sites (Table 1.2) even though there had not been significant differences between the two sites for data collected in 1988 (see the 1988 annual report). 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, but did not work in 1989. In all years in which there was a difference between

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

| Date     | pH                  |                     | Dissolved Oxygen     |                      |
|----------|---------------------|---------------------|----------------------|----------------------|
|          | Experimental (FEX)  | Control (FCD)       | Experimental (FEX)   | Control (FCD)        |
| 10/3/88  | 7.79 $\pm$ 0.14 (9) | 8.02 $\pm$ 0.08 (9) | 9.86 $\pm$ 0.23 (9)  | 9.78 $\pm$ 0.19 (9)  |
| 10/31/88 | 7.77 $\pm$ 0.14 (7) | 7.97 $\pm$ 0.08 (9) | 11.97 $\pm$ 0.27 (9) | 11.78 $\pm$ 0.25 (9) |
| 12/27/88 | 7.60 (1)            | 7.40 (1)            | 12.20 (1)            | 11.30 (1)            |
| 2/11/89  | 7.65 (1)            | 7.60 (1)            | 10.80 (1)            | 10.70 (1)            |
| 3/20/89  | 7.90 (1)            | 7.85 (1)            | 12.50 (1)            | 12.00 (1)            |
| 4/17/89  | 7.95 $\pm$ 0.05 (2) | 7.82 $\pm$ 0.02 (2) | 12.35 $\pm$ 0.15 (2) | 11.92 $\pm$ 0.08 (2) |
| 5/15/89  | 7.87 $\pm$ 0.05 (9) | 7.76 $\pm$ 0.11 (9) | 11.76 $\pm$ 0.24 (9) | 11.42 $\pm$ 0.26 (9) |
| 6/12/89  | 7.82 $\pm$ 0.02 (7) | 7.89 $\pm$ 0.03 (8) | 9.36 $\pm$ 0.21 (8)  | 9.19 $\pm$ 0.20 (8)  |
| 7/10/89  | 8.10 $\pm$ 0.07 (8) | 7.99 $\pm$ 0.06 (9) | 8.90 $\pm$ 0.22 (9)  | 8.70 $\pm$ 0.17 (9)  |
| 8/7/89   | 8.27 $\pm$ 0.03 (8) | 0.04 (9)            | 8.79 $\pm$ 0.17 (9)  | 8.53 $\pm$ 0.19 (9)  |
| 9/5/89   | 8.15 $\pm$ 0.07 (8) | 8.17 $\pm$ 0.02 (8) | 9.10 $\pm$ 0.11 (9)  | 9.10 $\pm$ 0.12 (9)  |



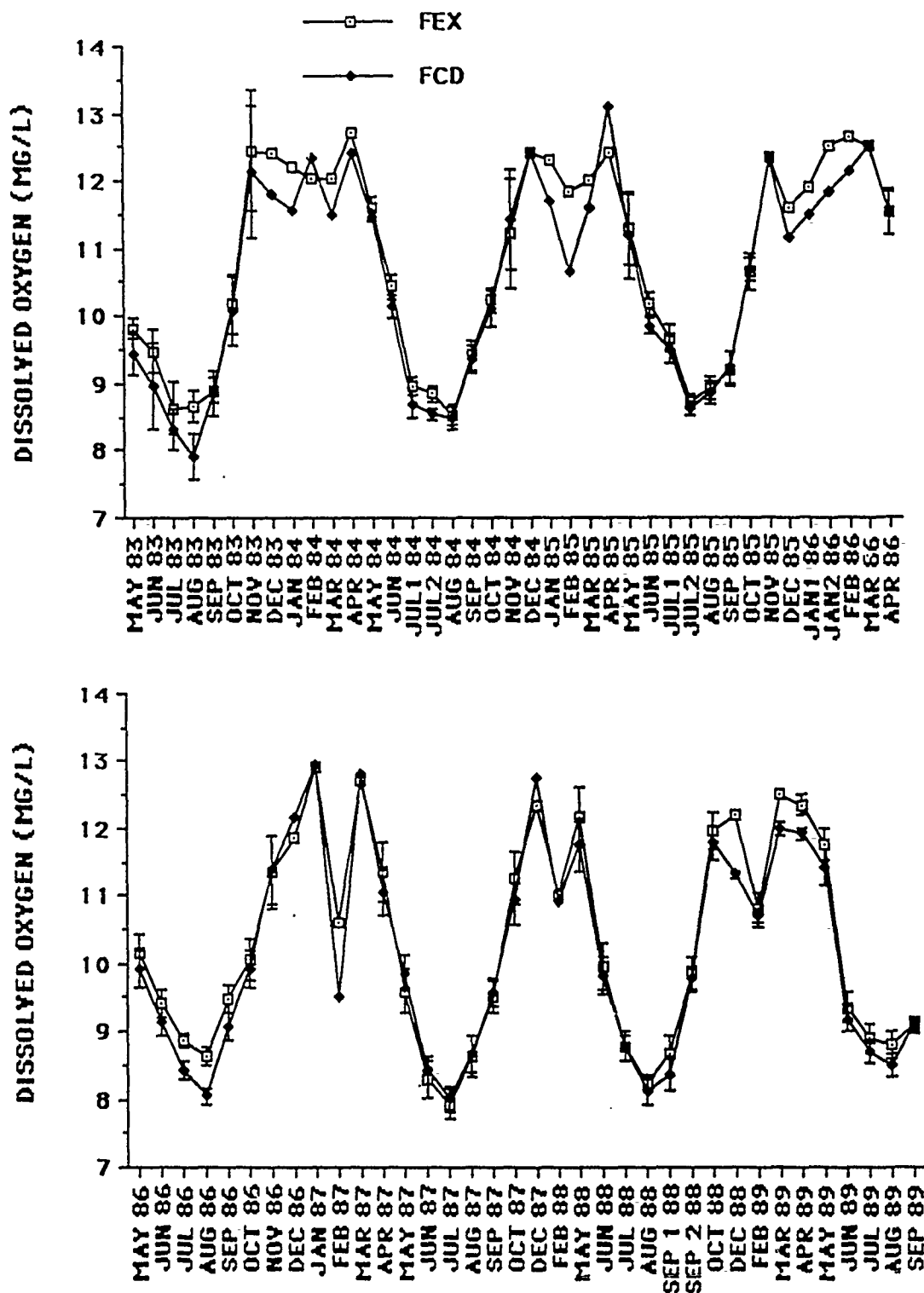


FIGURE 1.1 MEAN DISSOLVED OXYGEN LEVELS (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1989.

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 1988-1989.

| Parameter         | df | Paired<br>t-value | Significance | Correlation<br>Coefficient | Significance |
|-------------------|----|-------------------|--------------|----------------------------|--------------|
| Conductivity      | 10 | 0.684             | NS           | 0.96                       | P < 0.01     |
| Hardness          | 10 | -4.022            | P < 0.01     | 0.99                       | P < 0.01     |
| Alkalinity        | 10 | -1.665            | NS           | 0.99                       | P < 0.01     |
| Turbidity         | 10 | 1.016             | NS           | 0.79                       | P < 0.01     |
| pH                | 10 | -0.072            | NS           | 0.86                       | P < 0.01     |
| Dissolved Oxygen  | 10 | 3.790             | P < 0.01     | 0.99                       | P < 0.01     |
| Water Temperature | 9  | 2.869             | P < 0.05     | 1.00                       | P < 0.01     |

Table 1.3 Results of Paired t-tests and correlations between Experimental (FEX) and Control (FCD) sites for water chemical constituents and ambient parameters from June 1983 to September 1989.

| Parameter         | df | Paired<br>t-value | Significance | Correlation<br>Coefficient | Significance |
|-------------------|----|-------------------|--------------|----------------------------|--------------|
| Conductivity      | 74 | -0.434            | NS           | 0.82                       | P < 0.01     |
| Hardness          | 74 | -2.16             | P < 0.01     | 0.98                       | P < 0.01     |
| Alkalinity        | 74 | -1.965            | NS           | 0.98                       | P < 0.01     |
| Turbidity         | 73 | -1.921            | NS           | 0.72                       | P < 0.01     |
| pH                | 68 | 0.991             | NS           | 0.30                       | P < 0.05     |
| Dissolved Oxygen  | 73 | 5.645             | P < 0.01     | 0.98                       | P < 0.05     |
| Water Temperature | 73 | 3.442             | P < 0.01     | 0.99                       | P < 0.05     |

the 2 sites FEX has the higher D.O. (Fig. 1.1). The reason for this difference is not known but may be caused by many factors (ie. turbulent water upstream of FEX that is not present at FCD or anoxic springs upstream of 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 1989 pH data for the two sites followed the previous pattern of summer highs and winter lows (Fig. 1.2, Table 1.1) probably related to higher levels of primary production in the summer (see Element 2) coupled with lower stream discharge, and higher values for alkalinity (pH 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 1989, and there were no significant differences between sites (Table 1.2) as was true for all data collected over the course of the study (Table 1.3). Automatically acquired data for the two sites for 1989 were consistent in quality unlike the inconsistent data collected in 1986 and 1987. The changes in procedure described in the methods section resulted in this consistent data in 1988 and 1989.

Alkalinity and hardness followed similar trends for the two sites (Table 1.4. Figs. 1.3, 1.4) with high values occurring during times of low flows and low values occurring during times of high flows (Fig. 1.5, 1.6). 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, and it would be feasible to drop one of these two analyses from our sampling program. If we elect to drop one of these two in the future, we will drop hardness. Alkalinity at FCD was highly correlated with alkalinity at FEX both in 1989 ( $r = 0.99$ ,  $p < 0.01$ ) and when all data since 1983 are included ( $r = 0.98$ ,  $p < 0.01$ ), there was no significant difference between the sites (Table 1.2, Table 1.3). Hardness was just as highly correlated between the sites, but there was a significant difference between the sites (Table 1.2, Table 1.3). Hardness at FCD was slightly, but significantly, greater than at FEX. This increase may be related to the expected increase in cations in a downstream direction.

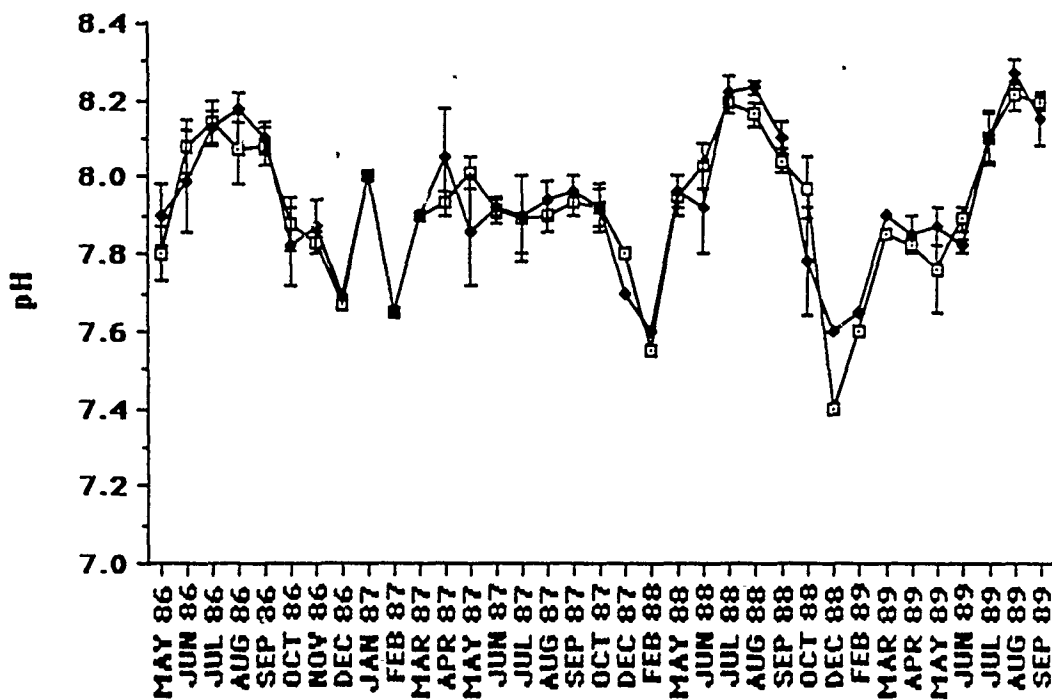
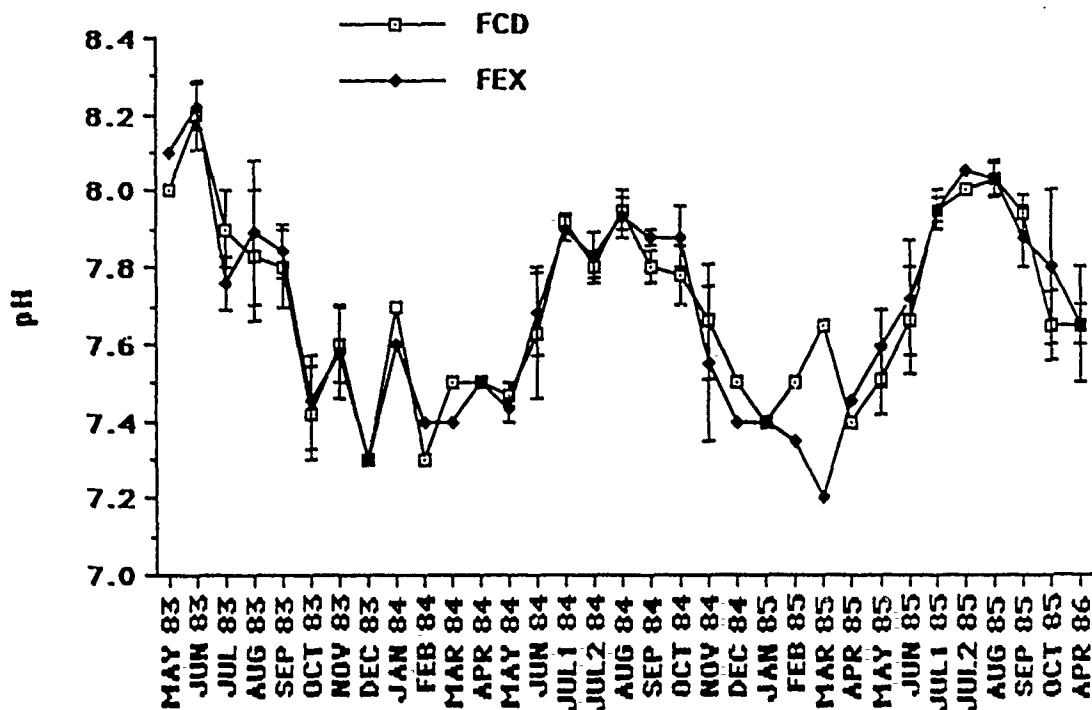


FIGURE 1.2 MEAN pH LEVELS (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1989.

Table 1.4 Alkalinity and Hardness (mg CaCO<sub>3</sub>/L) for the Ford River.  
Values are Means  $\pm$  S.E., N in parentheses.

| Date     | Alkalinity         |                  | Hardness           |                  |
|----------|--------------------|------------------|--------------------|------------------|
|          | Experimental (FEX) | Control (FCD)    | Experimental (FEX) | Control (FCD)    |
| 10/3/88  | 136 $\pm$ 3 (5)    | 137 $\pm$ 3 (5)  | 157 $\pm$ 2 (5)    | 159 $\pm$ 2 (5)  |
| 10/11/88 | 118 $\pm$ 10 (5)   | 124 $\pm$ 9 (5)  | 140 $\pm$ 7 (5)    | 147 $\pm$ 8 (5)  |
| 12/27/88 | 138 (1)            | 139 (1)          | 154 (1)            | 158 (1)          |
| 2/11/89  | 146 (1)            | 152 (1)          | 172 (1)            | 180 (1)          |
| 3/20/89  | 158 (1)            | 153 (1)          | 180 (1)            | 184 (1)          |
| 4/17/89  | 123 $\pm$ 36 (2)   | 124 $\pm$ 29 (2) | 149 $\pm$ 32 (2)   | 148 $\pm$ 36 (1) |
| 5/15/89  | 93 $\pm$ 4 (5)     | 97 $\pm$ 5 (5)   | 112 $\pm$ 5 (5)    | 113 $\pm$ 5 (5)  |
| 6/12/89  | 101 $\pm$ 5 (5)    | 105 $\pm$ 5 (5)  | 120 $\pm$ 3 (5)    | 123 $\pm$ 4 (5)  |
| 7/10/89  | 119 $\pm$ 14 (5)   | 121 $\pm$ 13 (5) | 139 $\pm$ 13 (5)   | 143 $\pm$ 12 (5) |
| 8/7/89   | 162 $\pm$ 2 (5)    | 163 $\pm$ 3 (5)  | 180 $\pm$ 2 (5)    | 181 $\pm$ 2 (5)  |
| 9/5/89   | 164 $\pm$ 3 (5)    | 162 $\pm$ 4 (5)  | 181 $\pm$ 2 (5)    | 181 $\pm$ 3 (5)  |

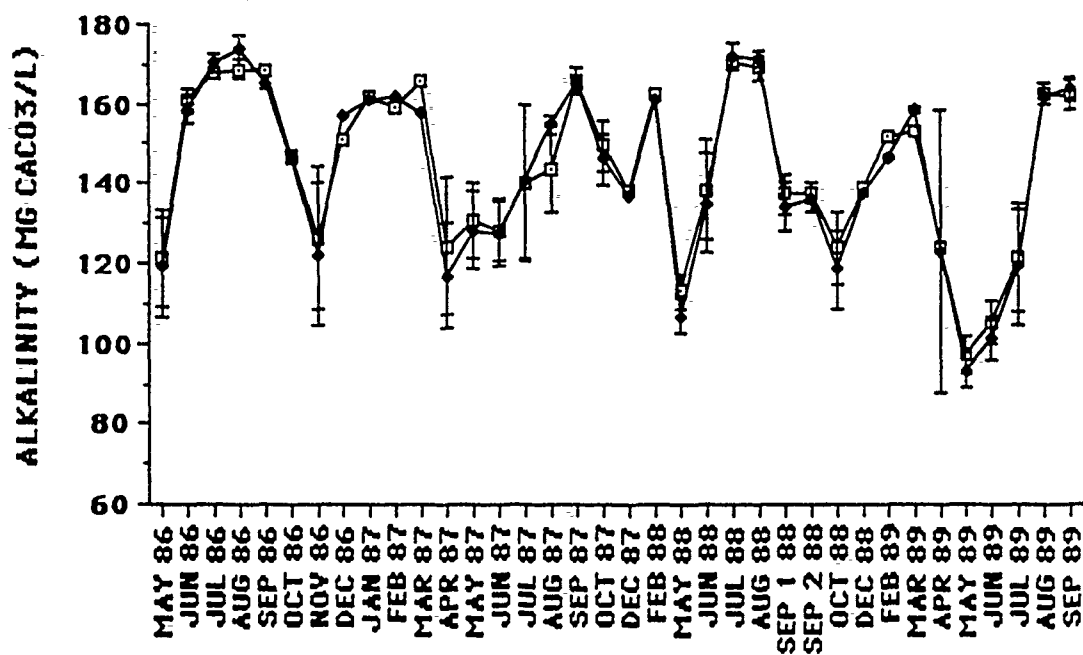
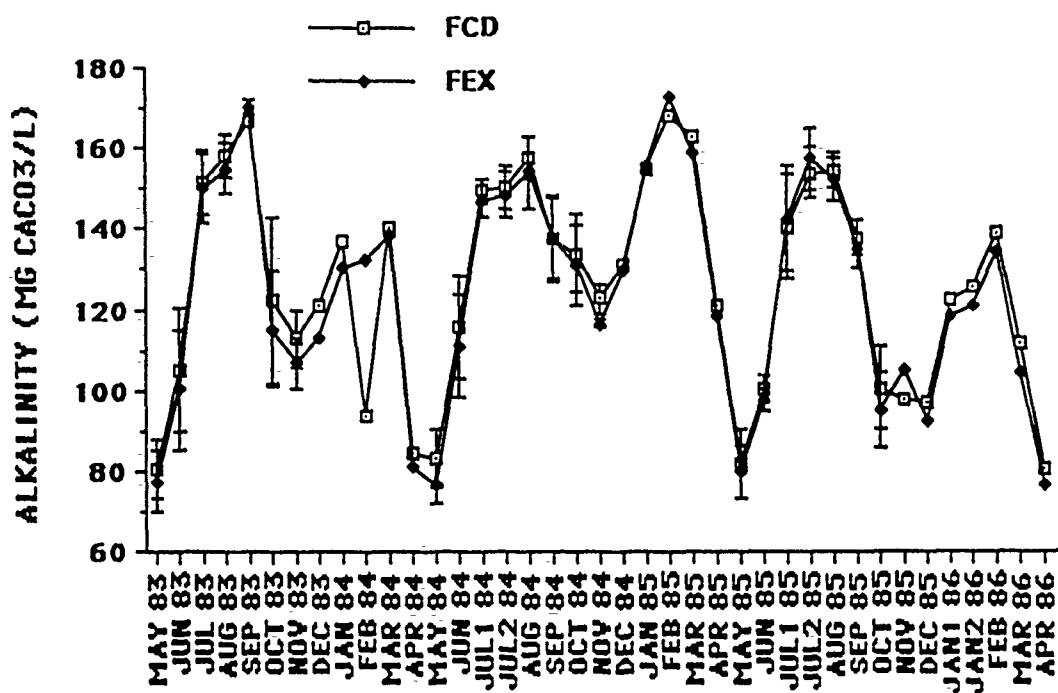


FIGURE 1.3 MEAN ALKALINITY LEVELS (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1989.

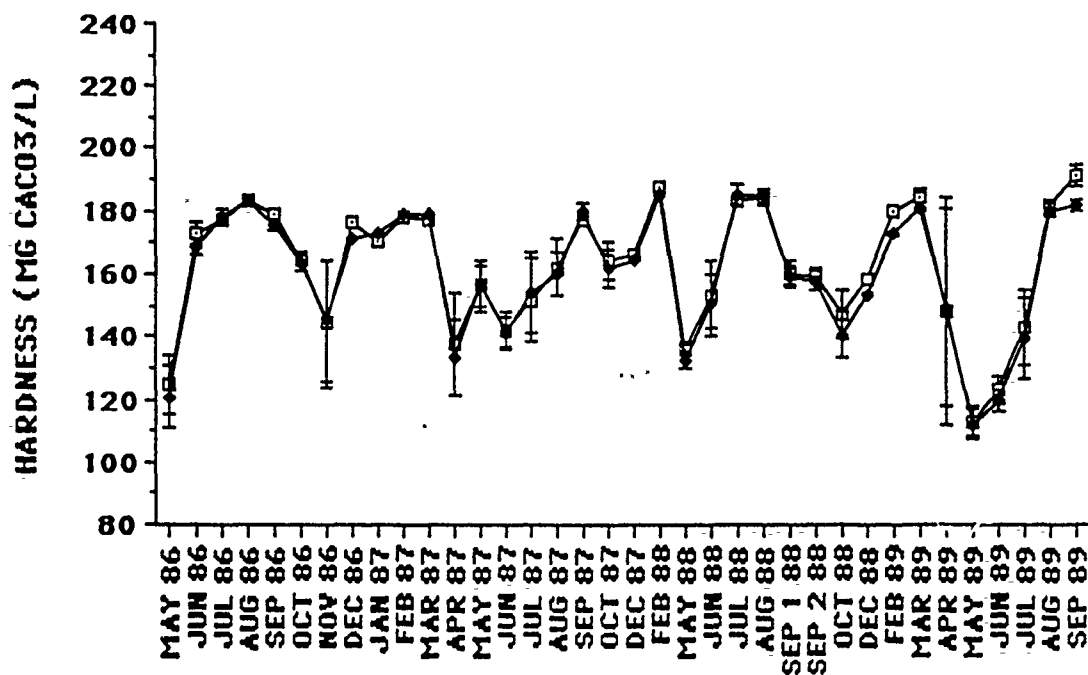
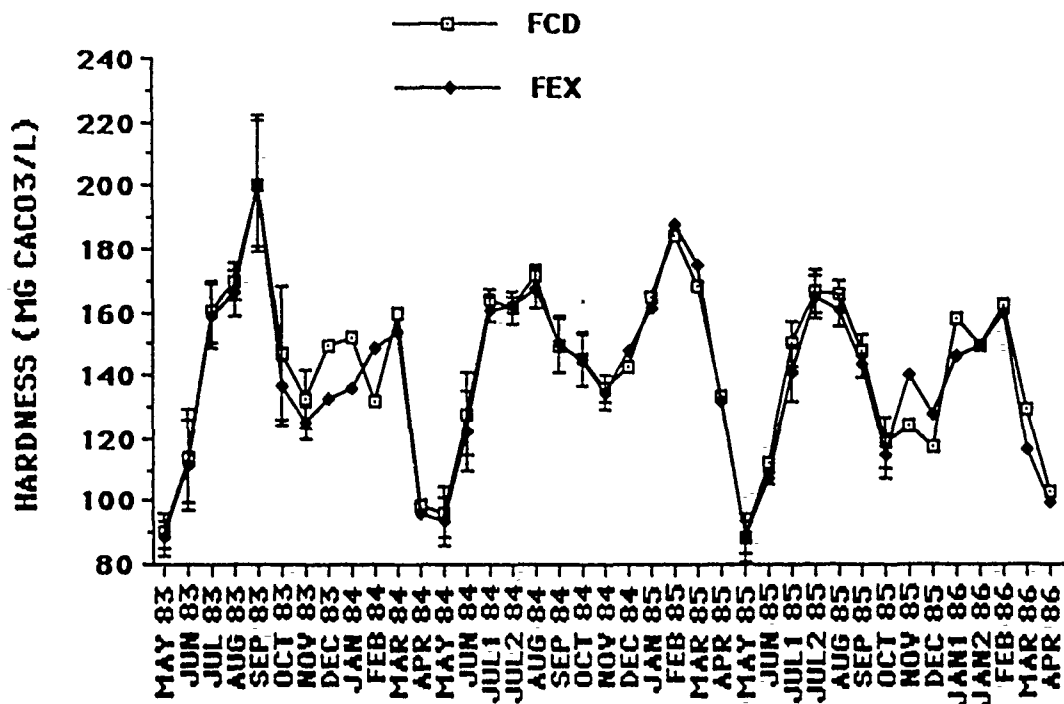


FIGURE 1.4 MEAN HARDNESS LEVELS (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1989.



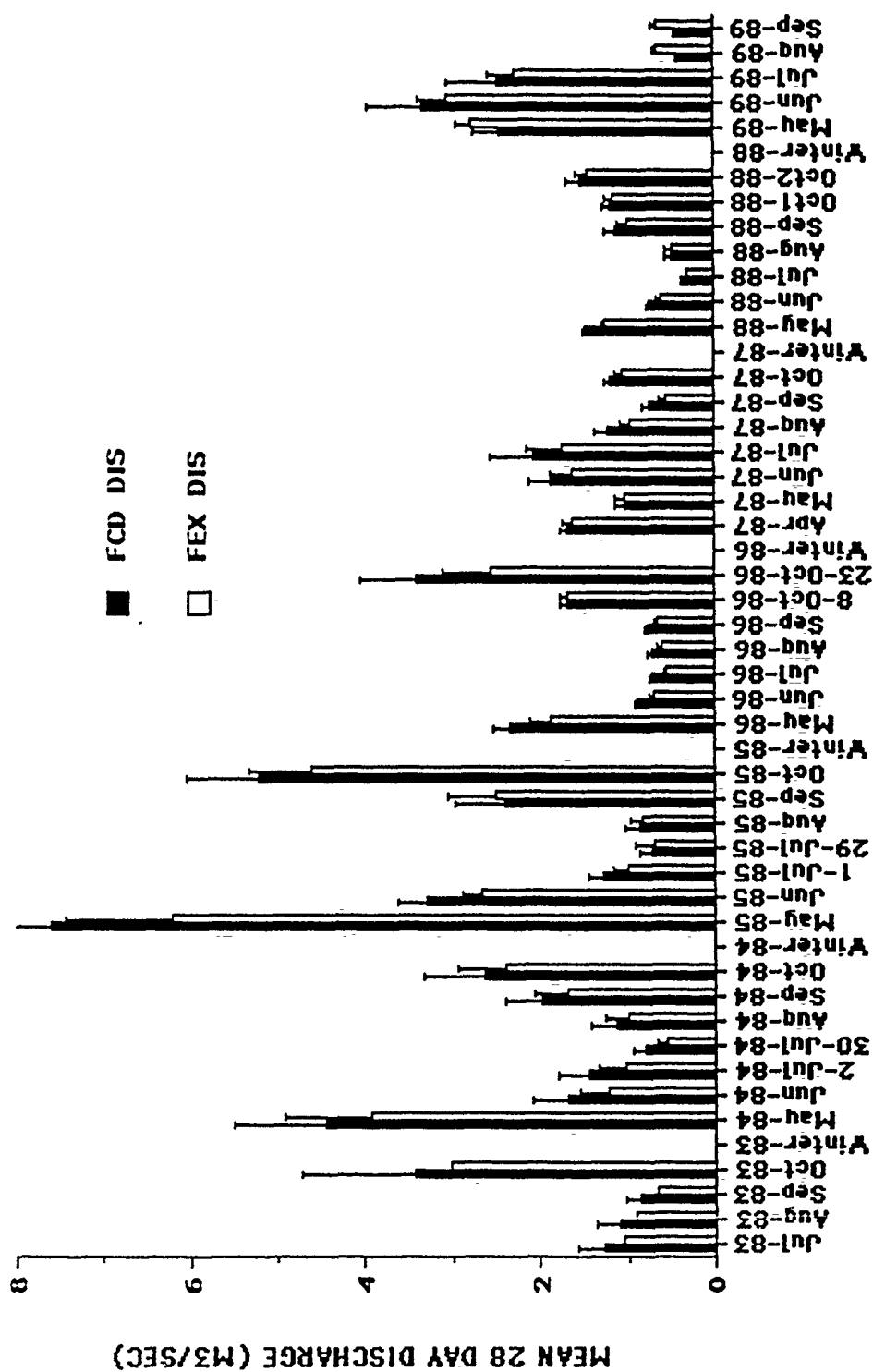


FIGURE 1.5 MEAN DISCHARGE LEVELS (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1989.

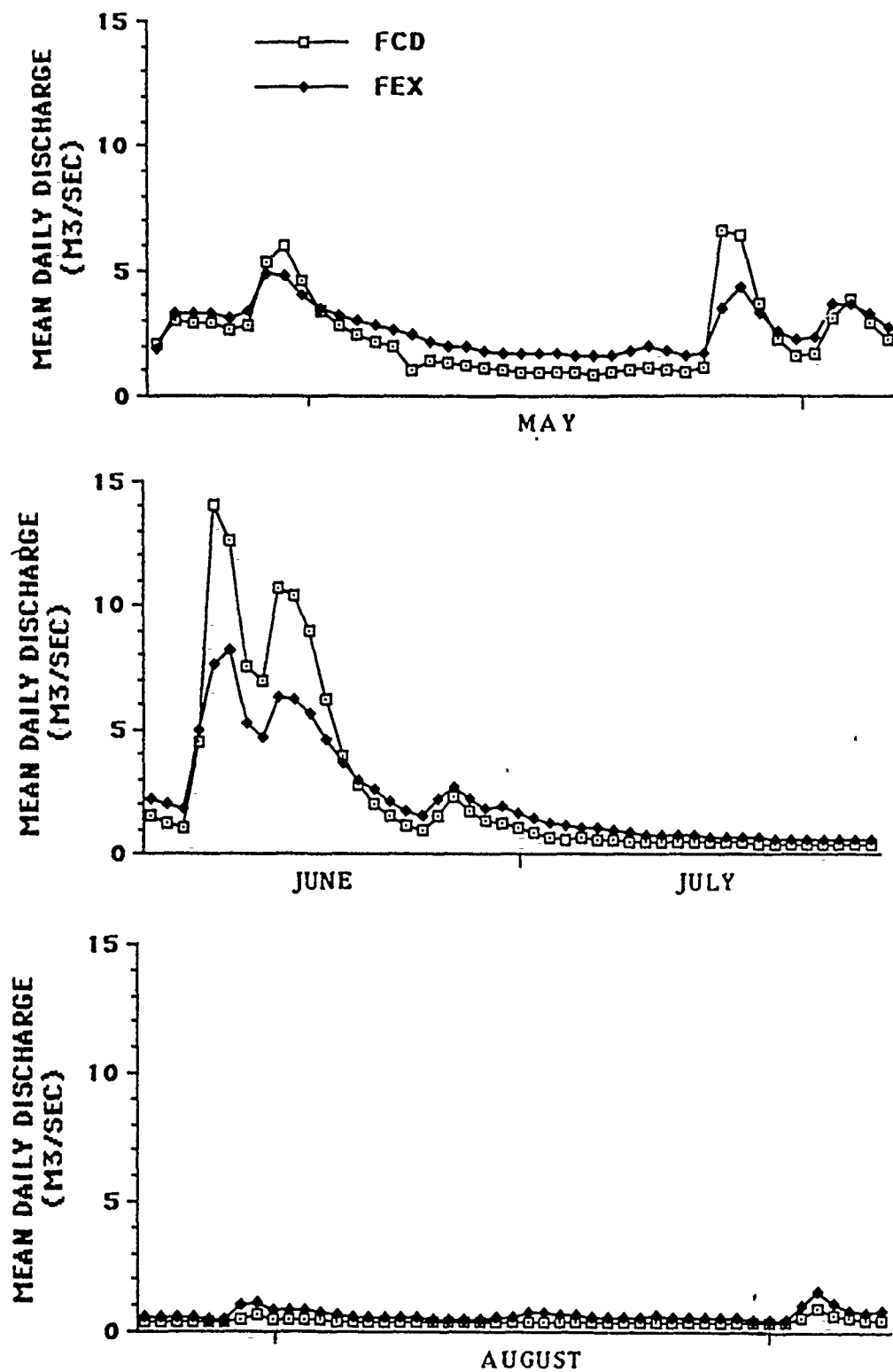


FIGURE 1.6 DAILY DISCHARGE MEANS FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES FOR 1989.

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 ( $p < 0.01$ ) with conductivity values at FCD during 1989 (Table 1.2) and for all data collected since 1983 ( $r = 0.82$ ) (Table 1.3). There were no significant differences between sites (Table 1.2).

Turbidity (Table 1.5, Fig. 1.8) remained relatively low reflecting the excellent water quality of the Ford River. Turbidity at FEX was highly correlated with turbidity at FCD, and there were no significant differences between the two sites for 1989 (Table 1.2).

The annual cycle of spring and fall high discharges has changed over the past few years (Fig. 1.5). Due to the trend towards dryer years the discharge has generally been lower than it was in the first few years of the study. In addition, the peak discharge for 1989 occurred in June (Fig. 1.6) and the late summer discharge values were some of the lowest recorded during this study. In general FCD has a slightly higher discharge than FEX, (this trend is expected in a downstream direction).

#### B. Nutrient Chemistry

Nutrient chemistry samples are frozen and analyzed during the following winter. Thus, data in this annual report do not include data for 1989.

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 and 1988 (Table 1.6, Fig. 1.9) 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. The concentrations of total P in the Ford River were characteristic of values for the eastern U.S. reflecting land use that is 50 to 90 % forest (Omernik 1977 placed Michigan in the eastern U.S. region). Land use in the Ford River watershed is dominated by short rotation forestry with Populus tremuloides (quaking aspen) being the predominant forest species. Total P at FEX was not significantly correlated with total P at FCD in 1988 (Table 1.7), as has been the case in all past years except 1987. There were no significant differences between the two sites in 1988 continuing the trend reported for the data from 1983 through 1987 (Table 1.8). Total P is positively

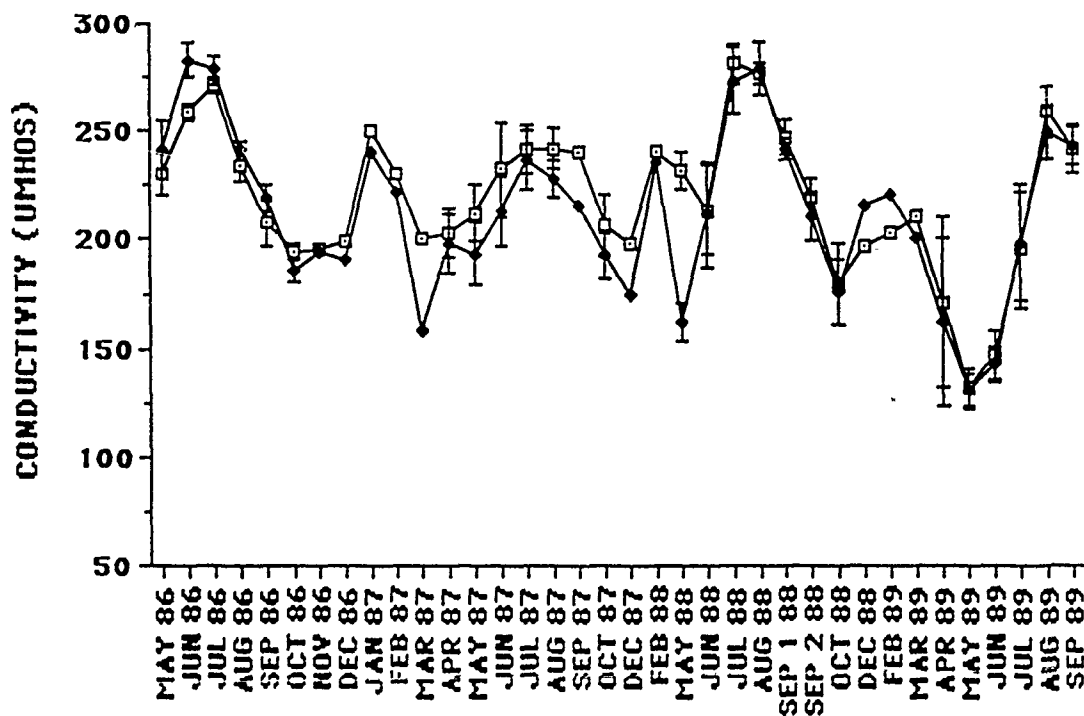
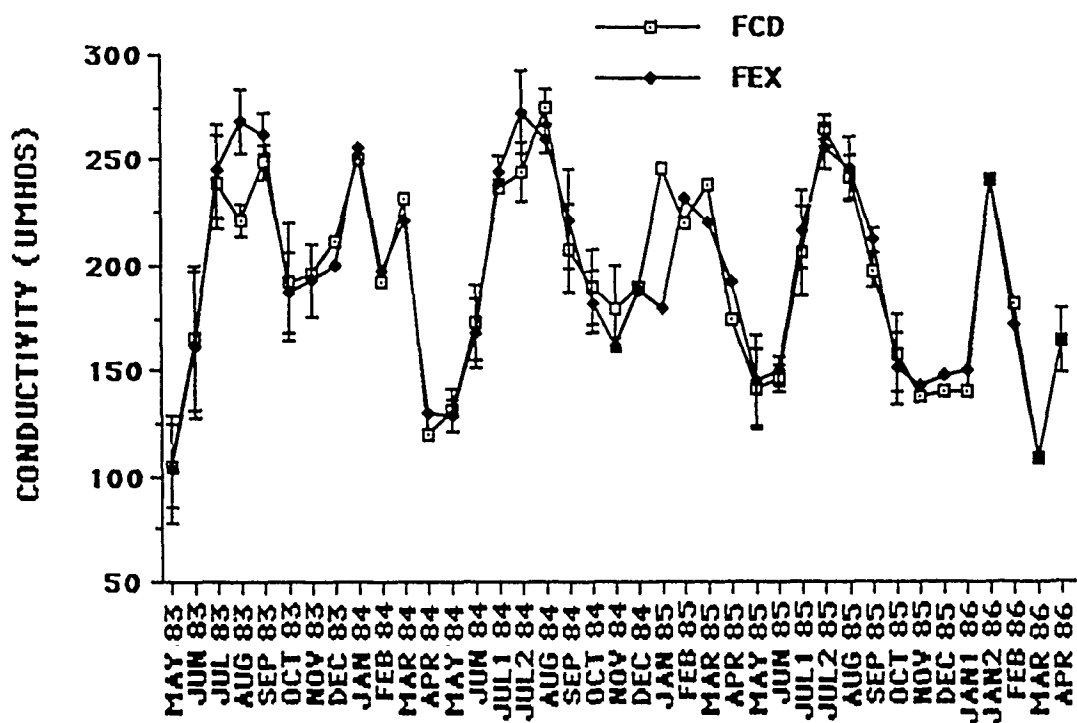


FIGURE 1.7 MEAN CONDUCTIVITY LEVELS (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1989.

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

| Date     | Conductivity       |                  | Turbidity          |                   |
|----------|--------------------|------------------|--------------------|-------------------|
|          | Experimental (FEX) | Control (FCD)    | Experimental (FEX) | Control (FCD)     |
| 10/3/88  | 210 $\pm$ 10 (5)   | 219 $\pm$ 9 (5)  | 1.0 $\pm$ 0.1 (5)  | 1.1 $\pm$ 0.1 (5) |
| 10/31/88 | 176 $\pm$ 15 (5)   | 180 $\pm$ 19 (5) | 1.1 $\pm$ 0.3 (5)  | 1.3 $\pm$ 0.1 (5) |
| 12/27/88 | 215 (1)            | 197 (1)          | 1.4 (1)            | 1.0 (1)           |
| 2/11/89  | 220 (1)            | 203 (1)          | 2.3 (1)            | 1.5 (1)           |
| 3/20/89  | 201 (1)            | 210 (1)          | 1.4 (1)            | 1.6 (1)           |
| 4/17/89  | 162 $\pm$ 39 (2)   | 171 $\pm$ 39 (2) | 2.5 $\pm$ 1.1 (2)  | 2.2 $\pm$ 0.6 (2) |
| 5/15/89  | 131 $\pm$ 7 (5)    | 132 $\pm$ 9 (5)  | 1.4 $\pm$ 0.5 (5)  | 1.4 $\pm$ 0.4 (5) |
| 6/12/89  | 144 $\pm$ 7 (5)    | 146 $\pm$ 12 (5) | 1.0 $\pm$ 0.1 (5)  | 1.2 $\pm$ 0.1 (5) |
| 7/10/89  | 199 $\pm$ 27 (5)   | 195 $\pm$ 27 (5) | 1.2 $\pm$ 0.0 (5)  | 1.1 $\pm$ 0.2 (5) |
| 8/7/89   | 249 $\pm$ 12 (5)   | 258 $\pm$ 12 (5) | 1.4 $\pm$ 0.1 (5)  | 1.4 $\pm$ 0.1 (5) |
| 9/5/89   | 243 $\pm$ 9 (5)    | 241 $\pm$ 11 (5) | 1.3 $\pm$ 0.1 (5)  | 1.3 $\pm$ 0.1 (5) |

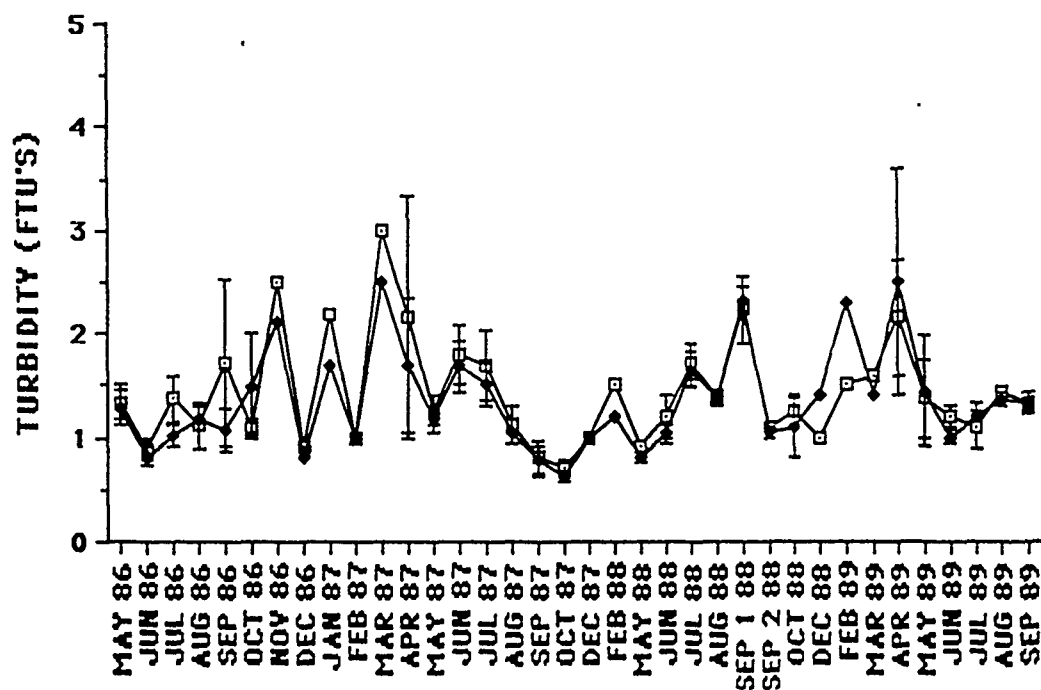
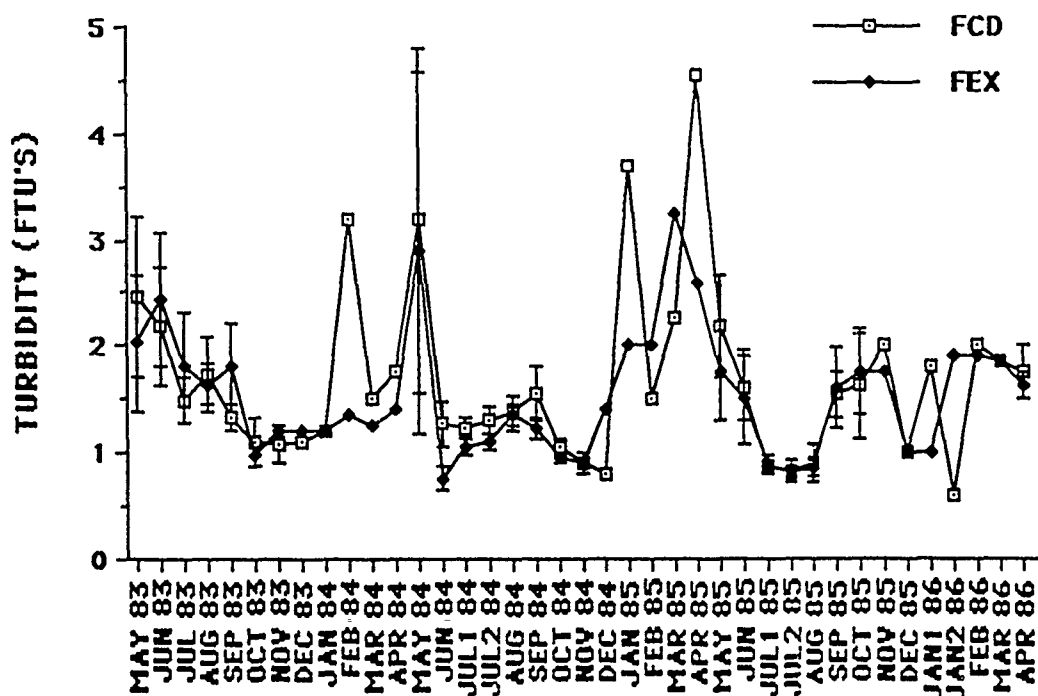


FIGURE 1.8 MEAN TURBIDITY LEVELS (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1989.

Table 1.6 Soluble Reactive Phosphorus ( $\mu\text{g P/L}$ ) and Total Phosphorus ( $\mu\text{g/L}$ ) for the Ford River for 1988. Values are Means  $\pm$  S.E., N in parentheses.

| Date     | Soluble Reactive Phosphorus |       |                 | Total Phosphorus   |                   |                          |
|----------|-----------------------------|-------|-----------------|--------------------|-------------------|--------------------------|
|          | Experimental                | (Fex) | Control (FCD)   | Experimental (FEX) | Control (FCD)     |                          |
| 2/28/88  | 4.03                        | (1)   | 4.25            | (1)                | 30.51             | (1) 28.13 (1)            |
| 4/19/88  | 4.46 $\pm$ 0.44             | (2)   | 4.79 $\pm$ 0.54 | (2)                | 38.84 $\pm$ 8.32  | (2) 30.51 $\pm$ 2.38 (2) |
| 5/16/88  | 3.18 $\pm$ 0.40             | (8)   | 3.32 $\pm$ 0.51 | (8)                | 35.10 $\pm$ 4.46  | (8) 32.94 $\pm$ 4.51 (7) |
| 6/13/88  | 3.76 $\pm$ 0.44             | (8)   | 3.13 $\pm$ 0.36 | (8)                | 21.50 $\pm$ 1.41  | (8) 29.19 $\pm$ 4.24 (8) |
| 7/11/88  | 3.65 $\pm$ 0.29             | (9)   | 3.87 $\pm$ 0.26 | (9)                | 30.81 $\pm$ 2.16  | (9) 30.92 $\pm$ 2.02 (9) |
| 8/8/88   | 2.82 $\pm$ 0.33             | (8)   | 2.96 $\pm$ 0.38 | (8)                | 55.54 $\pm$ 11.51 | (8) 23.21 $\pm$ 2.29 (8) |
| 9/8/88   | 4.41 $\pm$ 0.20             | (8)   | 4.05 $\pm$ 0.26 | (8)                | 35.08 $\pm$ 2.82  | (8) 35.28 $\pm$ 6.97 (8) |
| 10/3/88  | 4.60 $\pm$ 0.50             | (8)   | 4.24 $\pm$ 0.53 | (8)                | 24.33 $\pm$ 7.22  | (8) 19.58 $\pm$ 7.30 (7) |
| 10/31/88 | 3.89 $\pm$ 1.01             | (9)   | 4.05 $\pm$ 0.66 | (9)                | 19.52 $\pm$ 4.58  | (9) 18.10 $\pm$ 7.21 (9) |
| 12/27/88 | 2.54 $\pm$ 0.70             | (2)   | 2.29 $\pm$ 1.29 | (2)                | 7.64 $\pm$ 3.70   | (2) 12.14 $\pm$ 2.76 (2) |

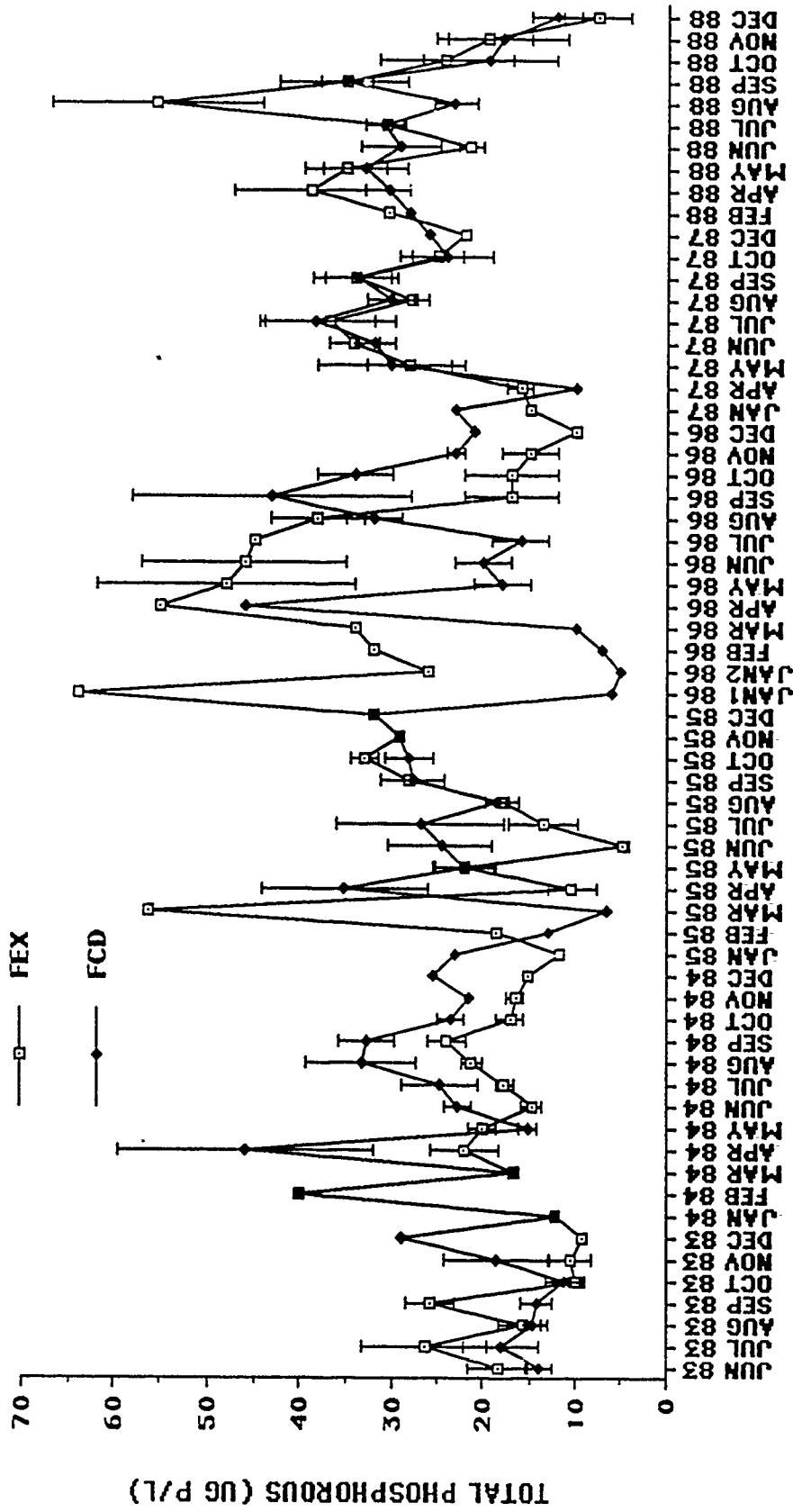


FIGURE 1.9 MEAN TOTAL PHOSPHOROUS CONCENTRATION (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1988.



Table 1.7 Results of Paired t-tests and correlations between Experimental (FEX) and Control (FCD) sites for nutrient chemistry parameters for 1987-1988.

| Parameter          | df | Paired t-value | Significance | Correlation Coefficient | Significance |
|--------------------|----|----------------|--------------|-------------------------|--------------|
| Organic Nitrogen   | 8  | -0.652         | NS           | 0.89                    | P < 0.01     |
| Inorganic Nitrogen | 8  | -0.480         | NS           | 0.82                    | P < 0.01     |
| Ammonium-N         | 8  | -0.926         | NS           | 0.69                    | P < 0.05     |
| Nitrate-N          | 8  | 0.577          | NS           | 0.97                    | P < 0.01     |
| Nitrite-N          | 8  | 1.049          | NS           | 0.96                    | P < 0.01     |
| Total Phosphorus   | 8  | 0.886          | NS           | 0.51                    | NS           |
| Soluble Reactive-P | 8  | 0.748          | NS           | 0.39                    | P < 0.01     |
| Silicate           | 8  | -0.426         | NS           | 0.99                    | P < 0.01     |
| Chloride           | 8  | 7.854          | P < 0.01     | 0.94                    | P < 0.01     |

Table 1.8 Results of Paired t-tests and correlations between Experimental (FEX) and Control (FCD) sites for nutrient chemistry parameters from June 1983 to September 1988.

| Parameter          | df | Paired<br>t-value | Significance | Correlation<br>Coefficient | Significance |
|--------------------|----|-------------------|--------------|----------------------------|--------------|
| Organic Nitrogen   | 63 | -2.786            | P < 0.01     | 0.71                       | P < 0.01     |
| Inorganic Nitrogen | 63 | -1.888            | NS           | 0.77                       | P < 0.01     |
| Ammonium-N         | 63 | 0.019             | NS           | 0.22                       | NS           |
| Nitrate-N          | 63 | -1.893            | NS           | 0.81                       | P < 0.01     |
| Nitrite-N          | 63 | 2.133             | P < 0.05     | 0.71                       | P < 0.01     |
| Total Phosphorus   | 63 | 0.677             | NS           | 0.06                       | NS           |
| Soluble Reactive-P | 63 | -1.621            | NS           | 0.75                       | P < 0.01     |
| Silicate           | 65 | 0.743             | NS           | 0.92                       | P < 0.01     |
| Chloride           | 63 | 3.387             | P < 0.01     | 0.90                       | P < 0.01     |

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 is usually directly correlated with discharge while Si is usually inversely correlated with discharge.

Soluble reactive phosphorus (SRP) consistently stayed below  $10 \mu\text{g P/L}$  except at FCD in late 1986 (Fig. 1.10, Table 1.6). There did appear to be an increase at FCD in 1986 that did not occur at FEX (Fig. 1.10), but this apparent trend towards increased P at the control site did not continue in 1987 and 1988. In fact, there was no significant difference in SRP between FCD and FEX in 1987 and 1988, and SRP at FCD was highly correlated with SRP at FEX (Table 1.7). Overall, from 1983 through 1988 there is no significant difference between FEX and FCD, and the 2 sites correlate well (Table 1.8). As with total phosphorus, soluble reactive phosphorus seems to be more consistent between the sites in the last 2 years than in the earlier years of the study. The SRP values for FEX and FCD (Fig. 1.10, Table 1.6) were characteristic of values for land that is 50 to 90 % forested according to Omernik (1977).

Nitrate-N, nitrite-N, and ammonium-N values were usually comparable at both FEX and FCD (Figs. 1.11, 1.12, 1.13, Table 1.8). We have no explanation for the high ammonium-N value reported at FCD in Dec. 1988 (Fig. 1.13, Table 1.9), but, given the recent match between the sites and the lack of any recent change in land use that might account for this, we believe this value probably results from a contaminated sample bottle. Including this value in the calculations results in a non-significant correlation between the sites in 1988 (Table 1.7). Removing this value from the calculations results in a significant ( $r=0.69$ ,  $p<0.05$ ) correlation between the sites. There was a divergence in nitrate-N values between the two sites in 1985 (Fig. 1.11), but nitrate-N was comparable for other time periods. One possibility for this difference is that leaching occurred from a small area of forest just upstream of FCD that was clearcut in 1985. This forest practice is known to lead to high nitrate losses in the first year or so after cutting for some northern hardwoods forests similar to 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 are attempting to locate aerial photographs of the watershed. Nitrate is the predominant form of inorganic nitrogen present in the Ford River. Thus, calculation of inorganic-N from the three components (Figs.

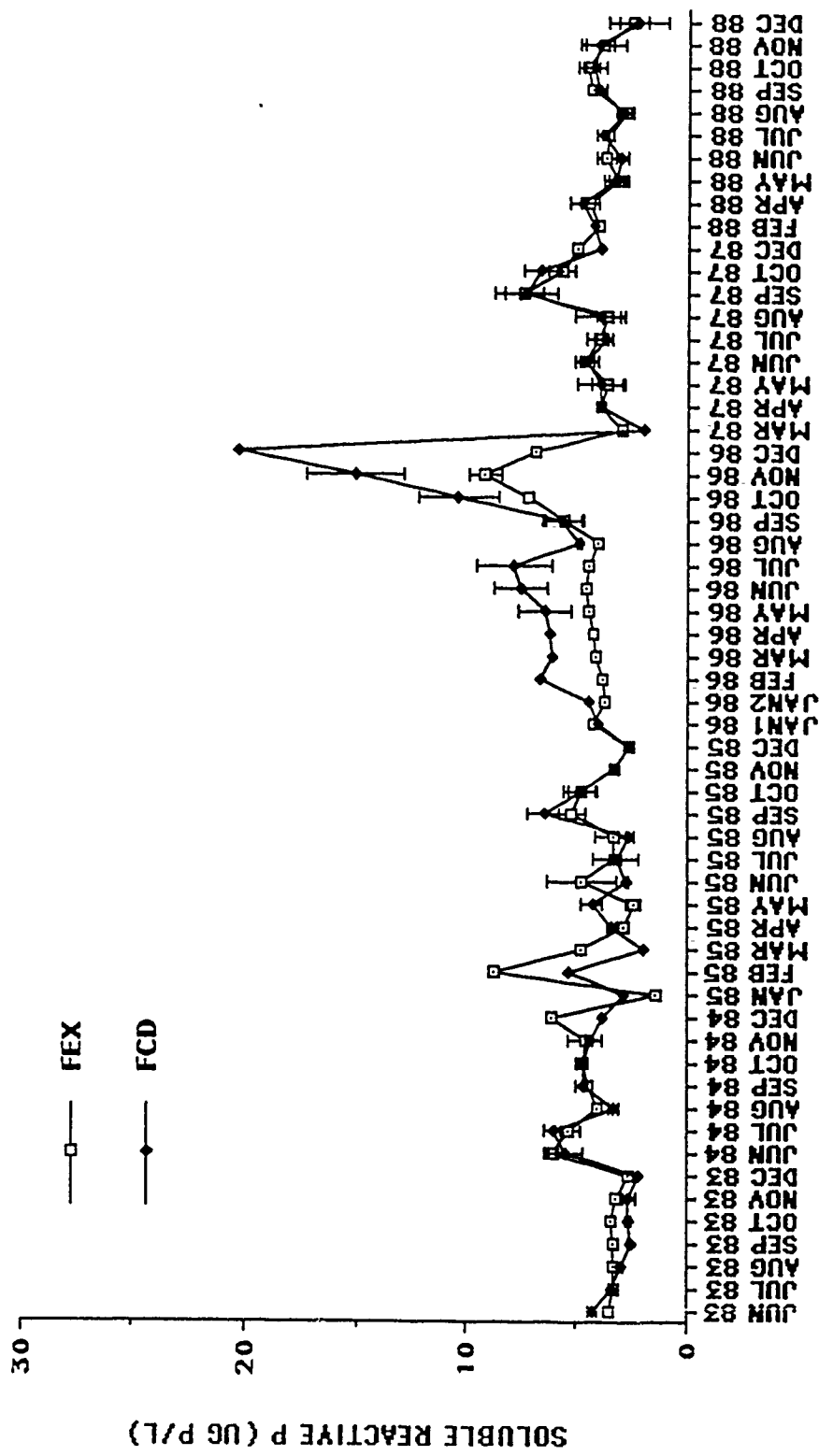


FIGURE 1.10 MEAN SOLUBLE REACTIVE PHOSPHORUS CONCENTRATION (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1988.

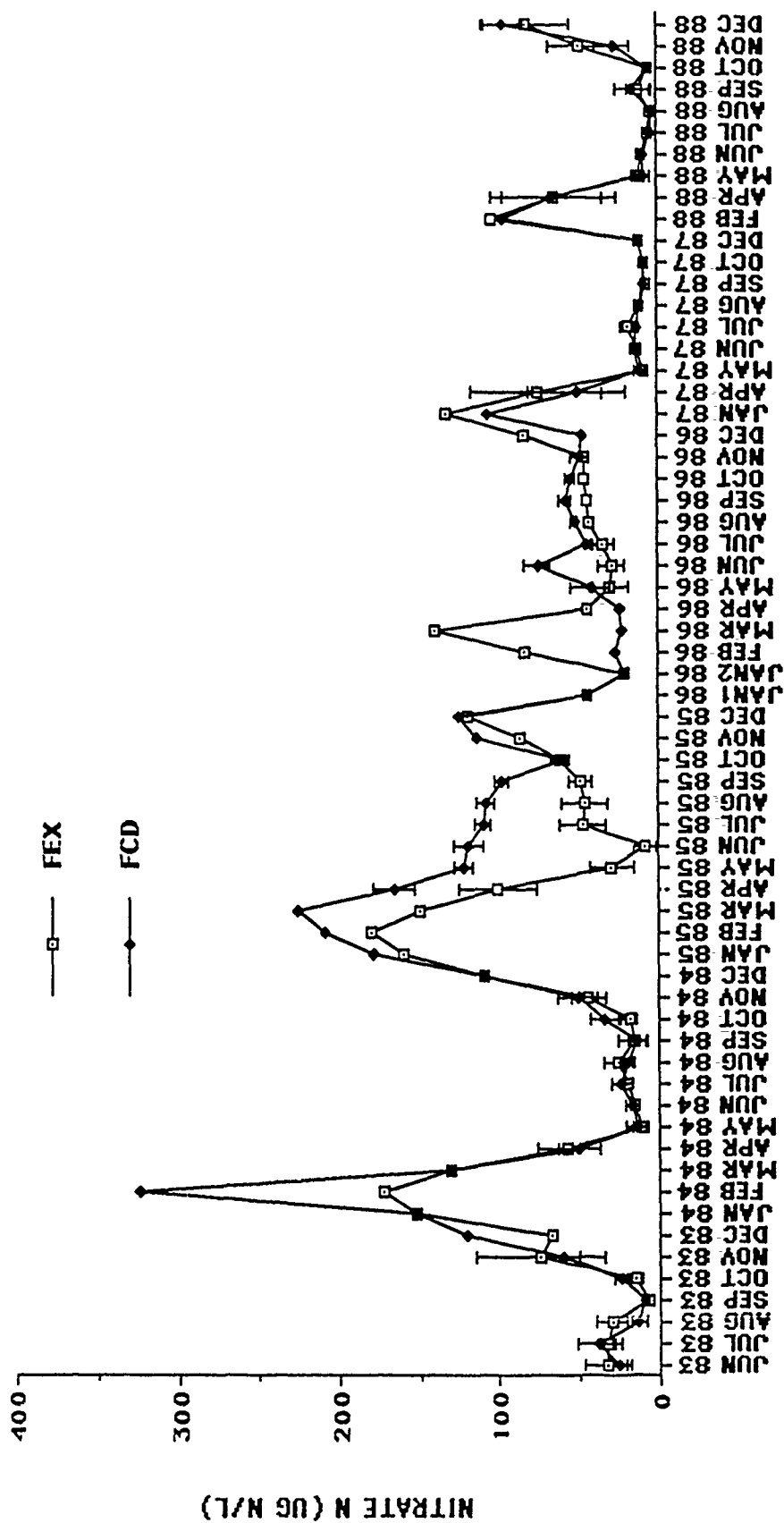


FIGURE 1.11 MEAN NITRATE-N CONCENTRATION (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1988.

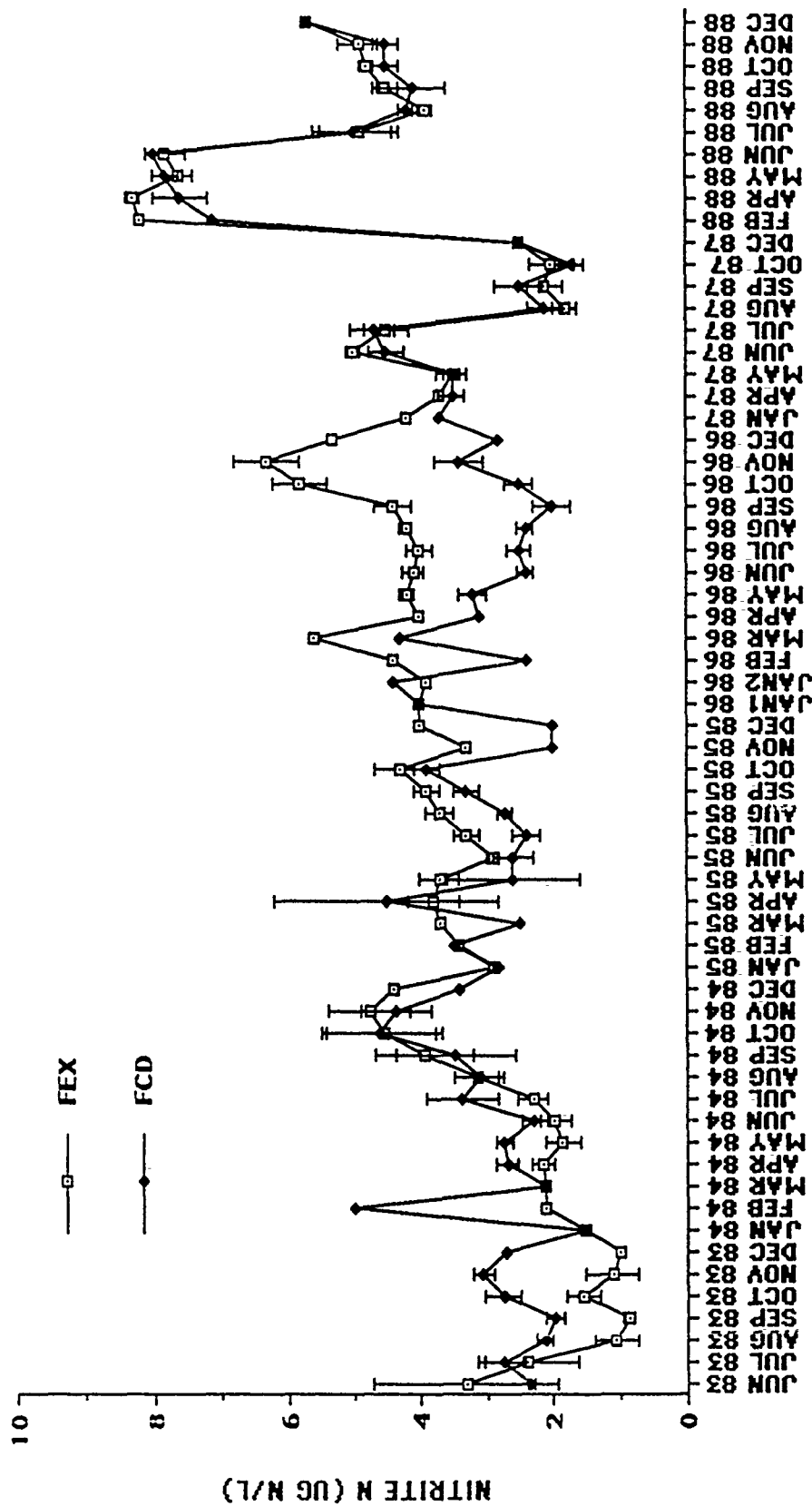


FIGURE 1.12 MEAN NITRITE-N CONCENTRATION (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1988.

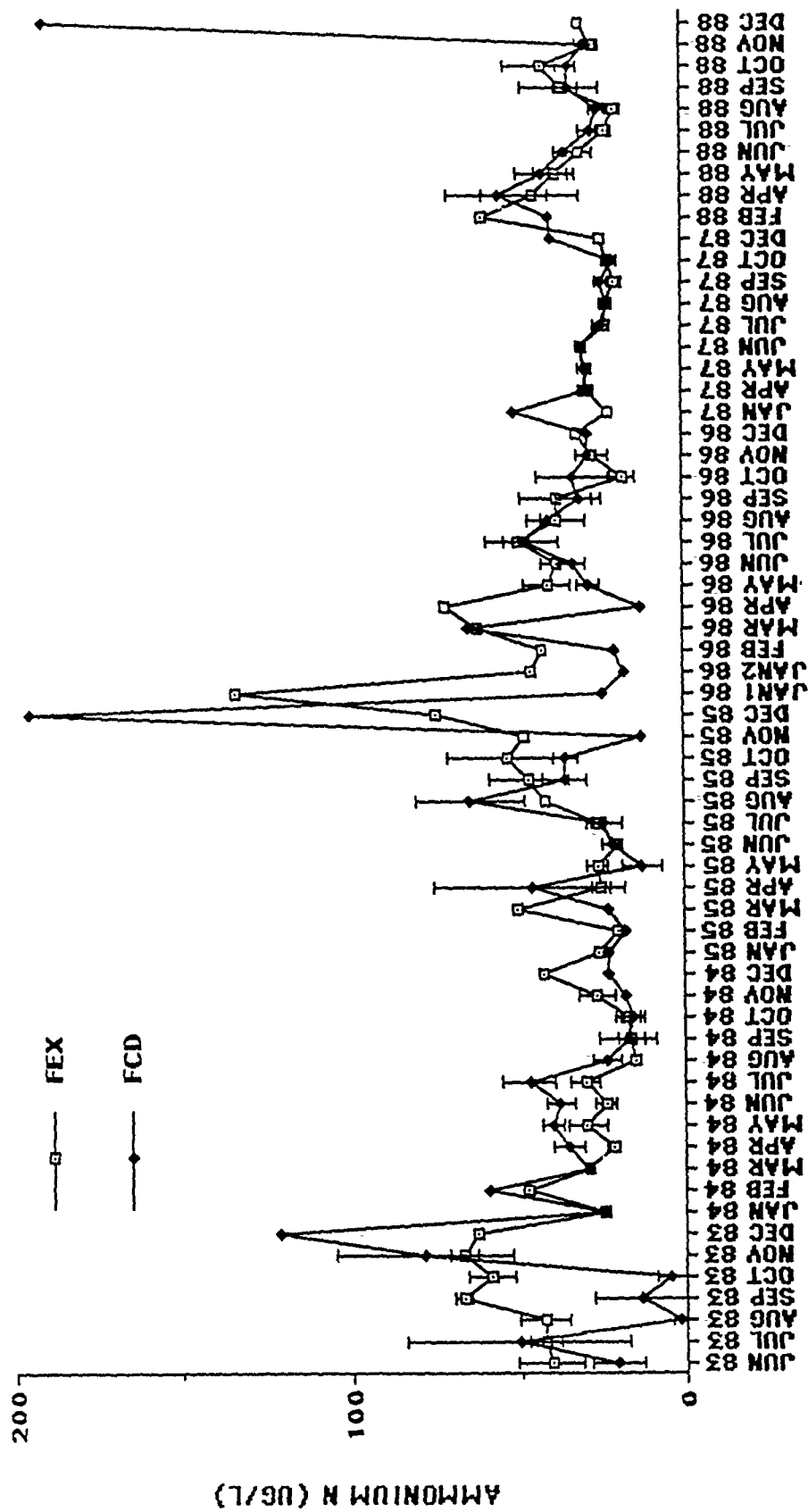


FIGURE 1.13 MEAN AMMONIUM CONCENTRATION (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1988.

Table 1.9 Ammonium ( $\mu\text{g N/L}$ ), Nitrate-N ( $\mu\text{g N/L}$ ) and Nitrite-N ( $\mu\text{g/L}$ ) for the Ford River for 1988. Values are Means  $\pm$  S.E., N in parentheses.

| Date               | Ammonium-N  | Experimental Site (FEX) |               |
|--------------------|-------------|-------------------------|---------------|
|                    |             | Nitrate-N               | Nitrite-N     |
| 2/28/88            | 60          | 103.0                   | 8.2           |
| 4/19/88            | 45 $\pm$ 15 | 64.8 $\pm$ 38.2         | 8.3 $\pm$ 0.1 |
| 5/16/88            | 38 $\pm$ 6  | 11.5 $\pm$ 3.9          | 7.6 $\pm$ 0.2 |
| 6/13/88            | 30 $\pm$ 4  | 10.1 $\pm$ 2.0          | 7.8 $\pm$ 0.3 |
| 7/11/88            | 23 $\pm$ 2  | 5.8 $\pm$ 1.5           | 4.9 $\pm$ 0.6 |
| 8/8/88             | 20 $\pm$ 2  | 3.7 $\pm$ 1.3           | 3.9 $\pm$ 0.1 |
| 9/8/88             | 36 $\pm$ 12 | 10.8 $\pm$ 8.3          | 4.5 $\pm$ 0.2 |
| 10/3/88            | 42 $\pm$ 11 | 5.8 $\pm$ 2.3           | 4.8 $\pm$ 0.1 |
| 10/31/88           | 26 $\pm$ 2  | 48.4 $\pm$ 19.4         | 4.9 $\pm$ 0.3 |
| 12/27/88           | 30          | 82.2 $\pm$ 27.4         | 5.7           |
| Control Site (FCD) |             |                         |               |
| 2/28/88            | 40          | 97.0                    | 7.1           |
| 4/19/88            | 55 $\pm$ 15 | 65.8 $\pm$ 31.2         | 7.6 $\pm$ 0.4 |
| 5/16/88            | 42 $\pm$ 8  | 8.3 $\pm$ 4.1           | 7.8 $\pm$ 0.2 |
| 6/13/88            | 35 $\pm$ 3  | 8.6 $\pm$ 1.7           | 8.0 $\pm$ 0.1 |
| 7/11/88            | 27 $\pm$ 3  | 4.5 $\pm$ 0.9           | 5.0 $\pm$ 0.6 |
| 8/8/88             | 25 $\pm$ 2  | 2.2 $\pm$ 1.0           | 4.2 $\pm$ 0.1 |
| 9/8/88             | 34 $\pm$ 4  | 15.4 $\pm$ 11.2         | 4.1 $\pm$ 0.5 |
| 10/3/88            | 34 $\pm$ 3  | 6.2 $\pm$ 1.7           | 4.5 $\pm$ 0.2 |
| 10/31/88           | 29 $\pm$ 2  | 27.7 $\pm$ 10.7         | 4.5 $\pm$ 0.2 |
| 12/27/88           | 190         | 95.7 $\pm$ 11.8         | 5.7           |



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).

Inorganic-N values were not significantly different between the two sites in 1988 (Table 1.7). Concentrations of inorganic-N and nitrate-N at FEX were significantly correlated to concentrations at FCD (Table 1.7). In the past nitrate-N concentrations were significantly different between the 2 sites. This did not occur in 1988 (Table 1.7), probably indicating a return to the patterns and levels exhibited prior to the 1985 clearcutting discussed above (Fig. 1.11). Ammonium-N (excluding the Dec 1988 data point) and Nitrate-N also exhibit stronger inter-site correlations in 1988 than in the past.

Organic nitrogen at FEX was significantly different from organic-N at FCD prior to 1987, but these differences disappeared in 1987 and 1988 (Fig. 1.15, Table 1.10). As was true for inorganic-N, total P, and SRP values, organic-N values were characteristic of streams draining areas of the eastern U. S. that are 50 to 90 % forested (Omernik 1977).

There were no significant differences for silicate-Si between FEX and FCD (Tables 1.7, 1.8, 1.11, Fig. 1.16), and concentrations at FEX were significantly related to concentrations at FCD (Table 1.7). Concentrations were relatively constant throughout the year at about 7 to 9 mg Si/L, although periods of dilution did occur during high flows in April or May each year and during other periods of high discharge (Fig. 1.16, 1.5, 1.6).

Chloride at FEX was significantly different from chloride at FCD in 1988 (and in all previous years except 1987) (Table 1.7, 1.8, 1.11, Fig. 1.17). Values for the two sites were significantly correlated in 1988 (Table 1.7), as they had been in previous years. Concentrations of Cl appeared to be larger at the upstream site (FEX) in 1984, 1985, 1986 and 1988 than they were at the downstream site (FCD) (Fig 1.17). This gradient may have reflected the fact that some of the chloride inputs were from road salting near Channing, MI with dilution of these inputs in a downstream direction. Chloride concentrations increased in 1986 but in 1987 and 1988 dropped back to values typical of the time period from 1983 through 1985. The reasons for this increase in 1986 followed by a decrease are unknown.

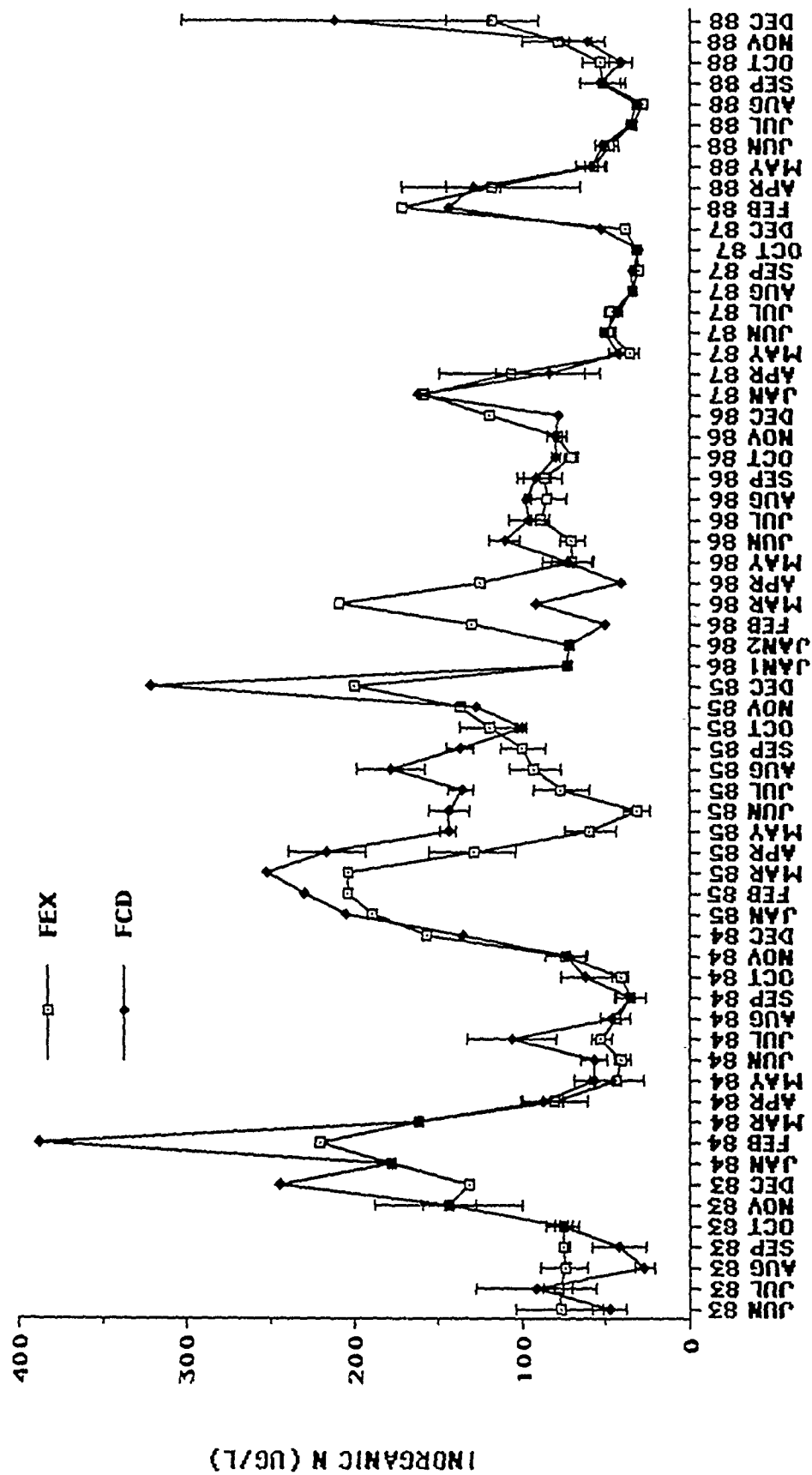


FIGURE 1.14 MEAN INORGANIC NITROGEN CONCENTRATION (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1988.

Table 1.10 Organic-N ( $\mu\text{g N/L}$ ) and Inorganic-N ( $\mu\text{g N/L}$ ) for the Ford River for 1988.  
Values are Means  $\pm$  S.E., N in parentheses.

| Date     | Organic Nitrogen   |               |             | Inorganic Nitrogen |                  |                          |
|----------|--------------------|---------------|-------------|--------------------|------------------|--------------------------|
|          | Experimental (FEX) | Control (FCD) |             | Experimental (FEX) | Control (FCD)    |                          |
| 2/28/88  | 1.0                | (1)           | 35.9        | (1)                | 171.2            | (1) 144.1 (1)            |
| 4/19/88  | 161.9 $\pm$        | 163.1 (2)     | 36.6 $\pm$  | 0.8 (2)            | 118.1 $\pm$ 53.1 | (2) 128.4 $\pm$ 15.8 (2) |
| 5/16/88  | 228.4 $\pm$        | 25.9 (8)      | 152.7 $\pm$ | 25.2 (8)           | 56.6 $\pm$ 6.3   | (8) 58.6 $\pm$ 9.6 (8)   |
| 6/13/88  | 174.6 $\pm$        | 21.5 (8)      | 180.9 $\pm$ | 30.9 (8)           | 47.9 $\pm$ 4.8   | (8) 51.6 $\pm$ 3.6 (8)   |
| 7/11/88  | 107.0 $\pm$        | 12.8 (9)      | 105.5 $\pm$ | 20.2 (9)           | 34.0 $\pm$ 2.7   | (9) 36.2 $\pm$ 3.0 (9)   |
| 8/8/88   | 156.1 $\pm$        | 37.6 (8)      | 176.1 $\pm$ | 37.6 (8)           | 27.6 $\pm$ 2.2   | (8) 31.4 $\pm$ 2.5 (8)   |
| 9/8/88   | 344.7 $\pm$        | 47.3 (8)      | 290.1 $\pm$ | 37.6 (8)           | 51.5 $\pm$ 13.3  | (8) 53.3 $\pm$ 11.6 (8)  |
| 10/3/88  | 358.6 $\pm$        | 117.9 (8)     | 509.2 $\pm$ | 147.2 (8)          | 52.7 $\pm$ 10.8  | (8) 40.8 $\pm$ 6.5 (8)   |
| 10/31/88 | 338.2 $\pm$        | 75.8 (9)      | 414.5 $\pm$ | 81.2 (9)           | 78.9 $\pm$ 20.2  | (9) 61.1 $\pm$ 11.2 (9)  |
| 12/27/88 | 292.2 $\pm$        | 2.4 (2)       | 268.8 $\pm$ | 102.0 (2)          | 117.8 $\pm$ 27.6 | (2) 211.2 $\pm$ 92.0 (2) |

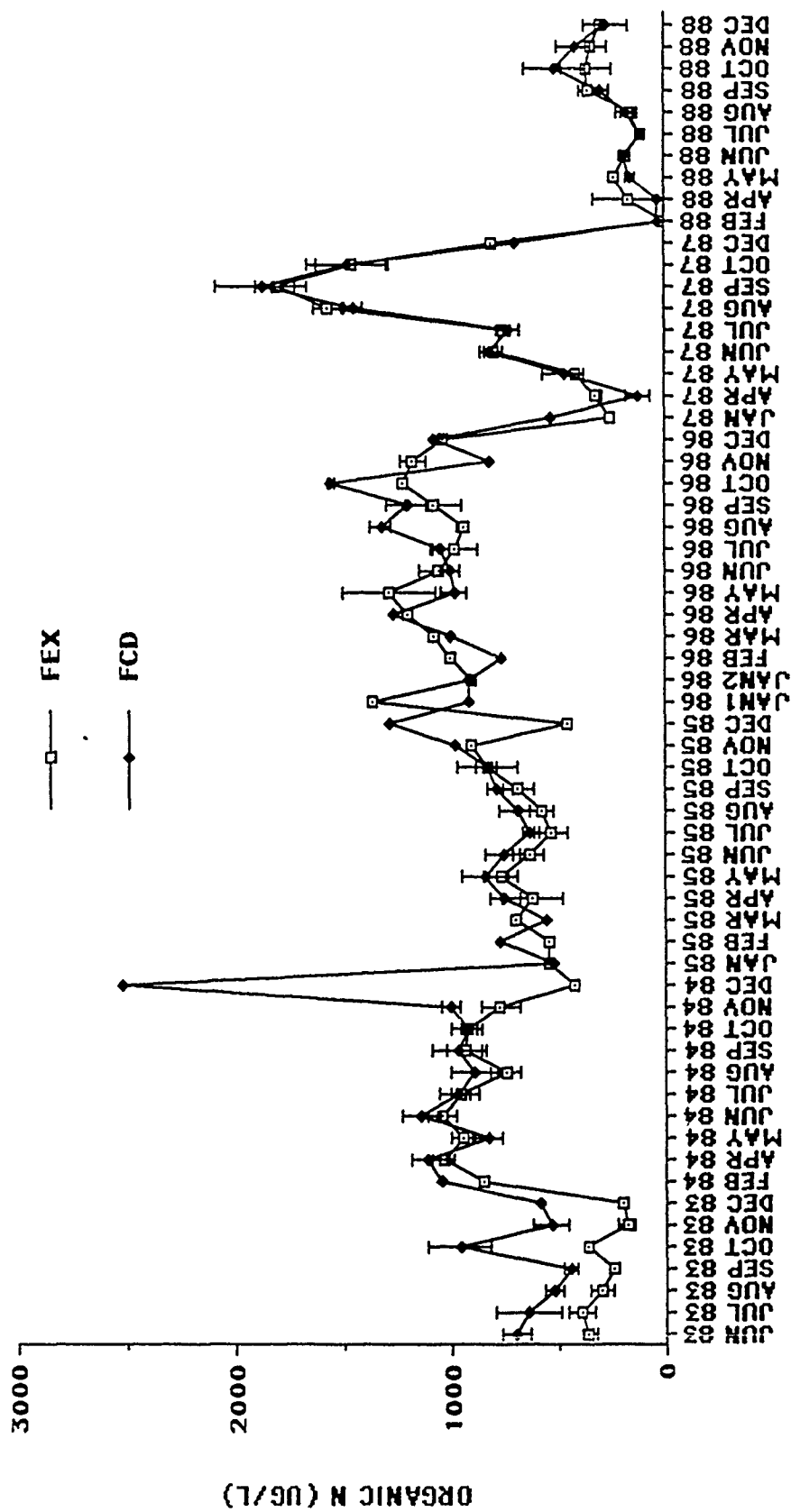


FIGURE 1.15 MEAN ORGANIC NITROGEN CONCENTRATION (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1988.

Table 1.11 Dissolved Silica (mg Si/L) and Chloride (mg Cl/L) for the Ford River for 1988. Values are Means  $\pm$  S.E., N in parentheses.

| Date     | Silica             |                   | Chloride           |                   |
|----------|--------------------|-------------------|--------------------|-------------------|
|          | Experimental (FEX) | Control (FCD)     | Experimental (FEX) | Control (FCD)     |
| 2/28/88  | 9.9 (1)            | 9.8 (1)           | 3.2 (1)            | 2.8 (1)           |
| 4/19/88  | 7.9 $\pm$ 2.0 (2)  | 7.8 $\pm$ 2.0 (2) | 2.9 $\pm$ 0.3 (2)  | 2.4 $\pm$ 0.4 (2) |
| 5/16/88  | 4.8 $\pm$ 0.2 (8)  | 5.0 $\pm$ 0.2 (8) | 3.5 $\pm$ 0.5 (8)  | 2.9 $\pm$ 0.4 (8) |
| 6/13/88  | 6.2 $\pm$ 0.3 (8)  | 6.5 $\pm$ 0.3 (8) | 2.6 $\pm$ 0.1 (8)  | 2.2 $\pm$ 0.2 (8) |
| 7/11/88  | 7.2 $\pm$ 0.2 (9)  | 7.2 $\pm$ 0.1 (8) | 2.3 $\pm$ 0.1 (9)  | 1.7 $\pm$ 0.1 (9) |
| 8/8/88   | 7.9 $\pm$ 0.3 (8)  | 7.7 $\pm$ 0.3 (8) | 2.4 $\pm$ 0.4 (8)  | 2.1 $\pm$ 0.4 (8) |
| 9/8/88   | 8.8 $\pm$ 0.2 (8)  | 8.7 $\pm$ 0.2 (8) | 3.4 $\pm$ 0.3 (8)  | 2.8 $\pm$ 0.4 (8) |
| 10/3/88  | 8.2 $\pm$ 0.1 (8)  | 8.2 $\pm$ 0.1 (8) | 3.5 $\pm$ 0.3 (8)  | 3.4 $\pm$ 0.4 (8) |
| 10/31/88 | 7.9 $\pm$ 0.2 (9)  | 7.8 $\pm$ 0.1 (9) | 3.2 $\pm$ 0.2 (9)  | 2.7 $\pm$ 0.1 (9) |
| 12/27/88 | 8.4 $\pm$ 0.7 (2)  | 8.5 $\pm$ 0.6 (2) | 3.0 $\pm$ 0.1 (2)  | 2.4 $\pm$ 0.0 (2) |

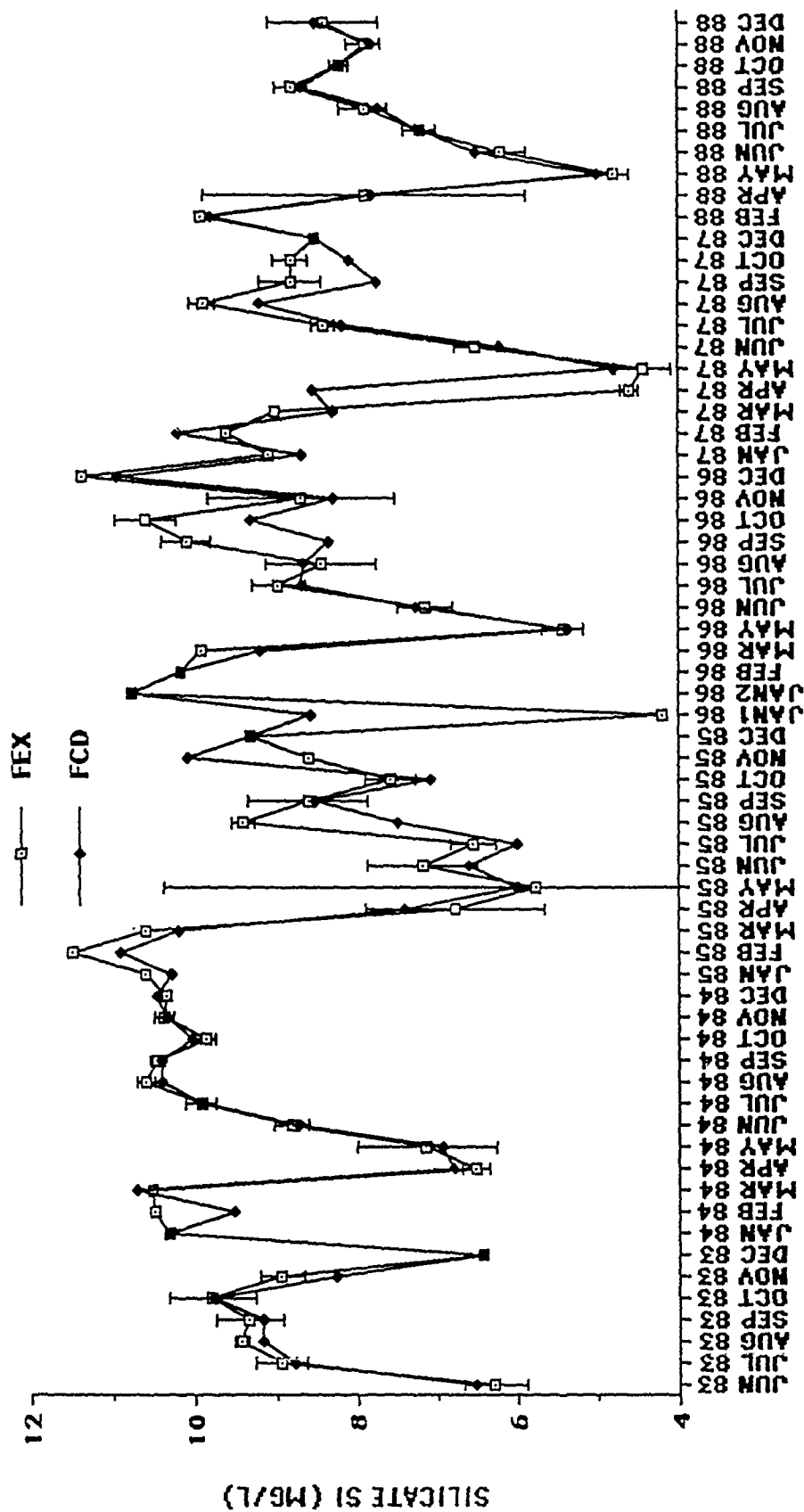


FIGURE 1.16 MEAN SILICATE CONCENTRATION (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1988.

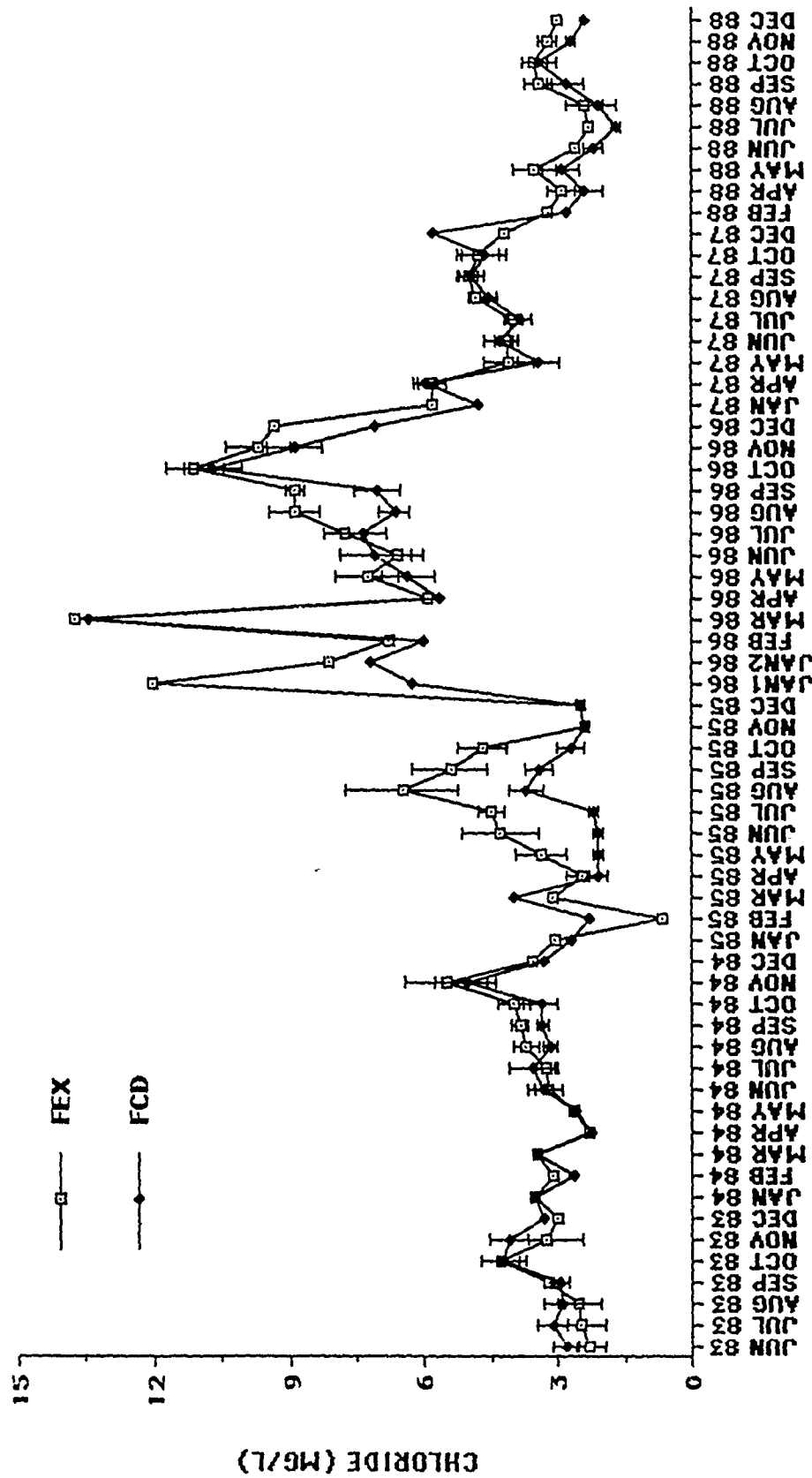


FIGURE 1.17 MEAN CHLORIDE CONCENTRATION (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1988.

However, these values are not much higher than one would expect from rainwater and are certainly much lower than any concentration known to cause problems for fish or other aquatic organisms (McKee and Wolf 1963).

### C. Physical and Meteorological Parameters

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

Solar radiation (PAR) was highly variable using the 30 minute interval data. An integrating instrument would have provided more useful data but was not included in our original equipment list. Our 28 day summaries have been calculated as an average of the 30 minute PAR values for the period from 1000 to 1400 hours daily (Fig. 1.18). These data from the experimental site (FEX) are characteristic of data from both sites. 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 open unshaded areas thus far. Therefore, one would expect only minor variations from site to site. This approach results in comparative data for each 28 day period.

Air and water temperature have been monitored since 1983 and are available as needed. The water temperatures for 1988 are typical (Fig. 1.19, 1.20) of data over the growing season with temperatures rising rapidly from at or near zero under ice to 5 to 10° C before our monitoring stations are installed. Temperature continues to rise to mid-summer from mid-June through mid-August followed by cooling to about 12° C at the end of our reporting season. On subsequent monthly sampling trips from November through April, stream temperatures are at or near zero. The average temperature data for the 28 day exposure periods for the benthic algal sampling are summarized in Fig. 1.20. These data illustrate that average summer temperatures have been less than 20° C for every summer except 1983 and 1988 with 1988 attaining the highest average temperatures since the start of the study. The temperatures experienced in 1989 were lower than those of 1988 but still reflect the recent trend of low flows (Fig. 1.5) and high temperatures of the past few years.

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



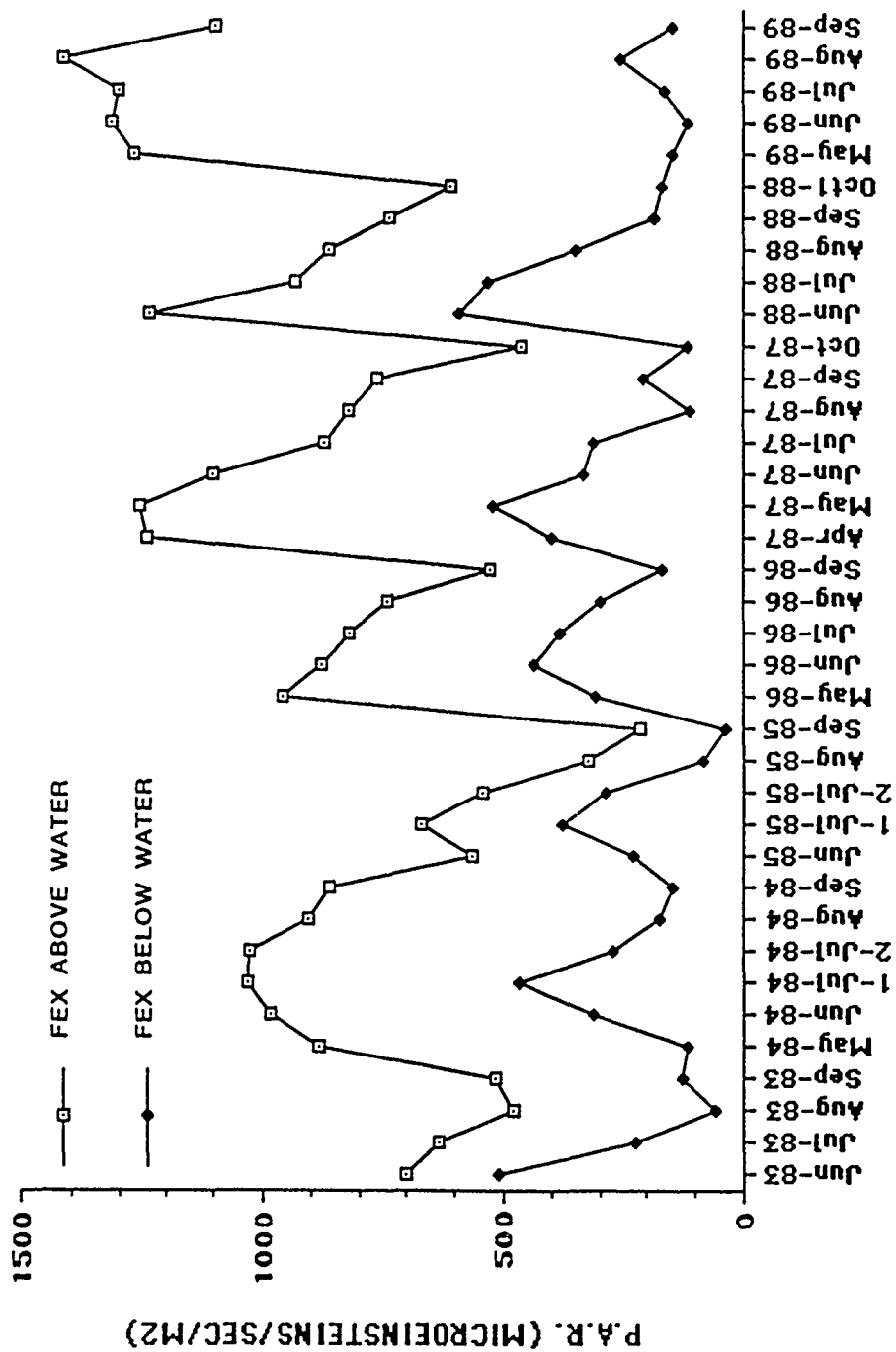


FIGURE 1.18 MEAN SOLAR RADIATION BETWEEN 10:00 AND 14:00 FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) SITE, 1983-1989

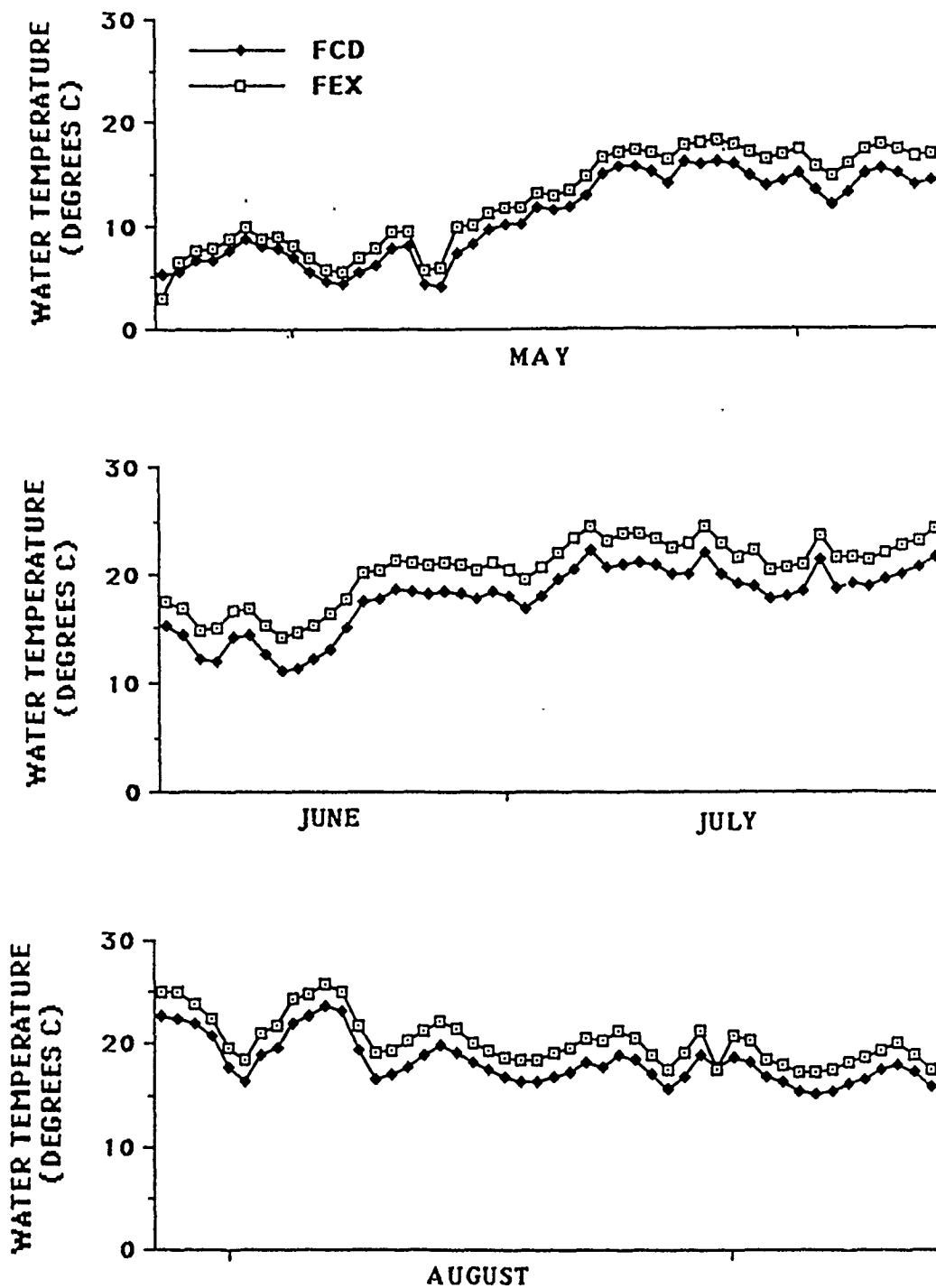


FIGURE 1.19 DAILY WATER TEMPERATURE MEANS FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES FOR 1989.

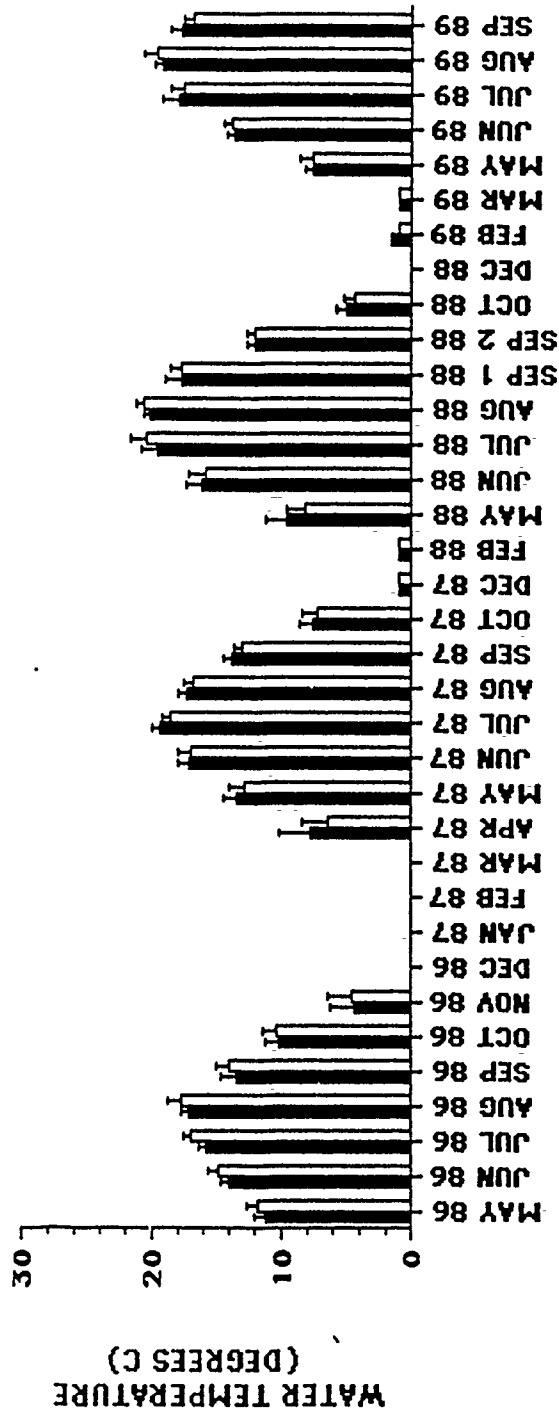
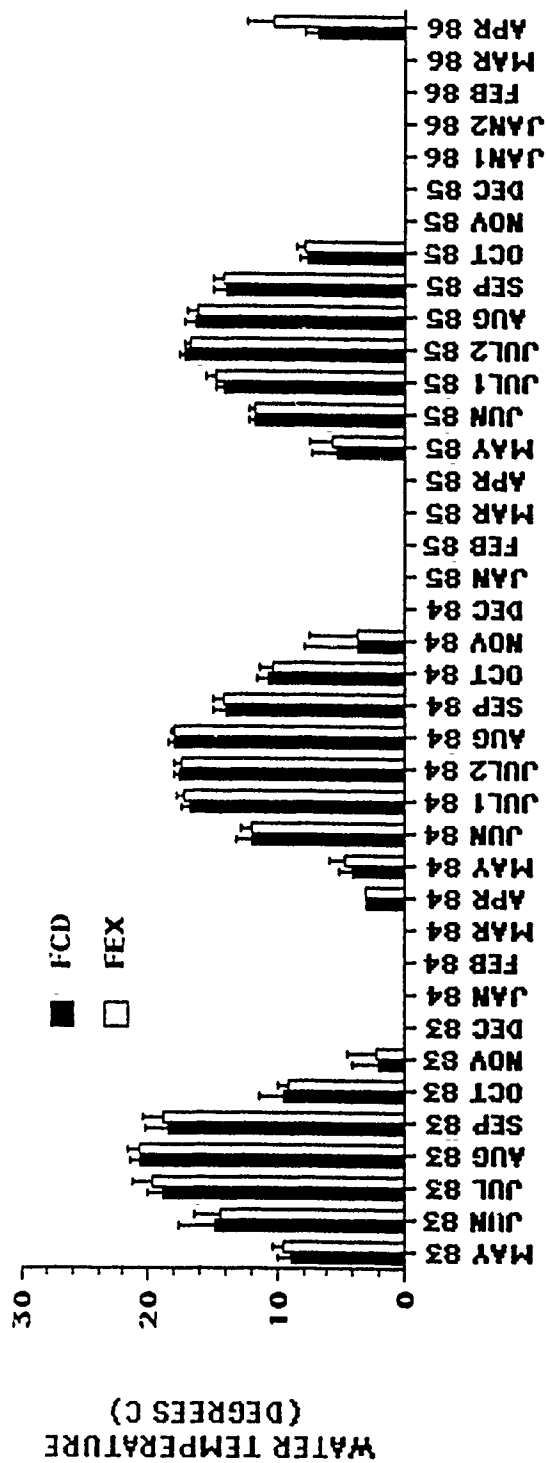


FIGURE 1.20 MEAN WATER TEMPERATURE (+S.E.) FOR EACH 28 DAY PERIOD FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1989.

for mean daily values for 1989 (Fig. 1.6). However, the first three years of these data were calculated from actual discharge measurements taken with current meters once or twice per week. Initially, data were logged on Omnidatapods using modified Stevens Type F recorders. These data had to be converted to discharge using two regressions. The first related electrical output from the recorders to the datapods to actual water depth. The second related water depth to discharge using a standard depth-discharge regression. The first of these regressions changed any time the float line was set to a different position on the float wheel. Thus, retrieval and conversion of these data proved to be quite a chore. We have not yet completed this task but hope to by the end of spring. In 1986, this system was abandoned and the simple but effective strip chart recorder has been used since. Data on mean daily flows are currently available for all years since 1986. We are currently working on regressions of the biological parameters with mean discharge (presented in element 2), minimum discharge, maximum discharge, time since last storm event, etc. for each of the 28 day benthic algal exposure periods. We suspect, for example, that maximum production of benthic algae occurs during times of low discharge with amount of production probably correlated with the length of time since the last storm.

Another way to get at the time since the last storm is to correlate the biological data with time since last major precipitation event. We are relying on National Weather Service data for Crystal Falls for these correlations. Entering this data into our data base was a priority for the winter of 1987-88. We completed this task and as reported last year, these data did not correlate with any of the biological parameters. Since Crystal Falls, MI data may not be precise for the Ford River watershed, we have collected supplemental rainfall data for each site for the last four summers. These data for 1989 are presented in Fig. 1.21. We are currently summarizing this data for future correlations and entry into multiple regression models.

#### 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 had been true for hardness, nitrate, and organic nitrogen in most years. The differences observed for hardness and for nitrate and

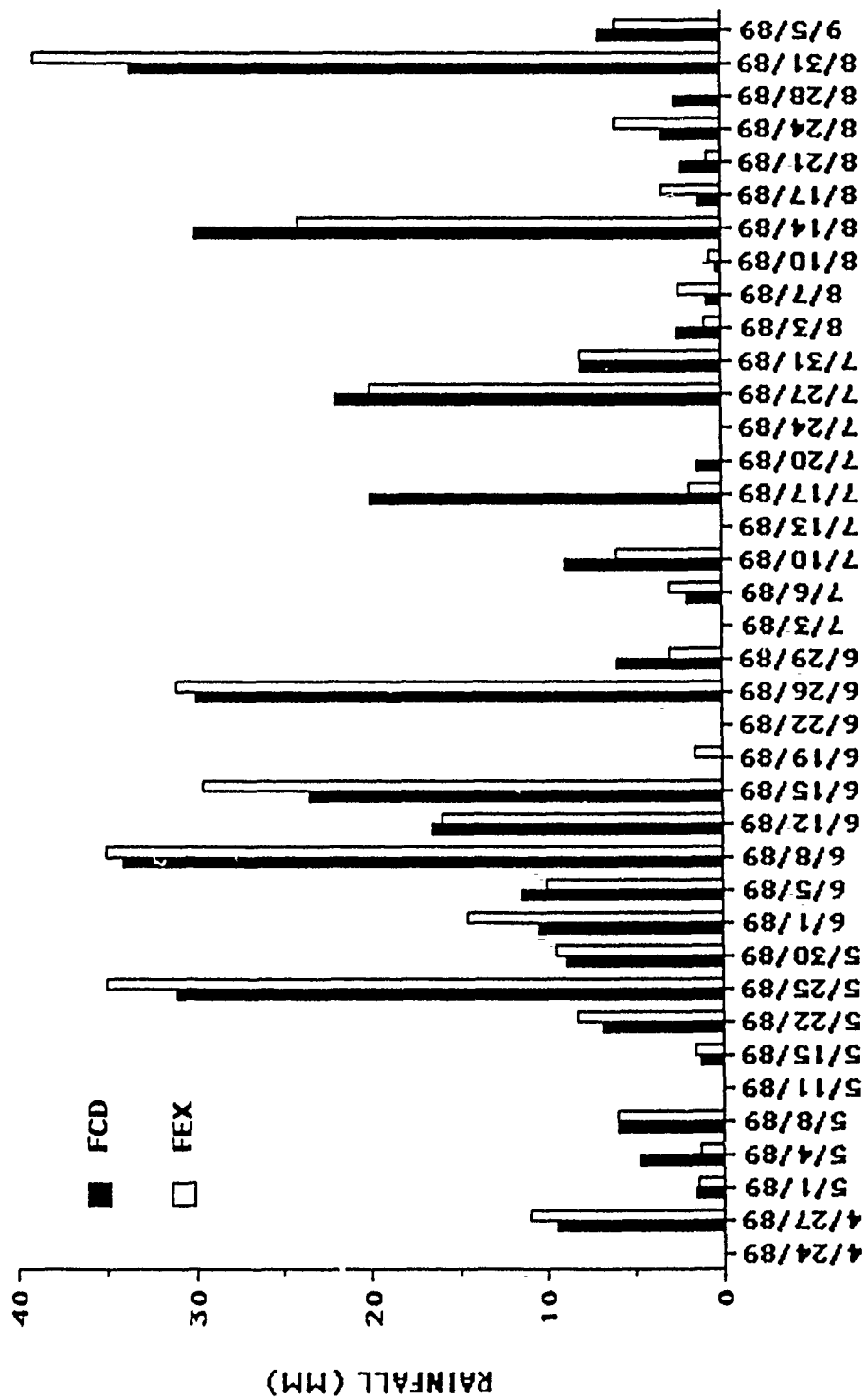


FIGURE 1.21 DAILY RAINFALL AMOUNTS FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES FOR 1989.

organic-N could 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.

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

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

Chemical and physical parameters for FEX and FCD demonstrated that these two sites were very similar with significant differences between sites showing up for less than one-third of the parameters monitored prior to 1989. The differences that did occur were slight and should have little impact on site productivity. Most of these differences were not present in 1988 with the exception of water temperature and hardness.

#### E. References

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## VII. A. PERIPHYTON STUDIES

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

Changes from workplan- The winter sampling schedule for the biological parameters was changed from monthly (28 days) to bimonthly sample collection in October 1987 resulting in three winter data sets. This routine was changed to once every 6 weeks for the 1988-89 winter, providing one more winter data set. This proved necessary because of our current approach of analysing the data on a summer/ winter basis as well as on an overall basis. In addition, in the past we reported the chlorophyll a to phaeophytin a ratio as an indicator of the physiological health of the algal community. The high variabilities encountered in this index make its usefulness questionable, therefore, we have eliminated it from this report.

### 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: Community composition of the attached algae has often been used by researchers to indicate subtle or dramatic changes in water quality. The effects of toxins, nutrients, or other pollutants has often



been linked to changes in abundances of particular diatom species and often to the presence or absence of sensitive species. The use of a species diversity index coupled with measurements of species evenness and percent dominance allows between site comparisons of attached algal 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 often consists of 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 algae, we are examining the relatively simple parameter of overall cell density. This directly determined density measure represents the numerical end product of species succession and abundance or dominance shifts by individual species in the attached algae community, and also includes the effects of physical environmental factors. The use of cell density, which is affected by both biological and physical factors, may reveal changes due to ELF effects. This single parameter is also a very important correlate with other estimates of production, such as chlorophyll *a*, or organic matter accrual. This labor intensive direct counting procedure is the yardstick against which other production estimates are often compared and should help separate potential ELF induced effects from other biological or physical influences.

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

This multiple approach of methodologies couples direct determinations of quantities of pigments present with direct measurements of oxygen levels produced by that pigment. Thus, these parameters allow

statistical comparisons of production between sites throughout the year. Utilizing several different approaches allows us to continue analyses at times when we must rely on single approaches due to weather or labor constraints. For example, measuring chlorophyll a and organic matter accrual directly during winter provide estimates of production when the more detailed production studies of photosynthetic rates are not feasible.

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

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

#### Materials and Methods

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

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

Slides were prepared for specimen identification by cleaning the diatoms removed from the exposed glass slides in concentrated hydrogen peroxide (30%) followed by further oxidation of the cellular contents with the addition of small amounts of potassium dichromate (Van der Weff 1955). The cleaned diatoms were then rinsed with distilled water and settled in graduated cylinders. The final volume of concentrate containing the cleaned diatom frustules was then measured and 1 ml subsamples pipetted onto 22 mm<sup>2</sup> coverslips, until an adequate counting density was achieved. The coverslips were air dried and permanently mounted on glass slides using Hyrax medium.

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

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

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

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

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

Statistical comparisons between sites emphasize the paired t-test, as recommended by one of our reviewers in past annual reports. Single year data for October, 1988 through September, 1989 and results for yearly and six year paired t-tests on all parameters measured will be presented in this report. Additionally, emphasis has been placed on the analysis of biological parameters using the BACI technique. Previous methods for analysis of "before" and "after" ELF effects as presented in earlier annual reports included the 3-way analysis of variance. The variables included a year, site and month effect for the selected parameter. While this analysis may prove to be the most statistically robust of several analyses available, they all may suffer from lack of true replication (Hulbert 1984). Because of such considerations and to expand our methods, we have analyzed our biological data according to the BACI method presented by Stewart-Oaten et al (1986). The design

requires replicated sampling over time; Before and After the antenna is operating at both Control and Impact sites.

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

Using the BACI analysis, we can examine seasonal variations of chlorophyll a and AFDW-biomass standing crop and production, cell volume, biovolume, cell density, species diversity, evenness, and diatom abundance. Seasons for this analysis consisted of a Summer (May to October) and a Winter (November to April) period, with all seasons prior to Summer, 1986 representing the "before" period. The "after" period commenced July 22, 1986 at FEX with an average 4 amp ELF exposure for variable time periods during the day over 31 consecutive days. During 1987, the site at FEX received 15 amps for variable time periods during daylight hours from May 22 through August 31, 1987. The experimental site was exposed to 75 amps for variable time periods throughout most of 1988 and 150 amps from May 1, 1989 to October 7, 1989. Using the BACI design we ran pooled comparisons on all the biological data except diatom abundance; i.e. all sampling dates from June, 1983 to April, 1986 as the "before" period and all dates from May, 1986 to September, 1989 as the "after" period. For each biological parameter, seasonal pooled comparisons were run; i.e. Summers (or Winters) 1983, 1984, 1985 as the "before" period and Summers (Winters) 1986, 1987, 1988 and 1989 as the "after" period. Additionally, individual seasons of the "before" period for each parameter were compared to other "before" seasons to determine whether any differences

occurred prior to impact. Each of the "before" seasons were then individually compared to each of the "after" seasons to see whether significant differences occurred as a result of ELF exposure. The results of all BACI analyses are in Appendices A and B with summary tables included in the body of this element. We were particularly interested in the comparison of each "before" season with the 1989 data, since 1989 was the year of highest amps used to date as well as the most days of exposure.

This year we 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 the past we ran a large correlation matrix in order to examine the relationship between our biological parameters and the physical/chemical variables. This year, in order to explore those relationships further we conducted stepwise multiple regression analysis ( $p$  to enter = 0.05 and  $p$  to remove = 0.10) for each biological parameter at each site using all the physical/chemical variables that produced a significant correlation with a biological parameter in last years correlation matrix. Those variables are water temperature, dissolved oxygen, discharge, pH, alkalinity, conductivity, silica, nitrate, and inorganic nitrogen. Regressions were run for the entire data set (1983-1989) using all variables except discharge, and on the total summer data set with all the variables including discharge (discharge data is only available for the summer months).

This year we have begun exploring randomized intervention analysis (RIA), described by Carpenter, et al (1989) as an additional statistical means of detecting possible ELF effects. This method uses randomization to create an error distribution from our collected set of data, eliminating the non-normality problem associated with tests such as BACI. Additionally, RIA is not affected by non-homogenous variances. Although Carpenter et al (1989) does mention that RIA may be affected by autocorrelations in the data, our regime of independent 28 day sample periods eliminates this potential problem. We feel that RIA represents an useful statistical analysis in addition to BACI. Results from our current attempt to analyze biological parameters using RIA will be presented in next year's 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 and 38% in 1988-89. AFDW-biomass had C.V.'s that averaged 40% in 84-85, 64% in 85-86, 45% in 86-87, 48% in 87-88 and 36% in 88-89. Diatom cell density averaged 38% in 84-85, 39% in 85-86, 33% in 86-87, 45% in 87-88 and 9% in 88-89 (this low C.V. is probably due to an increase in the number of valves counted per slide (from 300 to 500) effectively increasing the sample size and 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. Derived measurements of species diversity or species evenness calculated from the field samples showed much lower C.V.'s ranging from 1% to 27% and averaging 10% in 85-86, 10% in 86-87, 6% in 87-88 and 1% in 88-89 for species diversity, and species evenness averaging 7% in 85-86, 6% in 86-87, 4% in 87-88 and 5% in 88-89. 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 such times, when the C.V.'s are low, statistical comparisons made between sites therefore provided a sample size sufficient to be 95% certain of detecting a 40% difference in means between the two sites at the .05 significance level (Sokal and Rohlf 1969). Coefficients of variation tend to be lower during low flow periods in summer and more variable during the higher waters seen in spring and fall periods. Thus, statistical comparisons in future reports will emphasize these time periods to be able to detect small differences between single time period comparisons. Our main efforts have been to devise tests rigorous enough to detect differences using larger samples over time. We expect overall trends to be examined through the before mentioned BACI technique, and through regression analyses comparing pre-ELF exposure data with post-ELF exposure data and time series analysis.

## Results and Discussion

### A. Colonization Patterns

In previous annual reports (AE-020, AE-031 and AE-045 for 1982-83, 1983-84, and 1984-85), we summarized data on colonization patterns for periphyton for the Ford River. These data demonstrated that for determining rates of productivity and organic matter accumulation, a 14 day period was best during the active growing season (mid-April to mid-September). This 14 day period coincided with rapid

increases in chlorophyll a, phaeophytin a, and accrual of organic matter. Selecting this early period minimizes losses due to sloughing that increase as the periphyton community "matures" or approaches its maximum sustainable density on the slides (Burton and King 1983). This period of maximum daily increase in organic matter and chlorophyll a is often used as a measure of net production (APHA 1980; Burton and King 1983). Since the daily increases are less rapid during the cold weather, we used the 28 day period for estimates of daily productivity or accrual rate during the winter months and the 14 day period from April through October.

After 14-21 days during exposure periods without major flood events, the periphyton community composition was shown to change slowly through time (Oemke and Burton 1986), and qualitatively approximated the mature community on natural substrates in the stream. Thus, standing crop estimates of chlorophyll a, organic matter, and all community composition parameters (cell density, species diversity, species evenness, and species dominance) are based on a 28 day exposure period throughout the year. All data from 1983-1989, excluding the winters of 1987 and 1988, were based on this 28 day or this 14 day exposure period and sampling regime. As reported in the 1982-83 annual report (AE-20) and in Oemke and Burton (1986), differences between a slow flowing pool habitat, and the more rapidly flowing riffle habitat were either slight or insignificant as exposure length increased. Thus, all samples are presently collected from riffle areas only.

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

#### B. Patterns for Chlorophyll a

Chlorophyll a standing crop data for October 1988 through September 1989 followed annual patterns of summer peaks and winter lows (Fig. 2.1, Table 2.1). An unseasonably wet June is probably responsible for the low chlorophyll a standing crop in June. Annual patterns have indicated that chlorophyll a peaks during the summer months of July or August. The 1989 peak occurred in July for both sites (with the exception of the May values) and reached levels of 15-20 mg/m<sup>2</sup>. These chlorophyll a levels along with the 1988 levels are higher than previously recorded and are probably associated with the higher temperatures and lower flows experienced over the past few years. Most measures of algal standing crop (density, chlorophyll a, AFDW-organic matter accrual) as well as species composition appear to have increased as a consequence of the very dry weather in May and early summer for the past four years



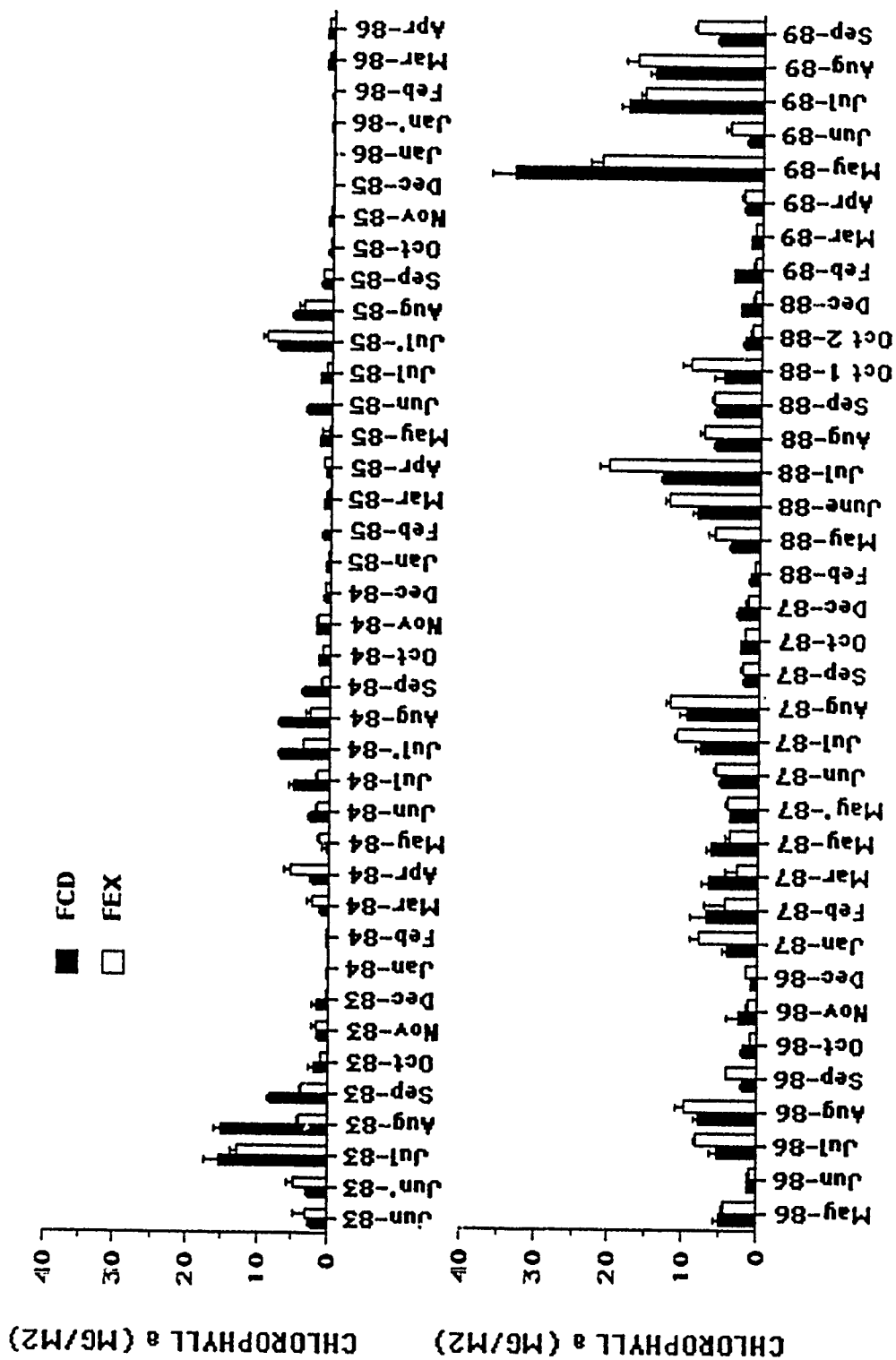


FIGURE 2.1 CHLOROPHYLL a STANDING CROP FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES ON THE FORD RIVER, 1983-1989.

Table 2.1 Chlorophyll  $a$  (mg/m<sup>2</sup>) from slide exposed for 28 days in the Ford River. Values are Means  $\pm$  S.E., N in parentheses.

| Date Out | Experimental (FEX)    | Control (FCD)         |
|----------|-----------------------|-----------------------|
| 10/3/88  | 9.50 $\pm$ 1.29 (10)  | 5.19 $\pm$ 1.26 (10)  |
| 10/31/88 | 1.37 $\pm$ 0.14 (10)  | 2.32 $\pm$ 0.14 (10)  |
| 12/27/88 | 1.06 $\pm$ 0.14 (25)  | 2.68 $\pm$ 0.29 (20)  |
| 2/11/89  | 0.91 $\pm$ 0.20 (25)  | 3.64 $\pm$ 0.25 (26)  |
| 3/20/89  | 0.98 $\pm$ 0.06 (24)  | 1.43 $\pm$ 0.10 (37)  |
| 4/17/89  | 2.59 $\pm$ 0.21 (25)  | 2.23 $\pm$ 0.21 (25)  |
| 5/15/89  | 21.76 $\pm$ 1.44 (9)  | 33.36 $\pm$ 3.28 (10) |
| 6/12/89  | 4.40 $\pm$ 0.72 (10)  | 2.01 $\pm$ 0.18 (10)  |
| 7/10/89  | 16.01 $\pm$ 0.68 (10) | 18.37 $\pm$ 0.95 (10) |
| 8/7/89   | 17.16 $\pm$ 1.39 (10) | 14.85 $\pm$ 0.61 (10) |
| 9/5/89   | 9.10 $\pm$ 0.44 (10)  | 5.93 $\pm$ 0.50 (10)  |

(1986, 1987, 1988, and 1989, with the exception of June). 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 winter for the previous years (Fig. 2.1). Winter 87-88 and 88-89 chlorophyll a levels were not as high as those reported for 1986, but were slightly greater than  $1.0 \text{ mg m}^{-2}$  (Fig. 2.1, Table 2.1).

The period of highest variability has generally been the periods from late March through June. This period sometimes contains secondary peaks in standing crop production, e.g. April 1984, May 1986 and 1989 (Fig. 2.1). This secondary peak seems to be associated with dry spring seasons with low flows and relatively warm temperatures following snow melt runoff events. Stepwise multiple regression models indicate that water temperature is the most consistent predictor of chlorophyll a standing crop at both sites (Table 2.2). This is consistent with the results of the correlation matrix reported last year. In addition to water temperature, last year chlorophyll a also correlated with discharge, pH, conductivity, alkalinity, nitrate and inorganic nitrogen. All these variables were available for use in the models by the stepwise procedure, yet only conductivity was incorporated into any of these models. This is probably because all these variables exhibit seasonal cycles similar to that exhibited by water temperature (see Element 1) and therefore do not account for any additional variance than water temperature does.

The annual comparison for 88-89 between sites showed no significant differences using a paired t-test for chlorophyll a levels (Table 2.3). Chlorophyll a levels between sites were highly correlated in 1989 ( $r=.92$ , Table 2.3) just as they were for the entire study period (Table 2.4). We have also computed the minimum detectable differences for each of our biological parameters (Table 2.5). The minimum detectable difference is the percent different the 2 sites must be in order for us to be able to detect it at our standard significance level of 0.05. This was done according to the method provided in Zar (1984) on the entire data sets and on the summer and winter data sets. The 44% needed for the winter data set highlights the variability found in our winter data for chlorophyll a and all other biological parameters. Ideally, we would be able to detect a difference of 15% or less, however the variability in the between-site relationship in chlorophyll a (FCD>FEX in May and July of 1989 and FEX>FCD in April, June, August and September of 1989) prohibits this.

Table 2.2 Results of stepwise multiple regressions for each biological parameter (total and summer data) on selected physical/chemical variables (Temperature, X-dissolved Oxygen, P-pH, A-alkalinity, C-conductivity, B-discharge, S-silica, N-nitrate and inorganic nitrogen)

| Parameter    | Site | Season | Model                                        | R <sup>2</sup> | P       | Major X variation explained by major factor |
|--------------|------|--------|----------------------------------------------|----------------|---------|---------------------------------------------|
| Chlorophylla | FCD  | Total  | $y = 1.42X + .571 + .03C - 21.8$             | 0.56           | < 0.001 | X                                           |
|              |      | Summer | $y = 2.73X + 1.15 + .36.7$                   | 0.55           | < 0.001 | T                                           |
| FEX          |      | Total  | $y = 0.345T + 0.52$                          | 0.33           | < 0.001 | T                                           |
|              |      | Summer | $y = 0.62T + .80S + 2.97$                    | 0.30           | < 0.001 | T                                           |
| AFDV         | FCD  | Total  | $y = -3.98N + 1111.1$                        | 0.21           | < 0.001 | N                                           |
|              |      | Summer | $y = -8.43A + 9.09C + 184.5$                 | 0.34           | < 0.001 | C                                           |
| FEX          |      | Total  | $y = 49.81T + 466.4$                         | 0.27           | < 0.001 | T                                           |
|              |      | Summer | $y = 1114.1P - 7752.8$                       | 0.11           | < 0.05  | P                                           |
| Evenness     | FCD  | Total  | no model fit                                 |                |         |                                             |
|              |      | Summer | $y = 0.002A + 0.472$                         | 0.10           | < 0.05  | A                                           |
| FEX          |      | Total  | no model fit                                 |                |         |                                             |
|              |      | Summer | $y = 0.035S + 0.49$                          | 0.08           | < 0.05  | S                                           |
| Cell volume  | FCD  | Total  | $y = 408.0X + 15.5A - 5696.9$                | 0.29           | < 0.001 | X                                           |
|              |      | Summer | $y = -42.19T + 6.37A + 25.92$                | 0.23           | < 0.01  | T                                           |
| FEX          |      | Total  | $y = -138.2T + 3004P + 190.25 - 2.3$         | 0.30           | < 0.001 | T                                           |
|              |      | Summer | $y = -49.91T + 3.91C + 145.6$                | 0.25           | < 0.01  | T                                           |
| Biovolume    | FCD  | Total  | $y = 0.06C - 1.65S + 6.92$                   | 0.12           | < 0.05  | S                                           |
|              |      | Summer | $y = -2.23S + 24.61$                         | 0.13           | < 0.05  | S                                           |
| FEX          |      | Total  | no model fit                                 |                |         |                                             |
|              |      | Summer | $y = -3.65S - 2.83D + 42.3$                  | 0.28           | < 0.01  | S                                           |
| Density      | FCD  | Total  | $y = 0.24C - 0.85S + 30.9$                   | 0.31           | < 0.001 | S                                           |
|              |      | Summer | $y = -10.55 - 0.26N + 119.9$                 | 0.29           | < 0.001 | S                                           |
| FEX          |      | Total  | $y = -14.66S + 0.45A + 86.6$                 | 0.27           | < 0.001 | S                                           |
|              |      | Summer | $y = -13.35 + 1.09N - 12.90 - 0.74T + 175.4$ | 0.49           | < 0.001 | S                                           |
| Diversity    | FCD  | Total  | $y = -0.12A + 20.4$                          | 0.00           | < 0.05  | A                                           |
|              |      | Summer | $y = 28.3P + 7.60 - 2.32$                    | 0.49           | < 0.001 | P                                           |
| FEX          |      | Total  | $y = 1.74P + 16.56$                          | 0.22           | < 0.001 | P                                           |
|              |      | Summer | $y = 0.27S + 0.300 + 0.05$                   | 0.39           | < 0.001 | S                                           |

Table 2.3 Paired t-test and correlations between the Experimental (FEX) and Control (FCD) sites for Biological parameters for 1988-89.

| Parameter                             | df | Paired<br>t-value | Significance | Correlation<br>Coefficient | Significance |
|---------------------------------------|----|-------------------|--------------|----------------------------|--------------|
| Chlorophyll <u>a</u>                  | 10 | 0.501             | NS           | 0.92                       | P < 0.01     |
| AFDW                                  | 10 | -2.570            | NS           | 0.91                       | P < 0.01     |
| Chlorophyll <u>a</u><br>daily accrual | 10 | 0.369             | NS           | 0.93                       | P < 0.01     |
| AFDW<br>daily accrual                 | 10 | -2.475            | NS           | 0.92                       | P < 0.01     |
| Species<br>Diversity                  | 9  | 0.663             | NS           | 0.52                       | NS           |
| Species<br>Evenness                   | 9  | 1.160             | NS           | 0.61                       | NS           |
| Cell density                          | 9  | -0.863            | NS           | 0.88                       | P < 0.01     |
| Cell Volume                           | 9  | -0.923            | NS           | 0.22                       | NS           |
| Biovolume                             | 9  | -1.560            | NS           | 0.81                       | P < 0.01     |

Table 2.4 Paired t-test and correlations between the Experimental (FEX) and Control (FCD) sites for Periphyton Parameters for 1983-89, Total and broken into Winter and Summer seasons.

|                                       |    | Paired  |              | Correlation |              |
|---------------------------------------|----|---------|--------------|-------------|--------------|
| Parameter                             | df | t-Value | Significance | Coefficient | Significance |
| Total                                 |    |         |              |             |              |
| Chlorophyll <u>a</u>                  | 74 | 0.962   | NS           | 0.851       | P<0.01       |
| AFDW                                  | 74 | -0.458  | NS           | 0.535       | P<0.01       |
| Chlorophyll <u>a</u><br>daily accrual | 78 | -0.274  | NS           | 0.845       | P<0.01       |
| AFDW<br>daily accrual                 | 78 | -0.831  | NS           | 0.610       | P<0.01       |
| Diversity                             | 73 | 1.731   | NS           | 0.832       | P<0.01       |
| Evenness                              | 73 | 1.310   | NS           | 0.776       | P<0.01       |
| Cell density                          | 73 | -0.714  | NS           | 0.794       | P<0.01       |
| Cell volume                           | 73 | 0.834   | NS           | 0.959       | P<0.01       |
| Biovolume                             | 73 | -1.304  | NS           | 0.716       | P<0.01       |
| Summer                                |    |         |              |             |              |
| Chlorophyll <u>a</u>                  | 43 | 0.507   | NS           | 0.831       | P<0.01       |
| AFDW                                  | 43 | -1.418  | NS           | 0.641       | P<0.01       |
| Chlorophyll <u>a</u><br>daily accrual | 47 | -0.703  | NS           | 0.832       | P<0.01       |
| AFDW<br>daily accrual                 | 47 | -1.089  | NS           | 0.491       | P<0.01       |
| Diversity                             | 42 | 4.099   | NS           | 0.847       | P<0.01       |
| Evenness                              | 42 | 3.678   | NS           | 0.767       | P<0.01       |
| Cell density                          | 42 | -0.682  | NS           | 0.693       | P<0.01       |
| Cell volume                           | 42 | 1.216   | NS           | 0.460       | P<0.01       |
| Biovolume                             | 42 | -1.348  | NS           | 0.717       | P<0.01       |
| Winter                                |    |         |              |             |              |
| Chlorophyll <u>a</u>                  | 31 | 1.413   | NS           | 0.673       | P<0.01       |
| AFDW                                  | 31 | 0.510   | NS           | 0.173       | NS           |
| Chlorophyll <u>a</u><br>daily accrual | 30 | 1.356   | NS           | 0.709       | P<0.01       |
| AFDW<br>daily accrual                 | 30 | 0.220   | NS           | 0.216       | NS           |
| Diversity                             | 31 | -1.414  | NS           | 0.866       | P<0.01       |
| Evenness                              | 31 | -2.185  | NS           | 0.854       | P<0.01       |
| Cell density                          | 31 | -0.048  | NS           | 0.918       | P<0.01       |
| Cell volume                           | 31 | 0.527   | NS           | 0.955       | P<0.01       |
| Biovolume                             | 31 | -0.536  | NS           | 0.719       | P<0.01       |

Table 2.5

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         | 29.0  | 31.0   | 44.0   |
| Organic Matter (AFDW) | 28.2  | 22.0   | 93.3   |
| Evenness              | 4.8   | 5.6    | 6.7    |
| Cell Volume           | 20.7  | 19.7   | 29.9   |
| Biovolume             | 52.7  | 58.0   | 106.8  |
| Density               | 59.2  | 64.0   | 75.5   |
| Diversity             | 6.8   | 7.6    | 11.4   |

Results of BACI comparisons of 6.5 year  $\log(x+1)$  transformed chlorophyll a data (Table 2.6 and appendix A Table A-1) indicated that a significant difference ( $p < 0.05$ ) occurred when "before" (6/83-4/86) and "after" (5/86-9/89) means were compared with an unpaired t-test ( $df = 62$ ,  $t$ -value = -2.328). When broken down on a seasonal basis, the significance was the result of a significant difference between S 83-85/86-88 summer regressions (Table 2.6). Since all the yearly "after" data were additive in 86, 87 and 88, as demonstrated in the Before and After columns for Tukey's test for Additivity in Table A-1, the significant difference probably reflected the unusually high chlorophyll a levels observed during the low flow, hot summers. Summer by summer comparisons showed that these differences primarily arose from differences between the summer of 83, 84, and 85 and the summers of 87 and 88; i.e. S 83/88, S 84/87, S 84/88, S85/87, and S 85/88 comparisons as presented in Table 2.6. There were no differences between sites based on the paired t-tests (Tables 2.3, 2.4) and the summer of 1989 (the summer of the highest ELF exposures to date) does not show up as a significant year, so it seems likely that these differences in before and after data are a result of different weather conditions and not due to ELF effects. The BACI procedure tests for a change in the relationship between sites after an "impact". It appears that the between site relationship in chlorophyll a is affected by the weather causing the the year to year differences discussed above. Even though the summer of 1989 was generally a warm dry summer, the unusually wet June may explain why this year did not show up in the BACI analysis as being different from the wetter, cooler years of 1984 and 1985.

Daily chlorophyll a accrual rates followed the same pattern as did standing crop with mid-summer peaks and winter lows (Fig. 2.2, Table 2.7). Peak daily rates in July were above those observed in any previous year and consistent with the pattern observed in the last three years. The daily accrual rates were very similar between FEX and FCD, and there were no significant differences between the sites in 1988-89 (Table 2.3). Differences were found to be significant between sites in the report for 1983-84, analyzing only a single year's data by paired t-tests. Since then, greater care has been taken to place slides in similar habitats with respect to current velocity (Fig. 2.3), shading, and depth. Subsequent reports have shown no significant site differences in the last four years. BACI analysis of the chlorophyll a accrual rates indicate that there is a difference in the between site relationship "before" impact (6/83-4/86) and that relationship "after" impact (5/86-9/89) (Table 2.6, A-2). This is due to differences between the summer of 1989 and the summers of 1984, 1985 (before years) and 1986 (an after



Table 2.6 Summary of Biological BACI Comparisons between Control (FCD) and Experimental (FEX) Sites for 1983-1989.

| Parameter                      | Comparison              | df | Significance ( $p < 0.05$ ) |
|--------------------------------|-------------------------|----|-----------------------------|
| Chlorophyll a                  | 6/83-4/86 vs. 5/86-9/89 | 73 | $p < 0.05$                  |
|                                | Summer 83-85 vs. 86-89  | 38 | $p < 0.01$                  |
|                                | S 83/88                 | 9  | $p < 0.05$                  |
|                                | S 84/87                 | 11 | $p < 0.05$                  |
|                                | S 84/88                 | 10 | $p < 0.05$                  |
|                                | S 85/87                 | 11 | $p < 0.05$                  |
|                                | S 85/88                 | 10 | $p < 0.01$                  |
|                                | Winter 83-85 vs. 86-88  | 28 | NS                          |
| Chlorophyll a<br>Daily Accrual | 6/83-4/86 vs. 5/86-9/89 | 77 | $p < 0.05$                  |
|                                | Summer 83-85 vs. 86-89  | 46 | $p < 0.05$                  |
|                                | S 84/89                 | 9  | $p < 0.01$                  |
|                                | S 85/89                 | 9  | $p < 0.01$                  |
|                                | S 86/89                 | 9  | $p < 0.05$                  |
|                                | Winter 83-85 vs. 86-88  | 29 | NS                          |
| AFDW-Biomass                   | 6/83-4/86 vs. 5/86-9/89 | 73 | NS                          |
| AFDW-Biomass<br>Daily Accrual  | 6/83-4/86 vs. 5/86-9/89 | 77 | NS                          |
| Cell Density                   | 6/83-4/86 vs. 5/86-9/89 | 72 | $p < 0.01$                  |
|                                | Summer 83-85 vs. 86-89  | 41 | $p < 0.05$                  |
|                                | S 83/88                 | 9  | $p < 0.05$                  |
|                                | Winter 83-85 vs. 86-88  | 29 | NS                          |
| Cell Volume                    | 6/83-4/86 vs. 5/86-9/89 | 72 | NS                          |

Table 2.6 Summary of Biological BACI Comparisons, continued.

| Parameter                                                  | Comparison              | df | Significance ( $p < 0.05$ ) |
|------------------------------------------------------------|-------------------------|----|-----------------------------|
| Biovolume                                                  | 6/83-4/86 vs. 5/86-9/89 | 72 | $p < 0.05$                  |
|                                                            | Summer 83-85 vs. 86-89  | 41 | NS                          |
|                                                            | Winter 83-85 vs. 86-88  | 29 | $p < 0.05$                  |
|                                                            | W 84/86                 | 10 | $p < 0.05$                  |
|                                                            | W 84/88                 | 8  | $p < 0.05$                  |
|                                                            | W 85/88                 | 9  | $p < 0.05$                  |
| Species Diversity                                          | 6/83-4/86 vs. 5/86-9/89 | 72 | $p < 0.05$                  |
|                                                            | Summer 83-85 vs. 86-89  | 41 | NS                          |
|                                                            | S 83/87                 | 10 | $p < 0.05$                  |
|                                                            | Winter 83-85 vs. 86-88  | 29 | NS                          |
| Species Evenness                                           | 6/83-4/86 vs. 5/86-9/89 | 72 | $p < 0.01$                  |
|                                                            | Summer 83-85 vs. 86-89  | 41 | $p < 0.05$                  |
|                                                            | S 83/87                 | 10 | $p < 0.05$                  |
|                                                            | S 85/87                 | 11 | $p < 0.05$                  |
|                                                            | Winter 83-85 vs. 86-88  | 29 | $p < 0.05^*$                |
| *No significant year to year comparisons.                  |                         |    |                             |
| *1985 transformed data failed Tukey's test for additivity. |                         |    |                             |
| Gross Primary Production                                   | 7/84-8/85 vs. 6/86-8/89 | 44 | NS                          |

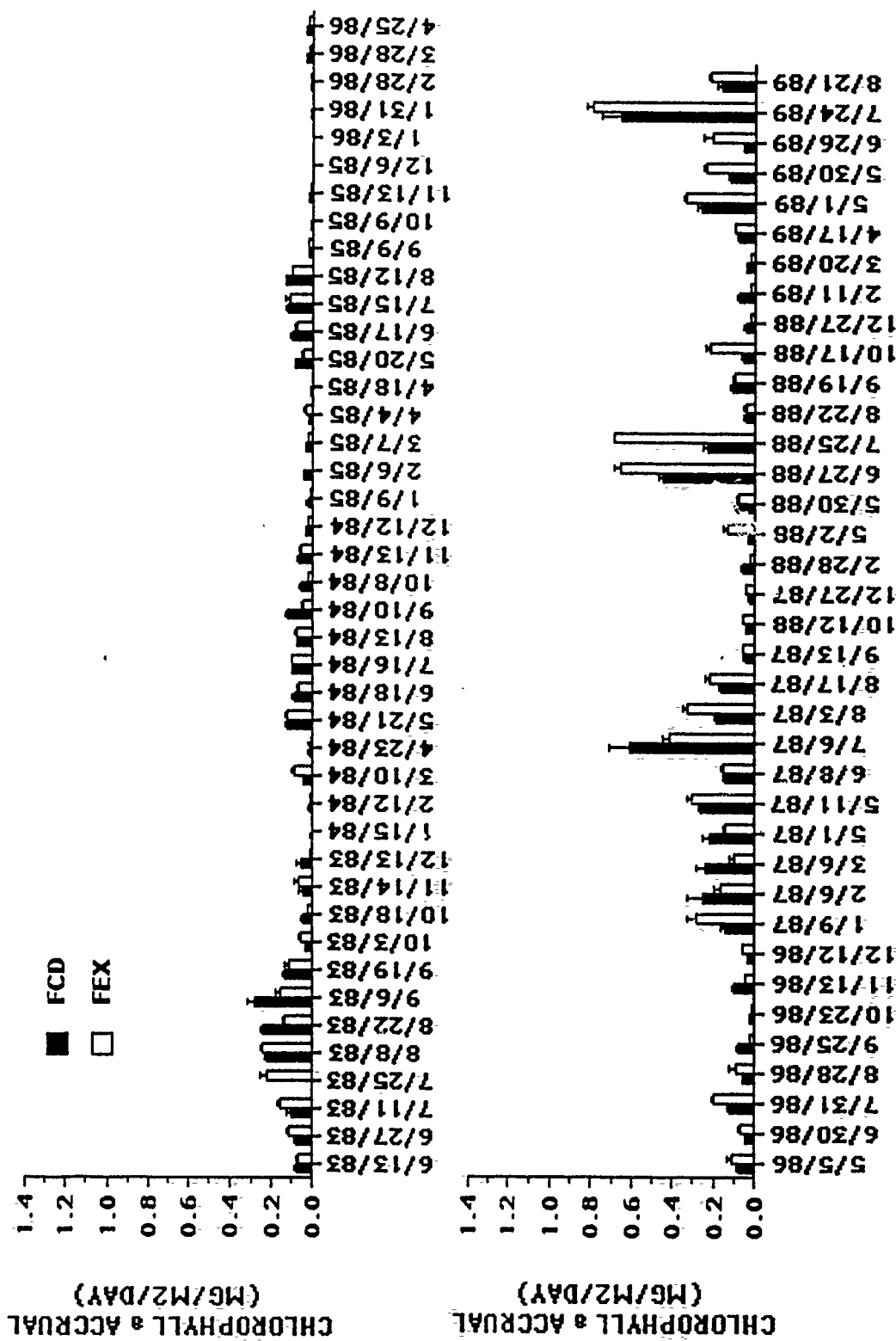


FIGURE 2.2 ACCRETION RATES OF CHLOROPHYLL a FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1989.

Table 2.7 Daily accrual rates of chlorophyll *a* (mg/m<sup>2</sup>/d) and AFDW-Biomass (mg/m<sup>2</sup>/d) for Control (FCD) and Experimental (FEX) sites on the Ford River. Values are Means  $\pm$  S.E., N in parentheses.

| Date     | Chlorophyll <i>a</i>   |                        | AFDW-Biomass        |                     |
|----------|------------------------|------------------------|---------------------|---------------------|
|          | Experimental (FEX)     | Control (FCD)          | Experimental (FEX)  | Control (FCD)       |
| 3/19/88  | 0.101 $\pm$ 0.008 (10) | 0.109 $\pm$ 0.005 (10) | 34.0 $\pm$ 3.0 (10) | 35.0 $\pm$ 3.0 (10) |
| 10/17/88 | 0.212 $\pm$ 0.027 (10) | 0.058 $\pm$ 0.002 (10) | 17.0 $\pm$ 3.0 (10) | 17.0 $\pm$ 2.0 (3)  |
| 12/27/88 | 0.018 $\pm$ 0.002 (25) | 0.046 $\pm$ 0.005 (20) | 4.0 $\pm$ 3.0 (24)  | 5.0 $\pm$ 1.0 (18)  |
| 2/11/89  | 0.020 $\pm$ 0.004 (25) | 0.079 $\pm$ 0.006 (26) | 19.0 $\pm$ 2.0 (25) | 10.0 $\pm$ 1.0 (25) |
| 3/20/89  | 0.026 $\pm$ 0.001 (22) | 0.040 $\pm$ 0.003 (25) | 6.0 $\pm$ 1.0 (11)  | 9.0 $\pm$ 1.0 (25)  |
| 4/17/89  | 0.093 $\pm$ 0.008 (25) | 0.080 $\pm$ 0.007 (25) | 14.0 $\pm$ 2.0 (24) | 9.0 $\pm$ 1.0 (25)  |
| 5/1/89   | 0.333 $\pm$ 0.018 (10) | 0.263 $\pm$ 0.023 (10) | 19.0 $\pm$ 2.0 (10) | 19.0 $\pm$ 3.0 (10) |
| 5/30/89  | 0.234 $\pm$ 0.014 (10) | 0.118 $\pm$ 0.009 (10) | 22.0 $\pm$ 2.0 (10) | 12.0 $\pm$ 1.0 (14) |
| 6/26/89  | 0.204 $\pm$ 0.051 (10) | 0.049 $\pm$ 0.006 (10) | 23.0 $\pm$ 3.0 (10) | 16.0 $\pm$ 2.0 (9)  |
| 7/24/89  | 0.793 $\pm$ 0.031 (9)  | 0.651 $\pm$ 0.095 (10) | 49.0 $\pm$ 7.0 (10) | 41.0 $\pm$ 3.0 (10) |
| 8/21/89  | 0.216 $\pm$ 0.017 (10) | 0.167 $\pm$ 0.022 (10) | 29.0 $\pm$ 2.0 (10) | 39.0 $\pm$ 1.0 (10) |

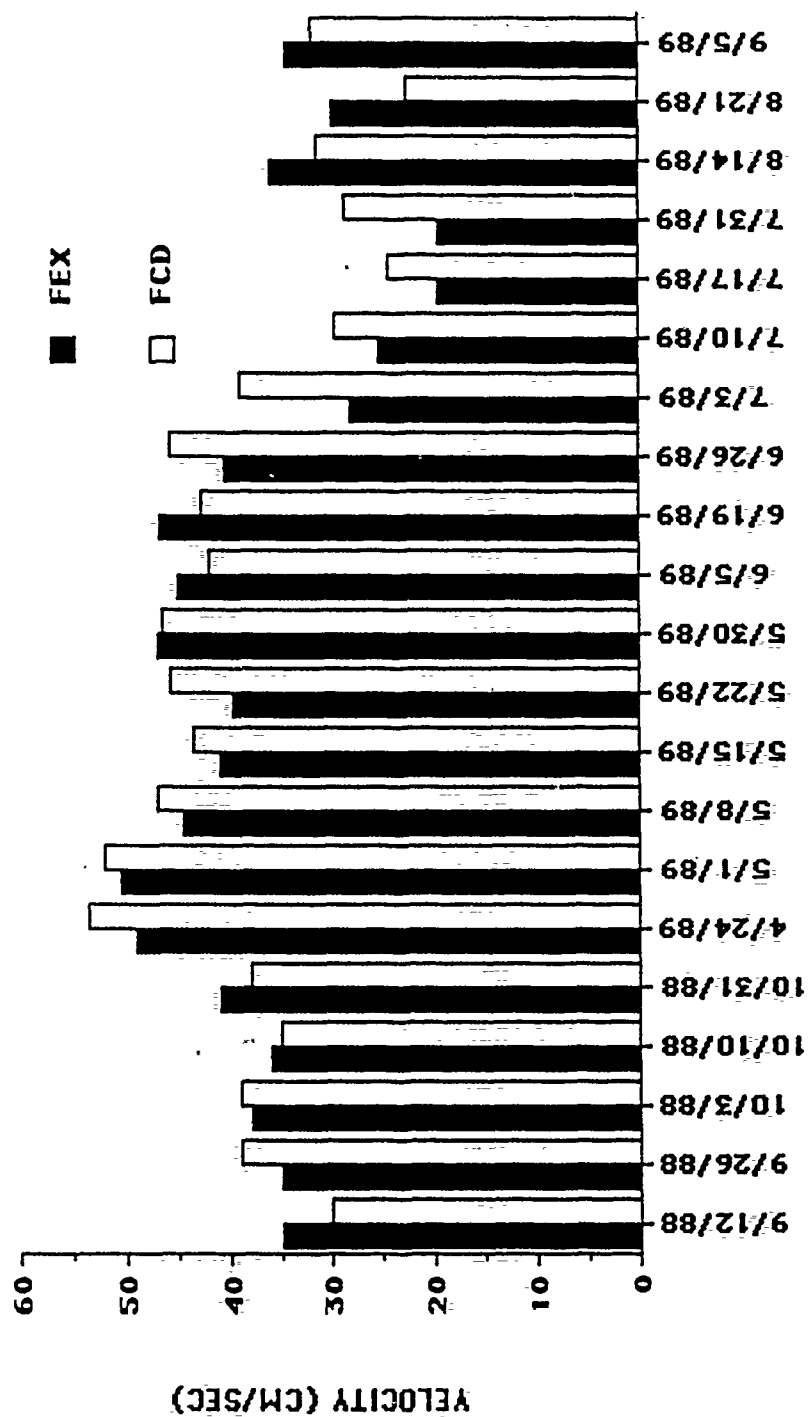


FIGURE 2.3 WATER VELOCITIES AT PERIPIYTON SAMPLERS FOR 1988-1989.

year). Once again, this may be related to weather differences between these years.

### C. Patterns of Organic Matter Accumulation

Organic matter measured as accumulation of ash free dry weight (AFDW) on glass slides generally followed the same trends in 1988-1989 as did chlorophyll a (Figs. 2.1, 2.4). The organic matter standing crop peaked in May and remained high throughout the summer (with the exception of June which was an unusually wet month) (Table 2.8). The pattern for the colder winter months was essentially the same for 1988 as for the previous winter periods.

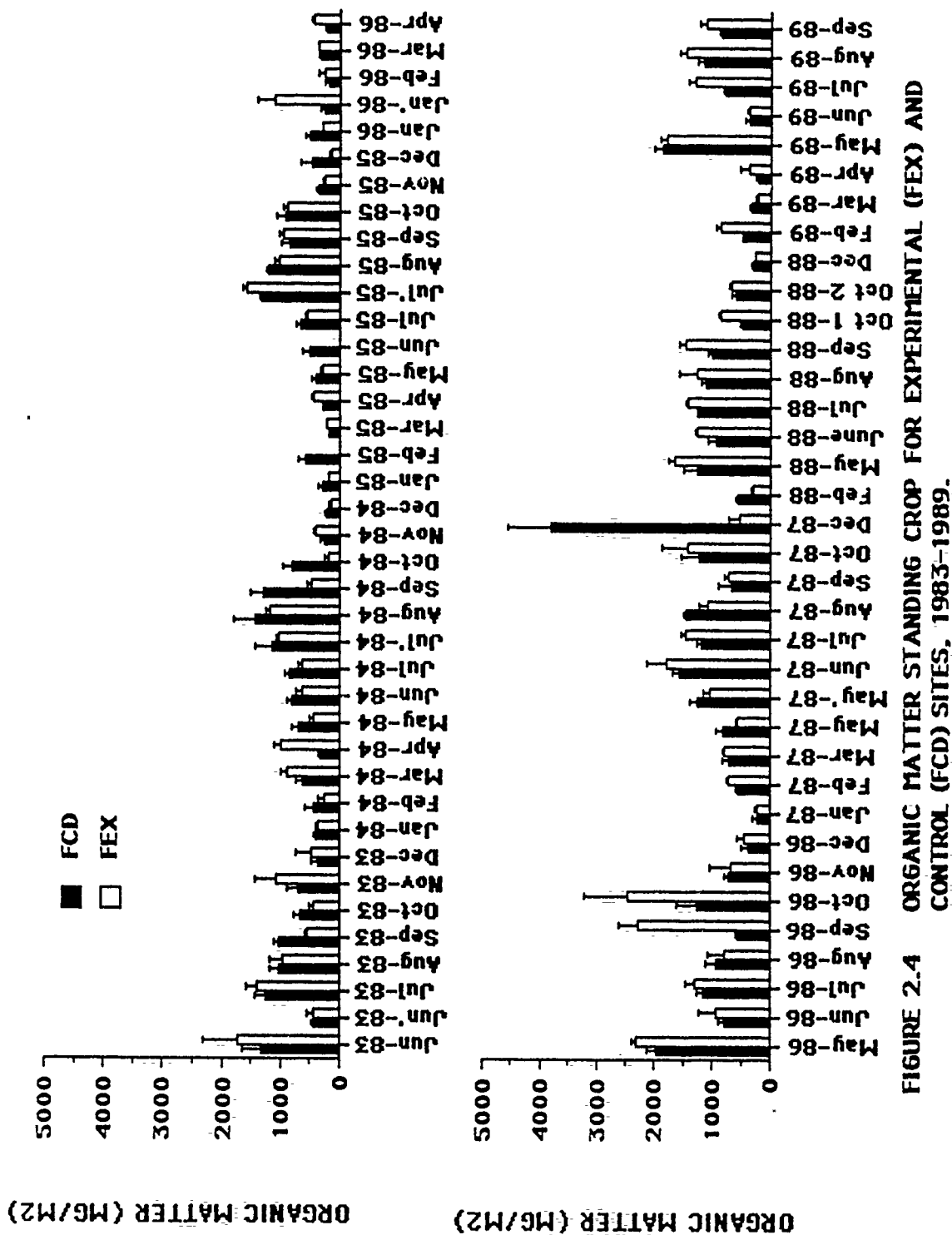
Paired t-tests between sites for AFDW-organic matter accumulation showed no significant differences for 1988-1989 data (Table 2.3) or for all the data taken since 1983 (Table 2.4). Correlations between both sites (Table 2.3) showed a significant correlation ( $r=.91$ ) in 1989 and for the entire data set (Table 2.4). The winter data sets do not correlate between sites. BACI analyses were conducted on AFDW-organic matter standing crop data (Table 2.6, A-3). The overall 6.5 year pooled comparison for AFDW mean differences for the 1983-86 "before" and 1986-89 "after" was found to be non-significant. The minimum detectable difference for AFDW-organic matter is 28% for the entire data set, 22% for the summer data set and 93% for the winter data set (Table 2.5). The high winter value is due to the high variability in our winter data sets which also accounts for the lack of a correlation between sites in the winter data sets (Table 2.4). The two sites tend to experience different winter conditions, ie; FEX tends to freeze over quicker than FCD and often will be frozen over while FCD remains open.

Stepwise multiple regression models generated for AFDW-organic matter at both sites for both the total and summer data sets were all significant (Table 2.2). However, little of the variance is explained in any of these models and no physical/chemical parameter consistently shows up in the models. Next year more variables will be included for model building (including some measure of electromagnetic radiation exposure).

Organic matter accrual rates (Table 2.7 and Fig. 2.5) were less variable between sites in 1988-89 than in previous years. The 2 sites were not significantly different and correlated well ( $r = 0.92$ ) (Table 2.3) in 1988-89 and overall (except for the winter data for reasons discussed above) (Table 2.4). BACI analysis on AFDW-organic matter accrual (Table 2.6, A-4) indicates that (as with AFDW accumulation) there are no differences in the between site relationship "before" and "after" testing began on the antenna in May of 1986.

Table 2.8      Ash Free Dry Weight Biomass (mg/m<sup>2</sup>)  
 from slides exposed for 28 days in the  
 Ford River. Values are Means  $\pm$  S.E., N  
 in parentheses.

| Date Out | Experimental (FEX)  | Control (FCD)       |
|----------|---------------------|---------------------|
| 10/3/88  | 870 $\pm$ 40 (2)    | 490 $\pm$ 50 (3)    |
| 10/31/88 | 690 $\pm$ 30 (10)   | 610 $\pm$ 80 (7)    |
| 12/27/88 | 250 $\pm$ 20 (24)   | 290 $\pm$ 30 (18)   |
| 2/11/89  | 860 $\pm$ 80 (25)   | 480 $\pm$ 20 (25)   |
| 3/20/89  | 220 $\pm$ 30 (11)   | 330 $\pm$ 30 (25)   |
| 4/17/89  | 390 $\pm$ 120 (24)  | 240 $\pm$ 30 (25)   |
| 5/15/89  | 1780 $\pm$ 130 (10) | 1860 $\pm$ 140 (9)  |
| 6/12/89  | 370 $\pm$ 30 (10)   | 390 $\pm$ 50 (10)   |
| 7/10/89  | 1320 $\pm$ 90 (10)  | 790 $\pm$ 20 (10)   |
| 8/7/89   | 1460 $\pm$ 100 (9)  | 1150 $\pm$ 120 (10) |
| 9/5/89   | 1130 $\pm$ 100 (10) | 840 $\pm$ 60 (10)   |





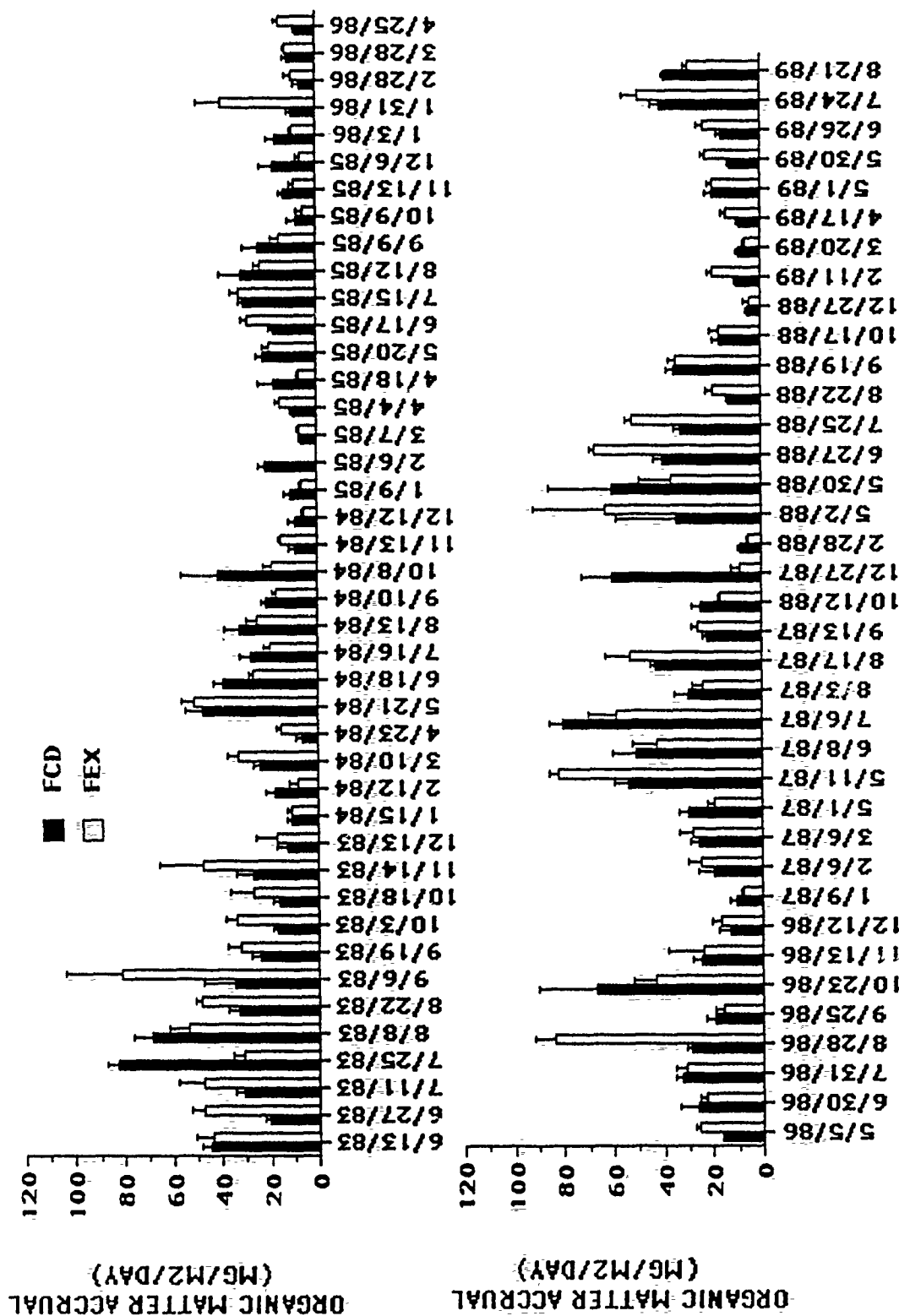


FIGURE 2.5 ACCRUAL RATES OF ORGANIC BIOMASS FOR EXPERIMENTAL (FEX) AND CONTROL (FCD) SITES, 1983-1989.

#### D. Patterns of Diatom Cell Density

Diatom cell density was characterized by wintertime low levels 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 and limited light penetration and water temperatures likely reduced the rate of photosynthesis and subsequent cell growth. The wintertime season, stretching from late October until April or even May, was a period characterized by diminished levels of periphyton production in terms of diatom density. Actual values ranged from  $10^7$  to  $10^8$  cells per square meter. The greatest periods of diatom production, as measured by cell density, were more sporadic and less predictable. The periods of highest cell density appeared to be most affected by the variations of climatic or environmental conditions or hydrologic changes. The highest monthly densities of cells were reported in August of 1983, June 1984, June 1985, May 1986, May 1987, May 1988 and May 1989 (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 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 1989, this peak density was for May and was followed by low densities in June (Fig. 2.6). The pattern exhibited for the remaining summer months is similar to that of 1987 and 1988. It appears that the most predictable pattern was for lowest cell densities in the winter and for greatest densities in the spring and/or summer (Fig. 2.6, Table 2.9).

The stepwise multiple regression models for cell density were all highly significant (Table 2.2). Silica appears to be the most important predictor of diatom density. From 52% to 99% of the explained variation is due to silica. Interestingly, cell density does not correlate with silica, and its major correlates (dissolved oxygen and water temperature - see the 1988 annual report) do not show up in the models. As silica is a major constituent of the diatom test, it's reasonable to expect silica concentrations to be low during the spring (Fig. 1.16) when diatom densities are high (Fig. 2.6) and high during the winter months when diatom densities are low.

In spite of the apparent high variability between years, paired t-tests showed that site differences in cell densities were not significant for 1988-89 (Table 2.3) or for all the data collected since 1983 (Table 2.4). Cell density for the two sites was also closely correlated (Tables 2.3, 2.4). BACI results from the overall 6.5 year

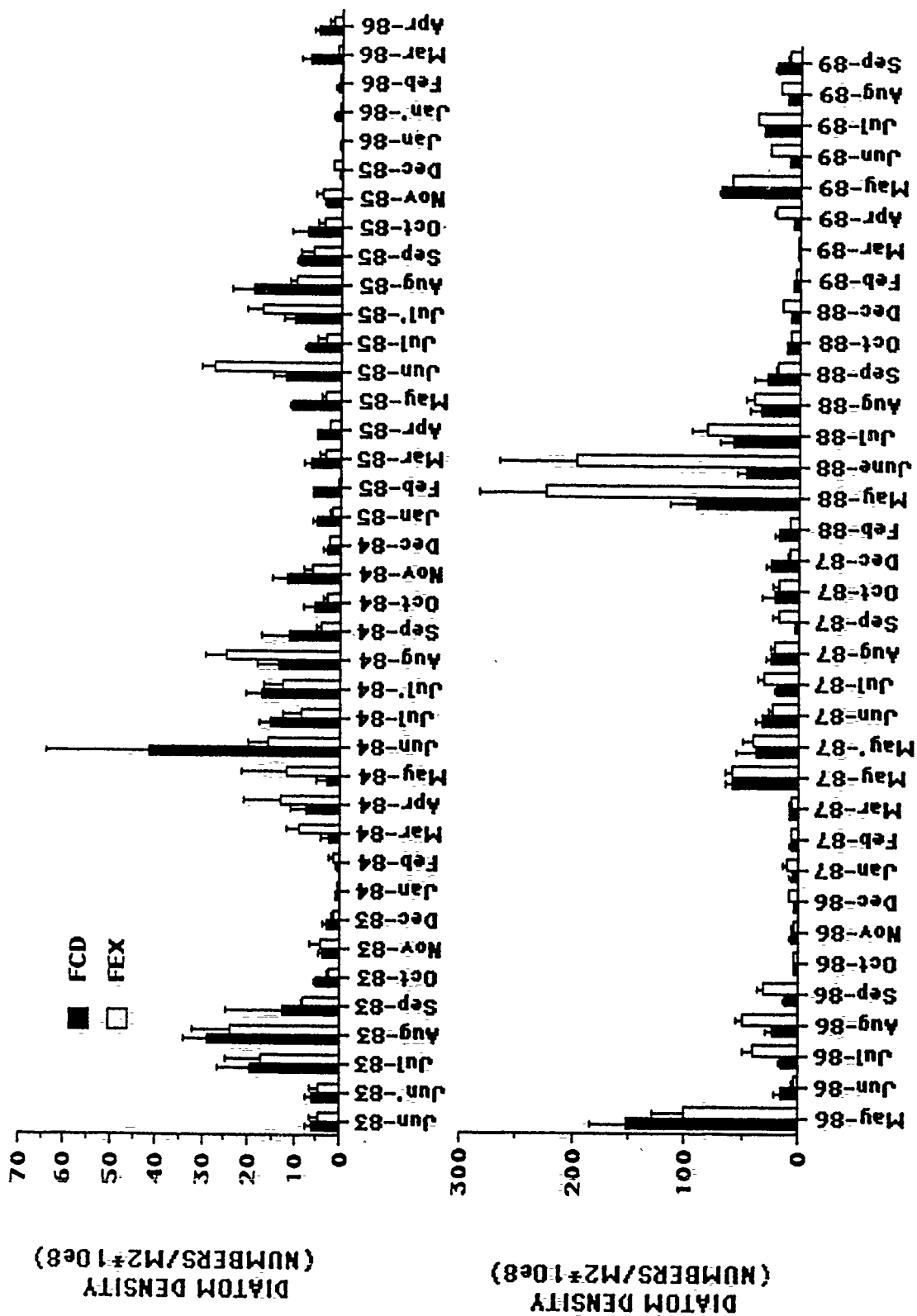


FIGURE 2.6 DIATOM CELL DENSITIES FOR THE FORD RIVER, 1983-89.

Table 2.9 Cell Density (Cells/m<sup>2</sup> x 10<sup>8</sup>) and Biovolume (cubic microns/m<sup>2</sup> x 10<sup>11</sup>) for Experimental (FEX) and Control (FCD) sites for 1988-89. Values are Means  $\pm$  S.E., N=3 except for 12/28 and 2/11 when N=6.

| Date     | Experimental (FEX) |                  | Control (FCD)    |                  |
|----------|--------------------|------------------|------------------|------------------|
|          | Density            | Biovolume        | Density          | Biovolume        |
| 10/3/88  | 8.12 $\pm$ 0.40    | 2.87 $\pm$ 0.53  | 10.83 $\pm$ 0.41 | 3.07 $\pm$ 0.09  |
| 12/28/88 | 15.08 $\pm$ 0.70   | 4.63 $\pm$ 0.24  | 7.72 $\pm$ 0.24  | 1.66 $\pm$ 0.10  |
| 2/11/89  | 3.56 $\pm$ 0.33    | 0.88 $\pm$ 0.10  | 5.11 $\pm$ 0.46  | 1.42 $\pm$ 0.14  |
| 3/20/89  | 2.06 $\pm$ 0.03    | 0.46 $\pm$ 0.01  | 2.39 $\pm$ 0.33  | 0.49 $\pm$ 0.06  |
| 4/17/89  | 21.04 $\pm$ 1.19   | 3.89 $\pm$ 0.30  | 5.65 $\pm$ 0.21  | 1.47 $\pm$ 0.06  |
| 5/15/89  | 60.18 $\pm$ 0.13   | 14.45 $\pm$ 0.13 | 69.47 $\pm$ 2.87 | 13.85 $\pm$ 1.13 |
| 6/12/89  | 26.64 $\pm$ 0.86   | 9.24 $\pm$ 2.85  | 9.05 $\pm$ 0.30  | 2.15 $\pm$ 0.04  |
| 7/10/89  | 37.32 $\pm$ 1.34   | 7.69 $\pm$ 0.82  | 31.33 $\pm$ 1.75 | 7.00 $\pm$ 0.39  |
| 8/7/89   | 16.44 $\pm$ 0.50   | 3.97 $\pm$ 0.23  | 11.76 $\pm$ 0.34 | 2.70 $\pm$ 0.06  |
| 9/5/89   | 9.70 $\pm$ 0.87    | 2.25 $\pm$ 0.24  | 20.89 $\pm$ 1.34 | 4.70 $\pm$ 0.58  |

cell density data, however, showed a significant difference between "before" (6/83-4/86) and "after" (5/86-9/89) periods (Table 2.6, A-5). Further analysis suggested that the summer variations was responsible for this significant result. We suspect that the greater impact of the 1988 drought at FEX caused this significance. Individual comparisons of mean differences for S 83/88, S 84/88, and S 85/88, all involving last year's data, were either significant ( $p < .05$ ), or close to being significantly different (Table 2.6 and A-5). Cell density is highly variable between the sites (Fig. 2.6) resulting in a rather large (appx. 60%) minimum detectable difference (Table 2.5).

#### E. Patterns in Individual Cell Volume and Total Biovolume

Individual cell volumes for the 6.5 year period (Fig. 2.7) were characterized by a trend towards larger volumes of diatoms in the periphyton occurring during the colder, winter months of November through March and smaller diatoms occurring during the summer months. The 1987-88 cell volume data did not follow this pattern however. Following the dramatic rise in mean cell volume during the winter of 1986 associated with dominance by Synedra and Diatoma, values dropped off during the spring-summer and did not increase over winter 1987 or 1988 as they had done in the past (Fig. 2.7, Table 2.10). These differences were related to differences in dominance for the algal community as will be described in detail below.

A paired t-test showed that mean cell volume was not significantly different between sites (Table 2.3) for either 1988-89 or all data collected since 1983 (Table 2.4). Mean cell volume at FEX in 1989 was not significantly correlated with mean cell volume at FCD (Table 2.3) despite the fact that they were highly correlated when all data collected since 1983 were considered (Table 2.4). BACI comparisons of cell volume showed that "before" data were not different from "after" data either on an overall basis or for any summer or winter season comparisons (Table 2.6). However, since the "before" data was not additive for most of these comparisons (Appendix A, Table A-6), the t-test cannot be considered valid (Stewart-Oaten 1986). Although cell volume is fairly variable between years (Fig. 2.7), it remains fairly consistent between sites resulting in a relatively low (appx. 20%) minimum detectable difference (Table 2.5).

Cell volume was correlated with water temperature in last years correlation matrix. Water temperature appears as a consistent predictor of cell volume in the stepwise multiple regression models (Table 2.2), accounting for 57 to 94 % of the explained variance. In the one case where water

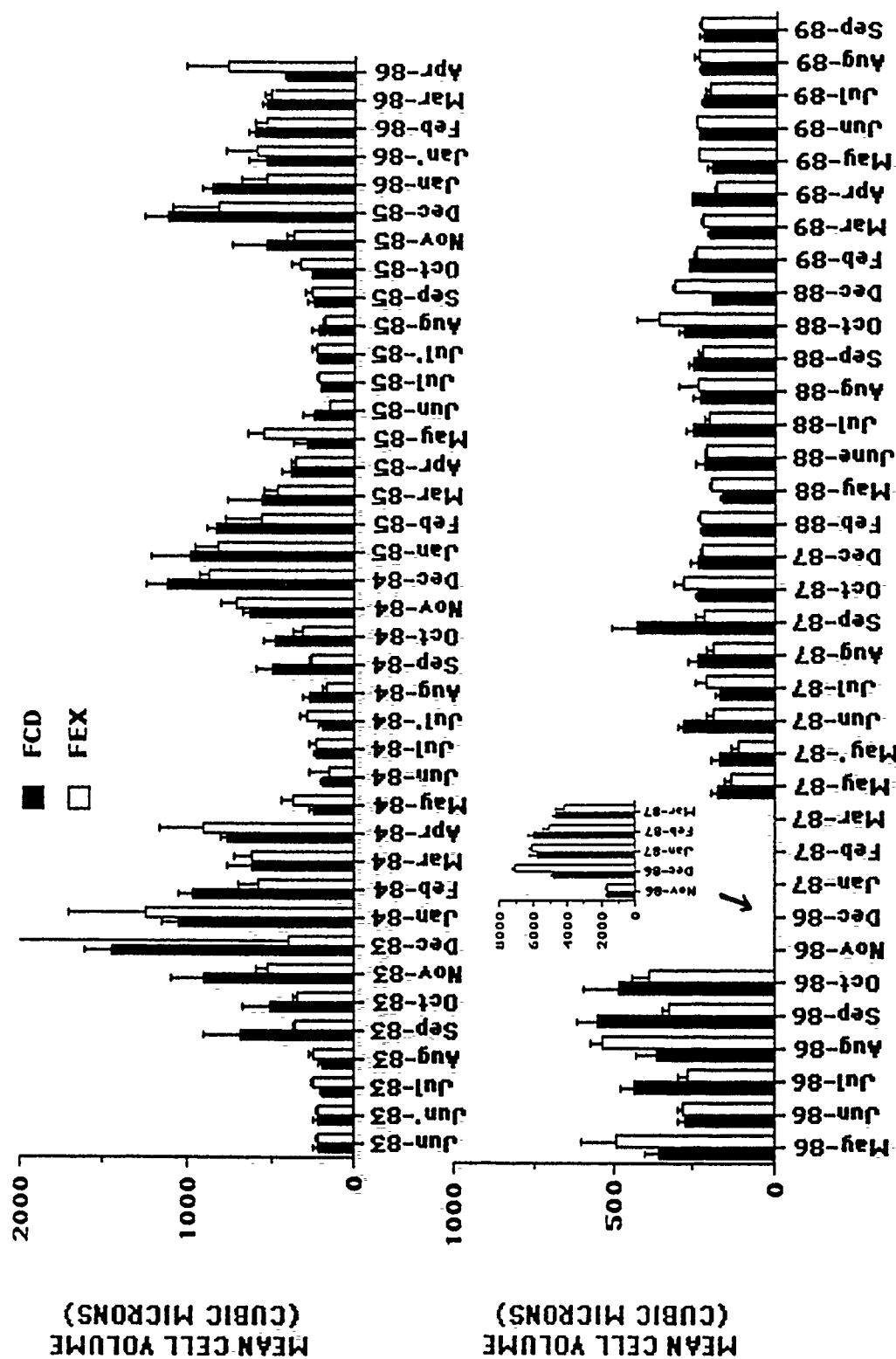


FIGURE 2.7 INDIVIDUAL CELL SIZES FOR THE FORD RIVER, 1983-89.

Table 2.10      Average Individual Diatom Cell  
Volume (microns<sup>3</sup>) for  
Experimental (FEX) and Control  
(FCD) sites for 1988-89. Values  
are Means  $\pm$  S.E., N=3 except for  
12/28 and 2/11 when N=6.

| Date     | Experimental (FEX) | Control (FCD)      |
|----------|--------------------|--------------------|
| 10/3/88  | 356.20 $\pm$ 72.00 | 283.70 $\pm$ 12.90 |
| 12/28/88 | 306.90 $\pm$ 8.00  | 195.70 $\pm$ 4.10  |
| 2/11/89  | 244.70 $\pm$ 8.60  | 267.40 $\pm$ 3.00  |
| 3/20/89  | 225.70 $\pm$ 3.50  | 207.60 $\pm$ 4.00  |
| 4/17/89  | 184.30 $\pm$ 4.80  | 259.10 $\pm$ 2.00  |
| 5/15/89  | 240.10 $\pm$ 1.80  | 199.60 $\pm$ 9.50  |
| 6/12/89  | 243.20 $\pm$ 4.50  | 237.10 $\pm$ 4.10  |
| 7/10/89  | 205.10 $\pm$ 14.20 | 223.80 $\pm$ 8.30  |
| 8/7/89   | 241.10 $\pm$ 10.00 | 230.50 $\pm$ 11.40 |
| 9/5/89   | 231.10 $\pm$ 7.70  | 223.50 $\pm$ 13.00 |

temperature does not enter the model (FCD total), dissolved oxygen (which is a function of water temperature) accounts for 96% of the explained variance.

Total biovolume for 1989 was highest in May but did not reach the levels experienced in 1986-88 (Fig. 2.8, Table 2.9). The biovolume levels for 1989 remain high, maintaining the trend of the past few years. 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. The large biovolume peak observed during the 1986-87 winter has not been repeated since due to the absence of the large species, Synedra ulna. The low densities, combined with low average cell volumes produced more typical biovolumes for the winter of 1988-89 (Fig. 2.8).

A comparison of total biovolume between sites with the paired t-test showed that biovolume at FEX was not significantly different ( $p < 0.05$ ) from biovolume at FCD either for the 1988-89 data (Table 2.3) or for all data collected since 1983 (Table 2.4). Biovolume at FEX was significantly ( $p < 0.05$ ) correlated with biovolume at FCD both in 1988-89 (Table 2.3) and for all the data collected since 1983 (Table 2.4). BACI comparisons of biovolume showed that there is a significant difference in the between site relationship "before" and "after" May 1986 (Table 2.6, A-7). This difference can be attributed to the fact that during the winters of 1984 and 85 FCD biovolume was consistently higher than FEX biovolume, which is not true for the years 1986 and 88. The high variability in between site differences (Fig. 2.8) probably accounts for the high minimum detectable difference in biovolume (Table 2.5).

The stepwise multiple regression models (Table 2.2) explain only a small portion of the variance, with silica accounting for most of that explanation. This is expected since total biovolume is computed from density, and silica was the best predictor of density.

#### F. Patterns of Species Diversity and Species Evenness

Changes in species community composition may reflect the effects of a host of environmental variables, such as changing light levels, increasing or decreasing water currents, or changing water temperatures that may act individually or synergistically to change the abundance of various algal species. The presence or absence of particular diatom species has been used as an indicator of potential pollution (Patrick 1966). Comparing the changes in the periphyton community through the use of a species



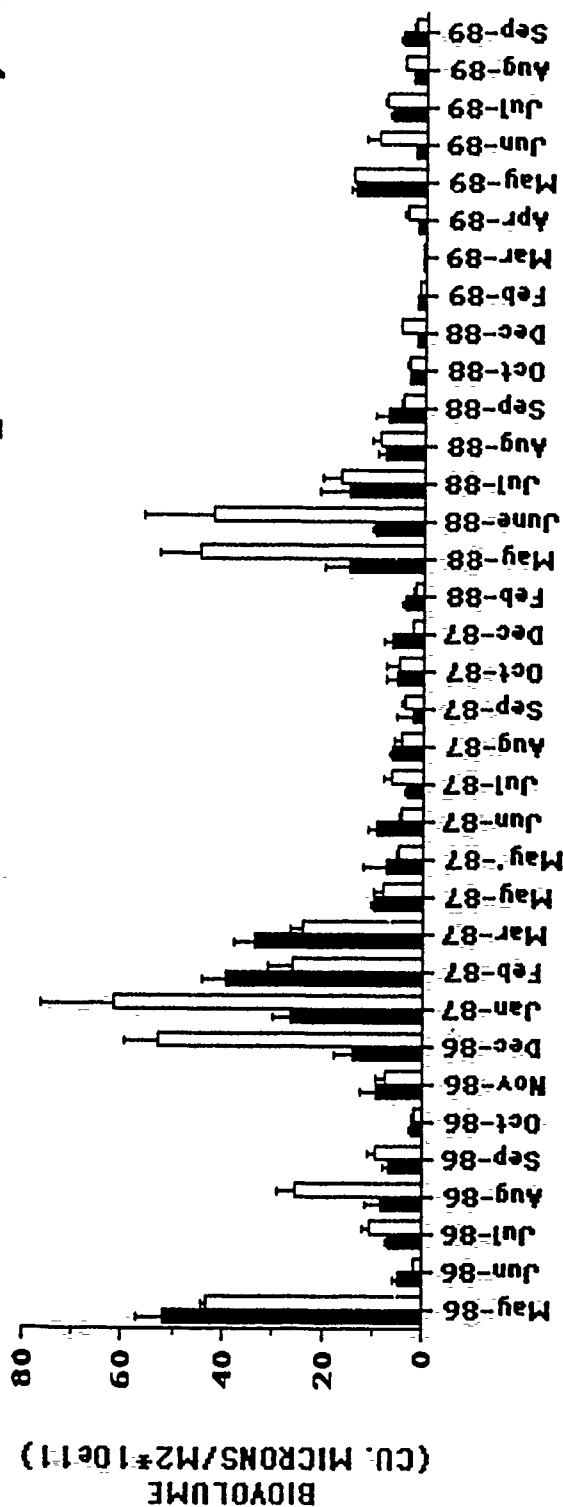
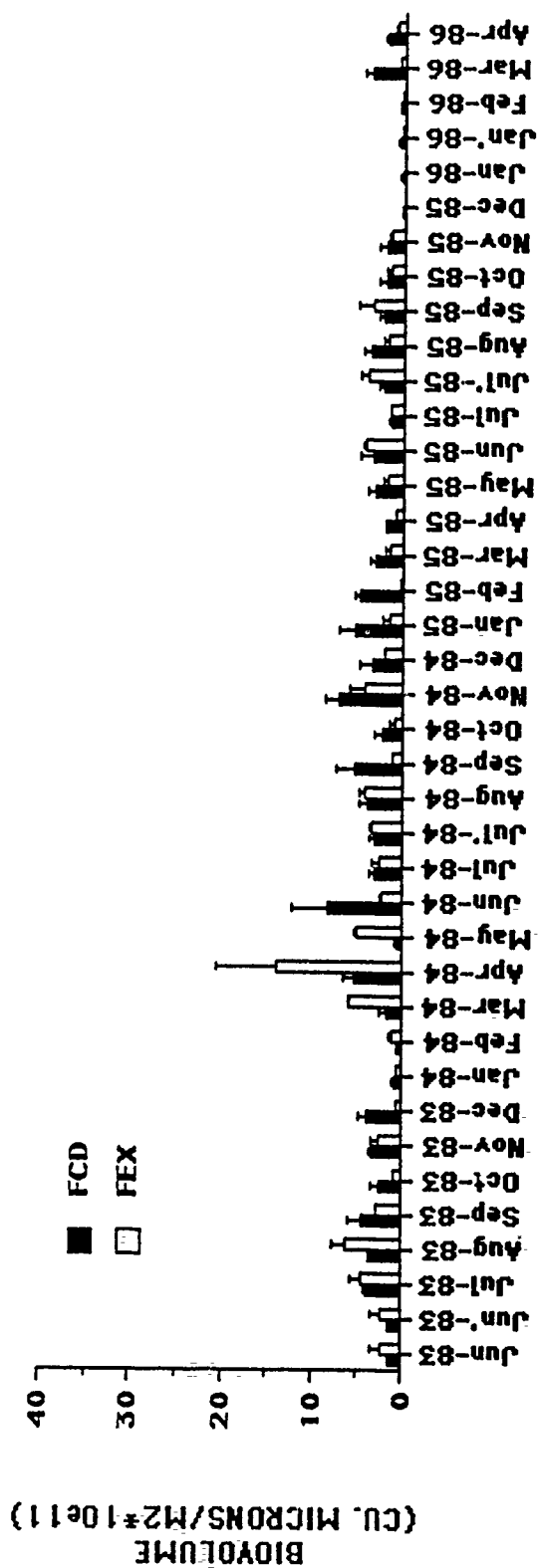


FIGURE 2.8 DIATOM BIOVOLUME FOR THE FORD RIVER 1983-89.

diversity index and a species evenness index will measure the extent of changes in number of species and the distribution of individuals within that community. Such indices may indicate potentially subtle shifts in community structure which are often unnoticed using other tests, such as chlorophyll a , organic biomass levels, or cell densities.

The pattern in the Shannon Wiener diversity index ( $H'$ ) and the evenness index ( $J'$ ) over the entire period from 1983 to 1989 (Figs. 2.9, 2.10, Table 2.11) 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. This pattern did not appear in 1988-1989. We have no explanation for this but, as the values were similar at both sites, we do not suspect that ELF exposures caused this change in pattern.

The pattern of winter highs and summer lows for diversity and evenness corresponded with predictable patterns in species abundance. During the summers from 1983 to 1988, only Achnanthes minutissima and Cocconeis placentula have ever achieved dominance greater than 10 % (Fig. 2.11; see also 1988 annual report Fig. 2.11). Typically, Achnanthes was the dominant species in May and June, until Cocconeis dominance increased in July and August. Achnanthes would then increase in dominance again in September and October as the abundance of Cocconeis declined (Fig. 2.12, 2.13). The summer of 1989 was atypical in that Fragilaria vaucheriae appeared to be dominant for the period of May through September. This unusual dominance pattern for Fragilaria can be explained by its unusually high abundances (40 % dominance) during the month of May, 1989 (Fig. 2.14). This high abundance of Fragilaria at both sites during May inflated the summer 1989 mean % dominance to greater than 10 % (Fig. 2.11).

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 (see 1988 annual report, Fig. 2.11). The winter of 1988 followed this same dominance pattern, resulting in the typical pattern of high diversity and evenness (Figs. 2.9 and 2.10).

Non-dominant (< 10%) species such as Achnanthes lanceolata, Cocconeis pediculus, Cymbella minuta, Fragilaria construens and Synedra ulna have also responded in a predictable manner throughout the six year period (Figs. 2.15, 2.16, 2.17, 2.18, 2.19). These species can also be divided into species that achieve greatest dominance in

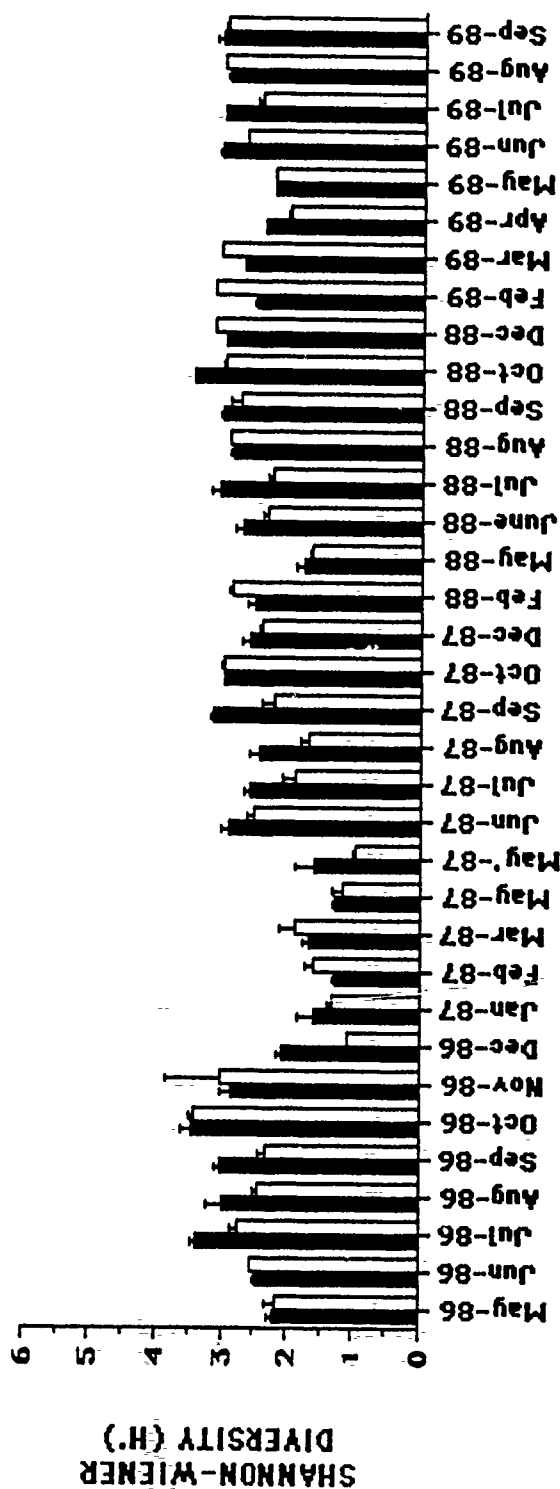


FIGURE 2.9 DIATOM SPECIES DIVERSITY FOR THE FORD RIVER 1983-89.

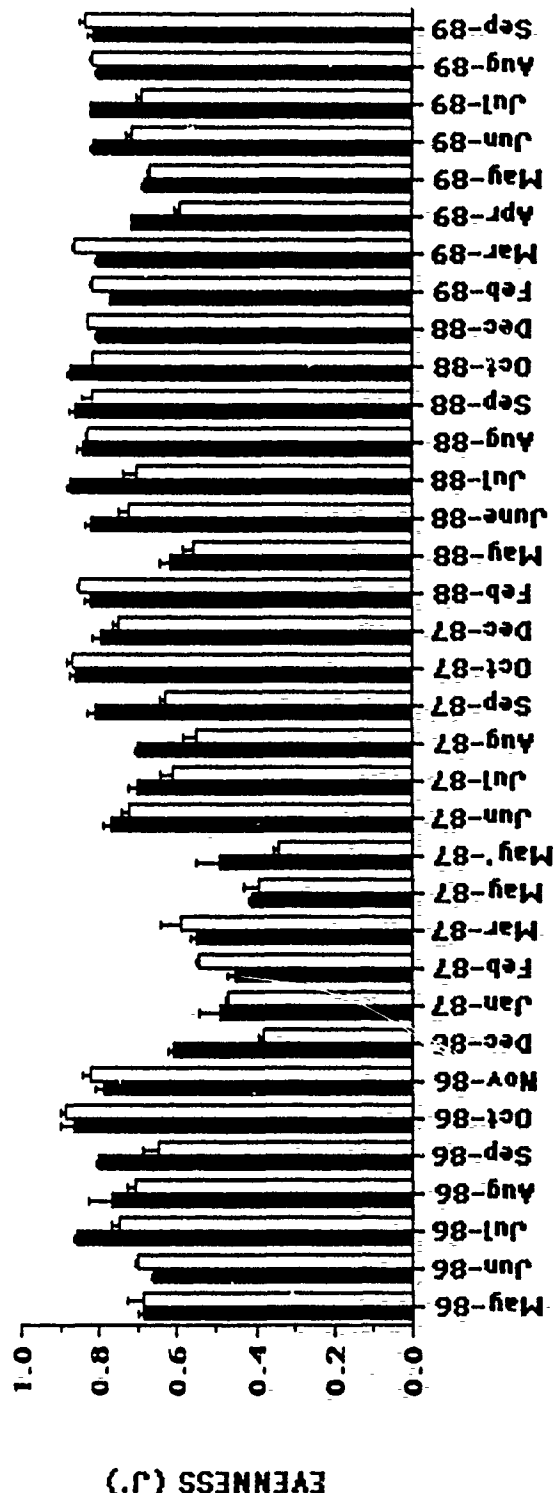
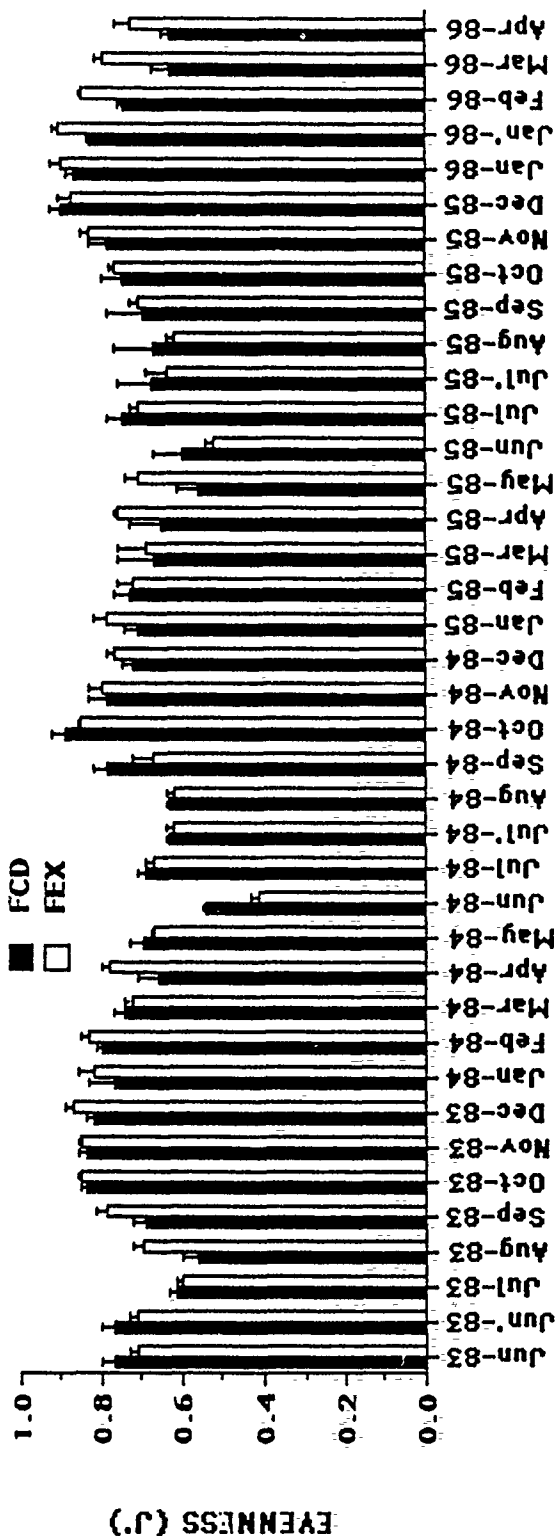
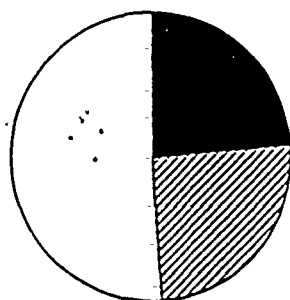


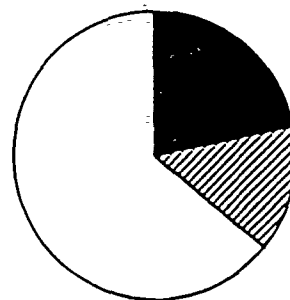
FIGURE 2.10 DIATOM SPECIES EVENNESS FOR THE FORD RIVER, 1983-89.

Table 2.11 Species Diversity (H') and Evenness (J') for Experimental (FEX) and Control (FCD) sites for 1988-89. Values are Mean  $\pm$  S.E., N=3 except for 12/28 and 2/11 when N=6.

| Date     | Experimental (FEX) |                 | Control (FCD)   |                 |
|----------|--------------------|-----------------|-----------------|-----------------|
|          | Diversity          | Evenness        | Diversity       | Evenness        |
| 10/3/88  | 2.99 $\pm$ 0.03    | 0.81 $\pm$ 0.00 | 3.45 $\pm$ 0.02 | 0.88 $\pm$ 0.01 |
| 12/28/88 | 3.13 $\pm$ 0.01    | 0.83 $\pm$ 0.01 | 2.98 $\pm$ 0.02 | 0.80 $\pm$ 0.00 |
| 2/11/89  | 3.12 $\pm$ 0.03    | 0.81 $\pm$ 0.01 | 2.52 $\pm$ 0.02 | 0.77 $\pm$ 0.00 |
| 3/20/89  | 3.05 $\pm$ 0.02    | 0.86 $\pm$ 0.01 | 2.71 $\pm$ 0.01 | 0.80 $\pm$ 0.00 |
| 4/17/89  | 1.98 $\pm$ 0.04    | 0.59 $\pm$ 0.01 | 2.38 $\pm$ 0.03 | 0.71 $\pm$ 0.01 |
| 5/15/89  | 2.22 $\pm$ 0.01    | 0.67 $\pm$ 0.01 | 2.22 $\pm$ 0.02 | 0.68 $\pm$ 0.01 |
| 6/12/89  | 2.65 $\pm$ 0.03    | 0.72 $\pm$ 0.01 | 3.07 $\pm$ 0.04 | 0.81 $\pm$ 0.01 |
| 7/10/89  | 2.44 $\pm$ 0.06    | 0.69 $\pm$ 0.01 | 3.02 $\pm$ 0.01 | 0.82 $\pm$ 0.00 |
| 8/7/89   | 3.01 $\pm$ 0.00    | 0.81 $\pm$ 0.01 | 2.95 $\pm$ 0.01 | 0.80 $\pm$ 0.01 |
| 9/5/89   | 2.98 $\pm$ 0.03    | 0.84 $\pm$ 0.01 | 3.07 $\pm$ 0.07 | 0.82 $\pm$ 0.01 |

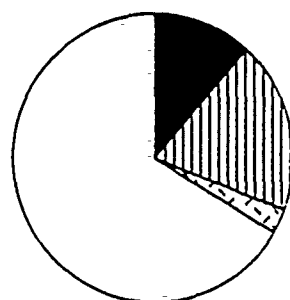


FEX

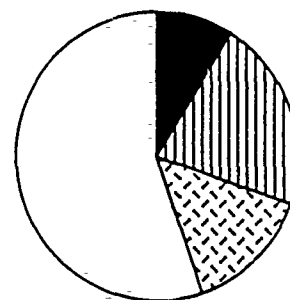


FCD

Summer 1988 (5/88-10/88)

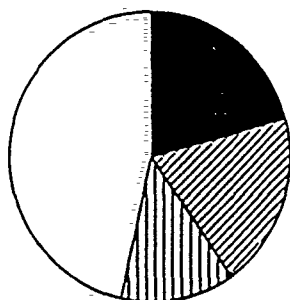


FEX

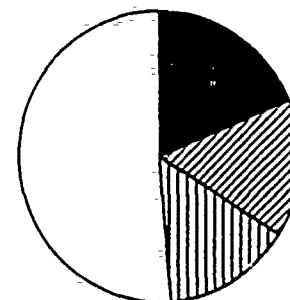


FCD

Winter 1988 (12/88-4/89)



FEX



FCD

Summer 1989 (5/89-9/89)

■ *Achnanthes minutissima*    ▨ *Fragilaria vaucheriae*    □ Other  
 ▩ *Cocconeis placentula*    ▤ *Gomphonema olivaceum*

FIGURE 2.11 Seasonal Percent Dominance for Experimental (FEX) and Control (FCD) Sites from the Ford River, 1983-89.

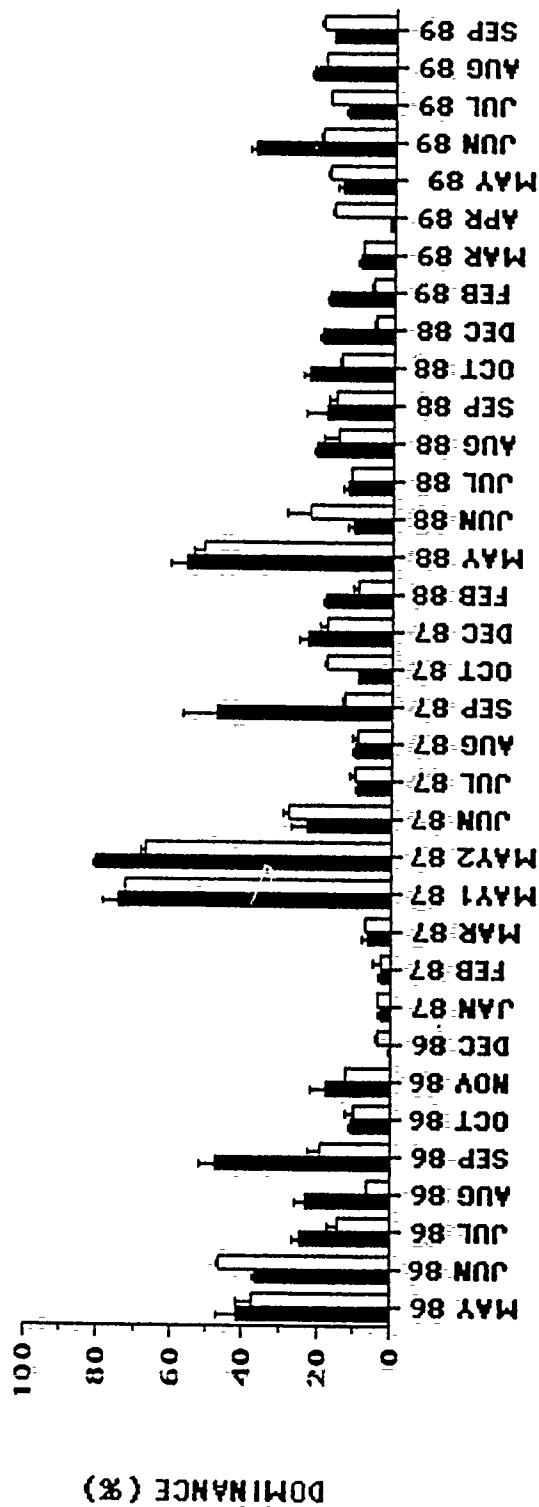
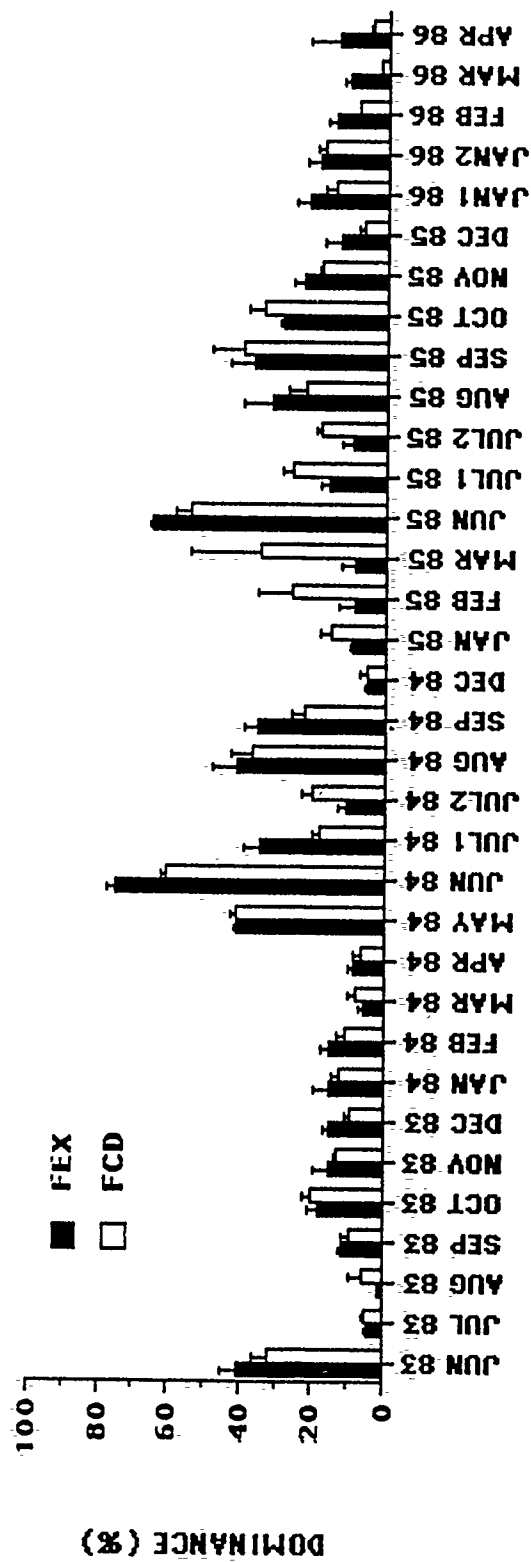


FIGURE 2.12 *Achnanthes minutissima* PERCENT DOMINANCE FOR THE FORD RIVER, 1983-89.

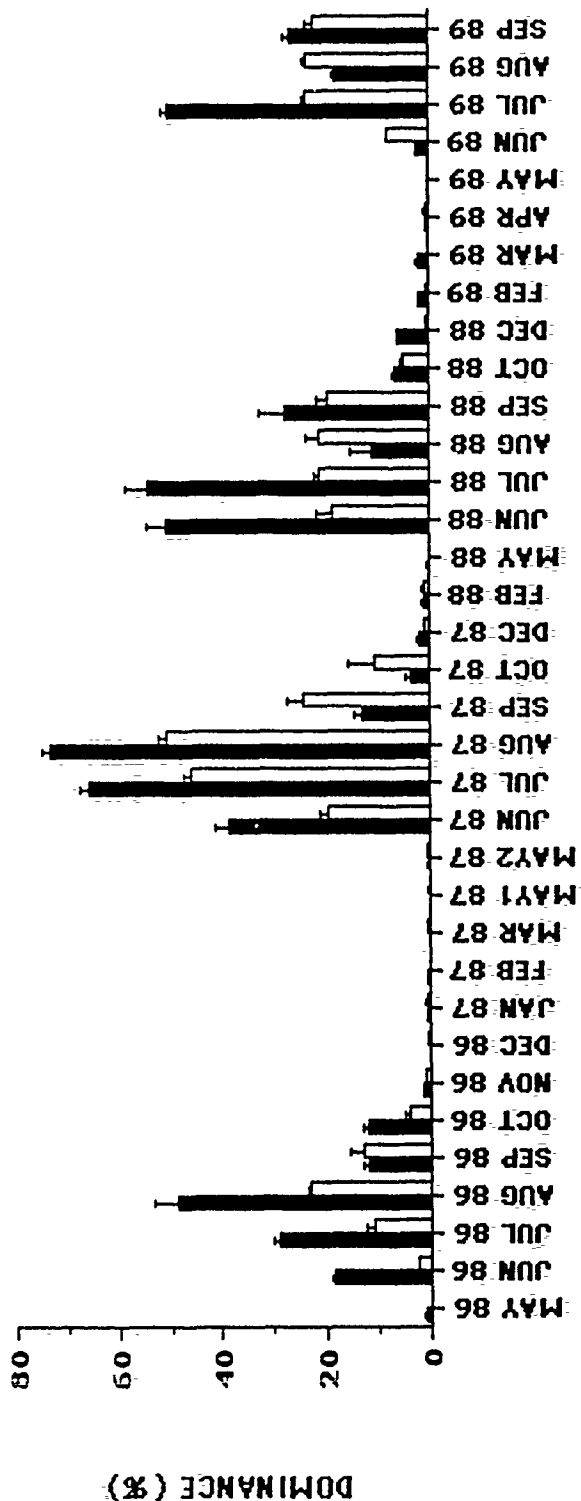
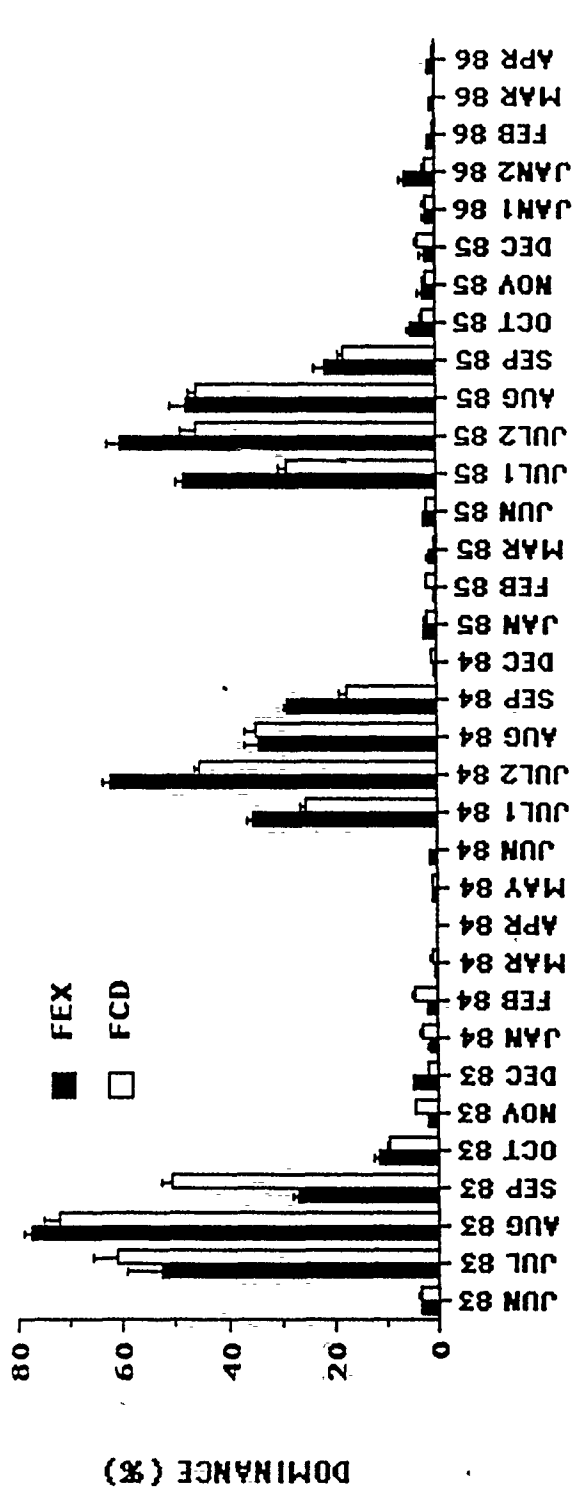


FIGURE 2.13 *Cocconeis placentula* PERCENT DOMINANCE FOR THE FORD RIVER, 1983-89.



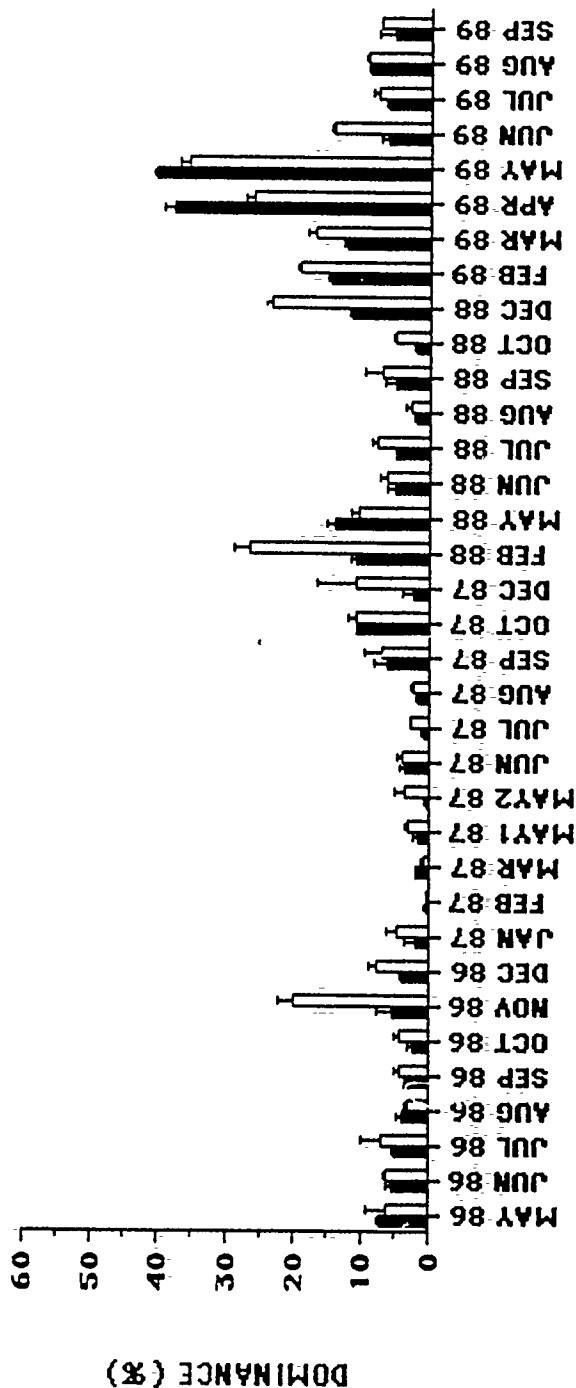
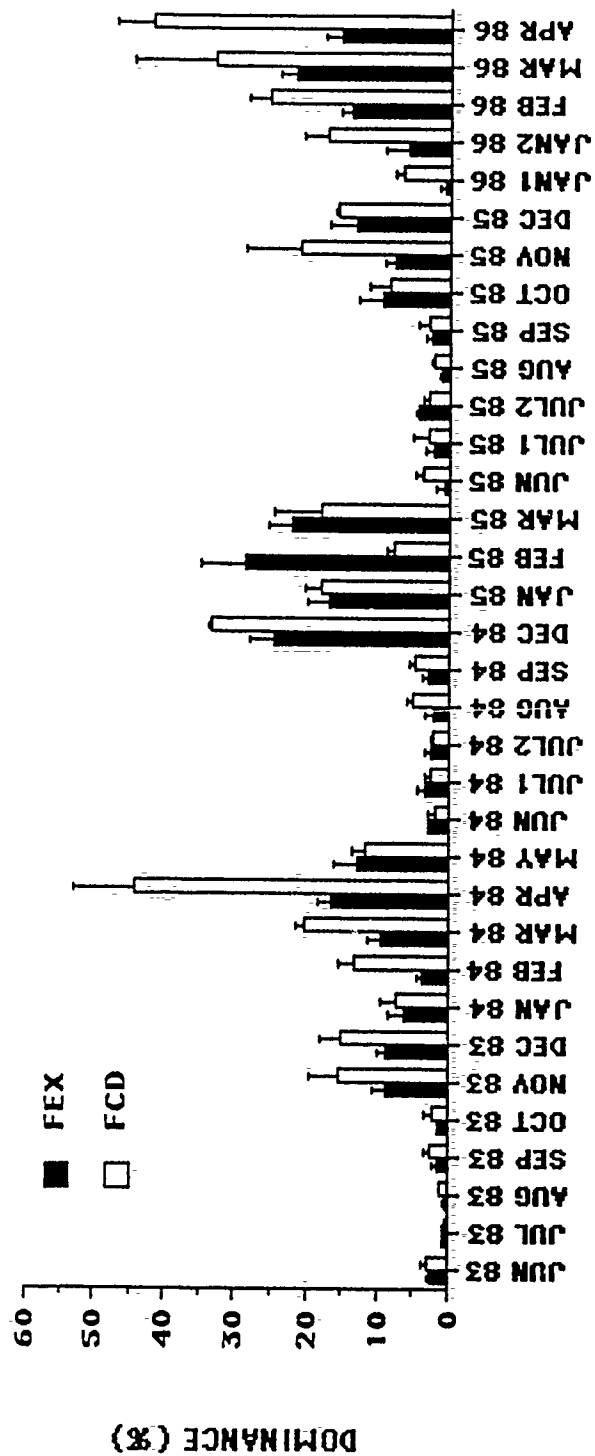


FIGURE 2.14 *Fragilaria vaucheriae* PERCENT DOMINANCE FOR THE FORD RIVER, 1983-89.

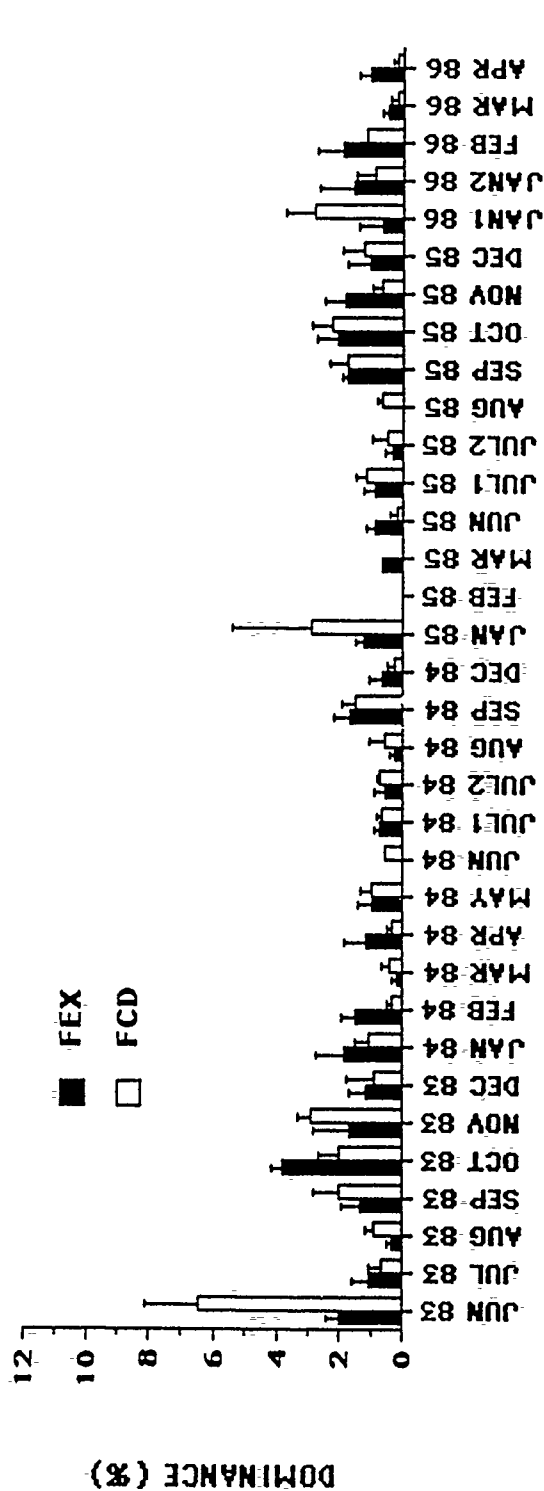


FIGURE 2.15 *Achnanthes lanceolata* PERCENT DOMINANCE FOR THE FORD RIVER, 1983-89.

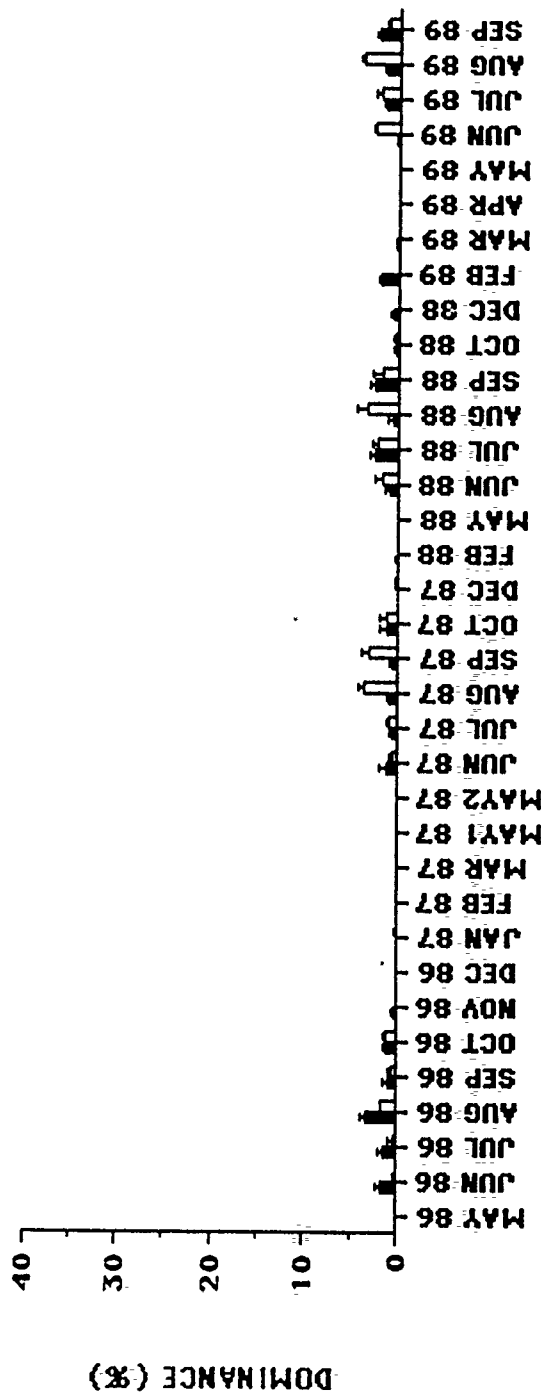
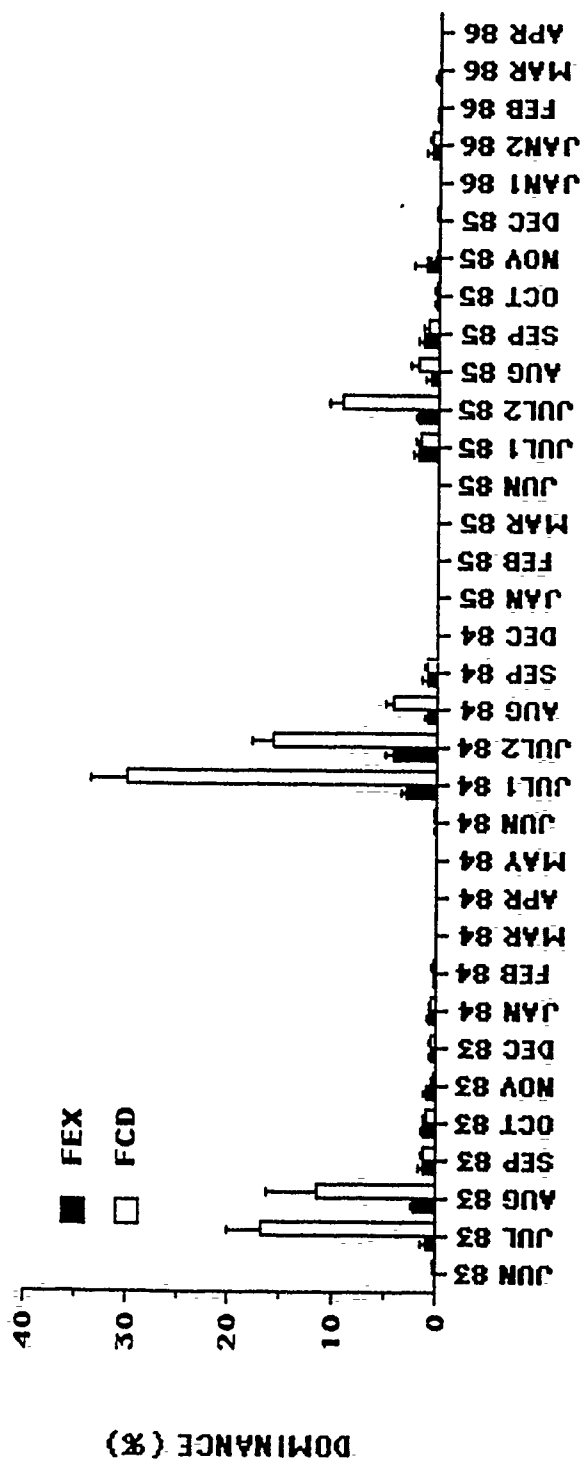


FIGURE 2.16 *Cocconeis pediculus* PERCENT DOMINANCE FOR THE FORD RIVER, 1983-89.

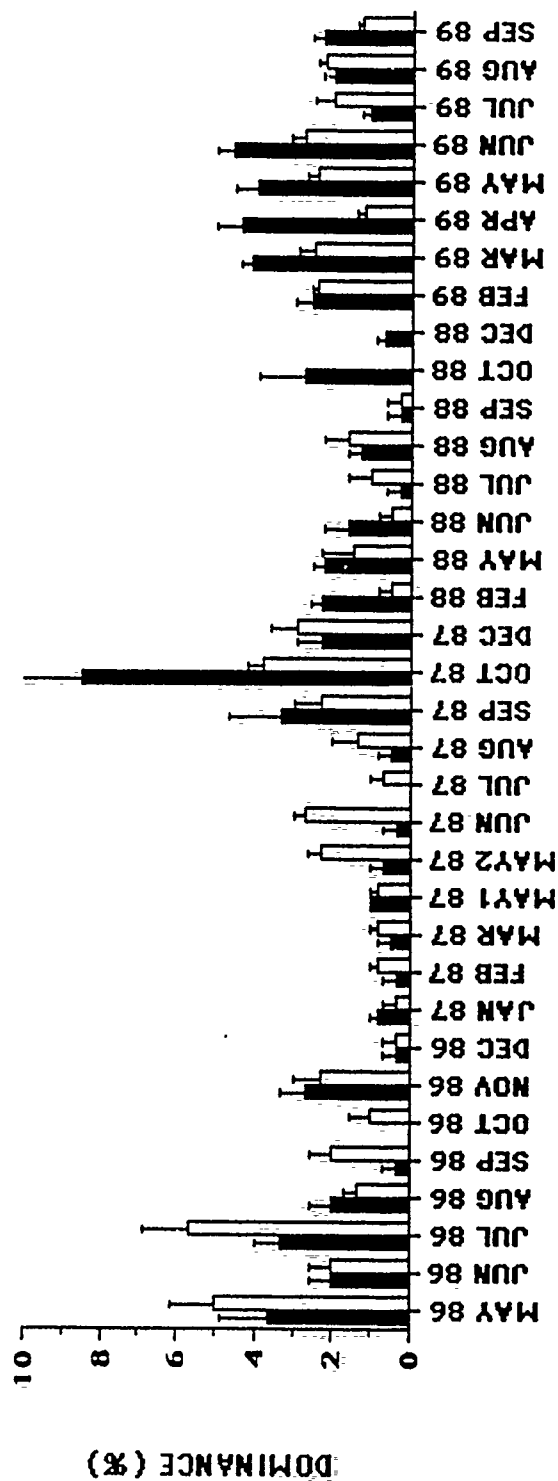
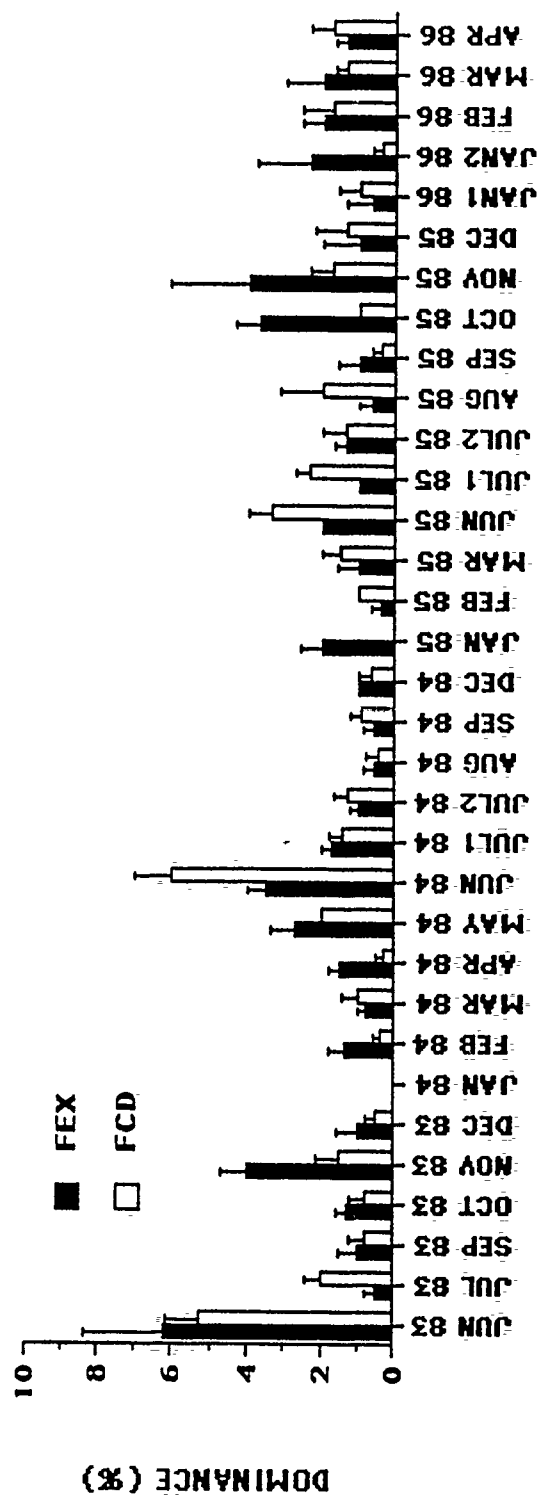


FIGURE 2.17 *Cymbella minuta* PERCENT DOMINANCE FOR THE FORD RIVER, 1983-89.

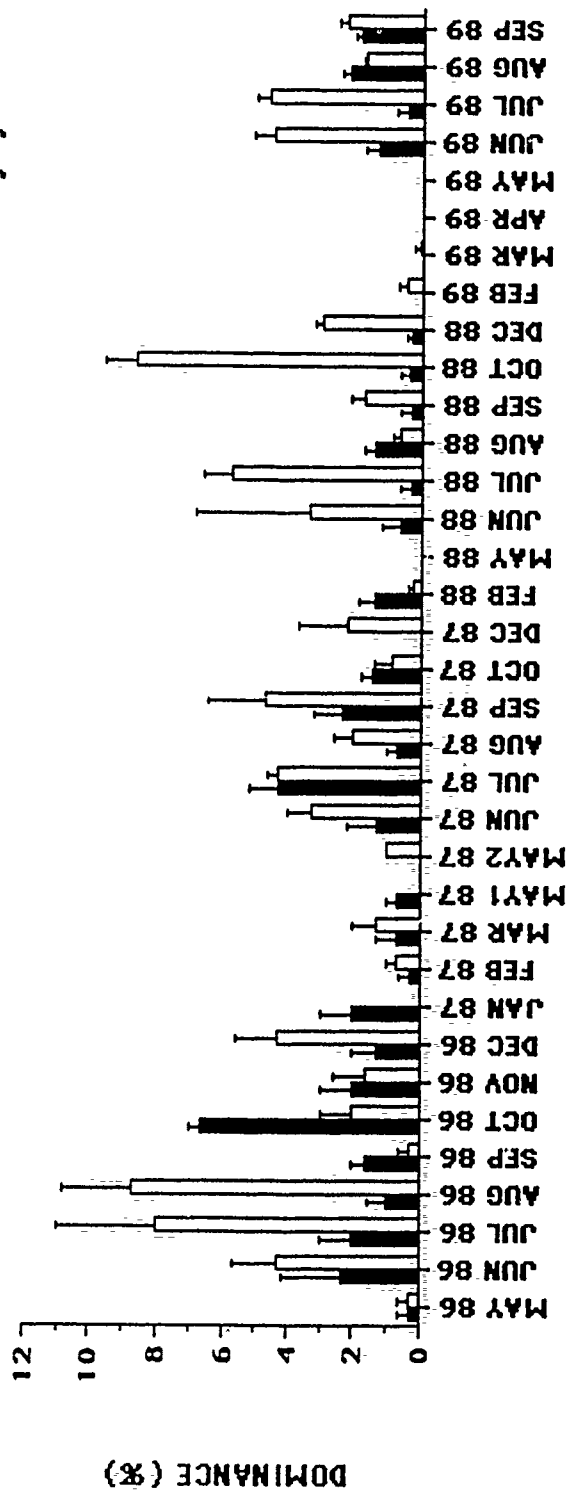
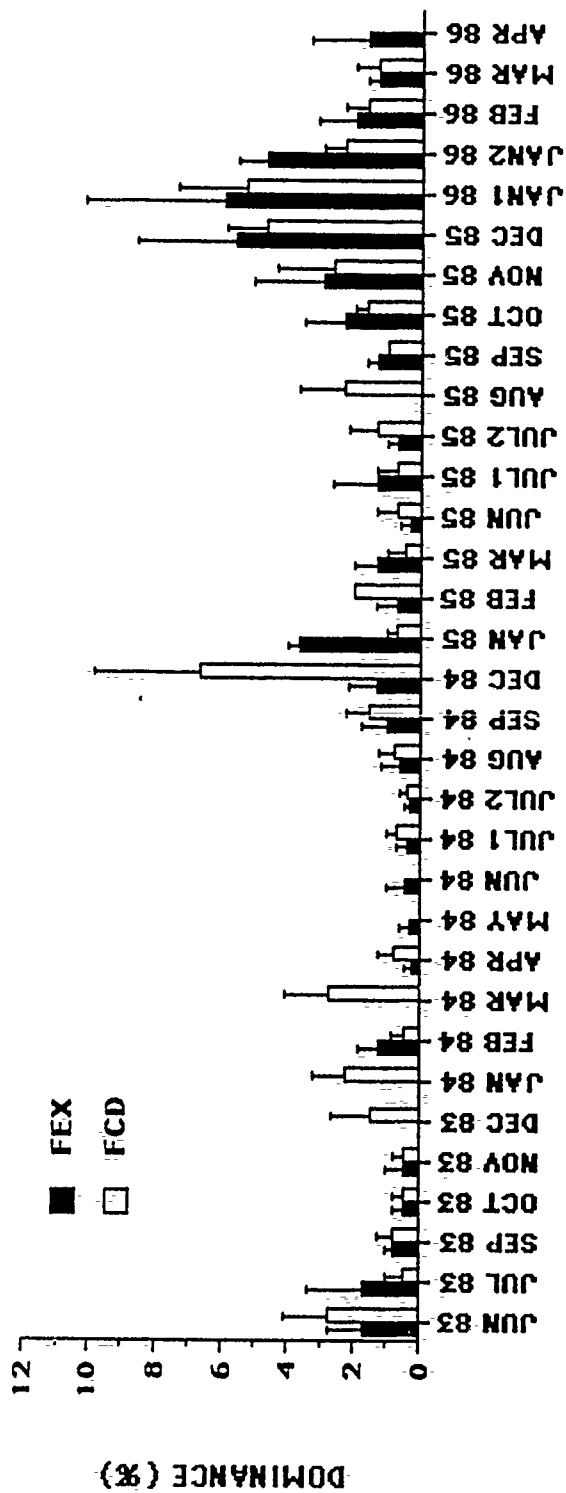


FIGURE 2.18 *Fragilaria construens* PERCENT DOMINANCE FOR THE FORD RIVER, 1983-89.

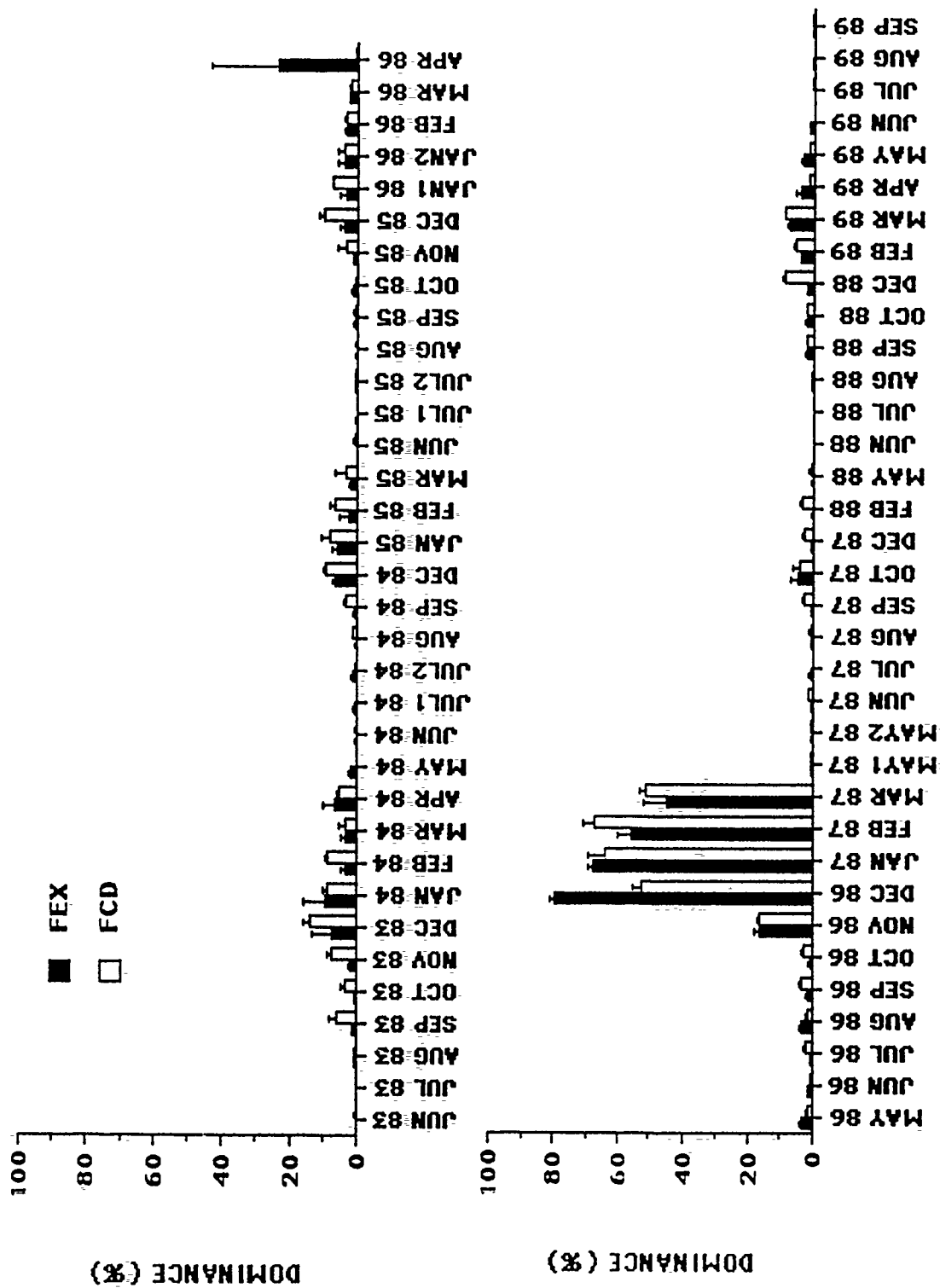


FIGURE 2.19 *Synedra ulna* PERCENT DOMINANCE FOR THE FORD RIVER, 1983-89.

winter or summer. Species that are most abundant in summer include only Cocconeis pediculus (Fig. 2.16) and perhaps Cymbella minuta (Fig. 2.17). There are three winter abundant species: Achnanthes lanceolata, Fragilaria construens and Synedra ulna (Figs. 2.15, 2.18, 2.19). 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 analysing dominant species (> 10%) present in winter and summer and several non-dominant (< 10%) species with the BACI technique (Table 2.12, Appendix B). Differences between the control and impact sites were calculated using the arcsin square root of x transformation suggested by Steel and Torrie (1960) for percentage data. There were no significant differences in FEX and FCD before and after testing of the ELF antenna began in the summer of 1986 for any of the five dominant summer (Achnanthes, Cocconeis) or winter species (Achnanthes, Fragilaria, Gomphonema) when the entire seasonal 83-85 "before" data were compared to the 86-89 "after" data (Table 2.12). Results from unpaired t-tests for the two dominant summer species indicated that there were no significant differences between means for any of the before years of 1983, 84, 85 and any of the years after testing began in 1986 (1986, 87, 88, 89). Regressions run on the winter species indicated that some "before" and "after" data were not additive (Tables B-3, B-4, B-5). The small number of available data points for several years probably increased the chance for finding significant regressions. Significant differences between means were produced for several year-to-year comparisons. These significant differences were produced for comparisons within the "before" period, and were the result of a limited number of available data points. Nevertheless, the use of species abundance data for individual diatom species coupled with the BACI analysis of this diatom percent dominance data may provide a powerful tool for determining the impact of ELF exposure.

This year we expanded our diatom BACI analyses to include a non-dominant summer and winter species (Cymbella minuta and Synedra ulna). Seasonal pooled comparisons of mean differences were not significant (Table 2.12). Also, no year-to-year comparisons for the summer species Cymbella or the winter species Synedra were found to be significant ( $p < 0.05$ ). Additionally, in an attempt to detect even more subtle changes in diatom abundances due to ELF exposure, we ran 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. 2.12). By pooling all the May and June data for the years

Table 2.12 Summary of Seasonal Diatom BACI Comparisons between Control (FCD) and Experimental (FEX) Sites for 1983-1989.

| Species                       | Comparison             | df | Significance<br>( $p < 0.05$ ) |
|-------------------------------|------------------------|----|--------------------------------|
| Summer                        |                        |    |                                |
| <i>Achnanthes minutissima</i> | Summer 83-85 vs. 86-89 | 38 | NS                             |
| <i>Cocconeis placentula</i>   | Summer 83-85 vs. 86-89 | 38 | NS                             |
| <i>Cymbella minuta</i>        | Summer 83-85 vs. 86-89 | 37 | NS                             |
| Winter                        |                        |    |                                |
| <i>Achnanthes minutissima</i> | Winter 83-85 vs. 86-88 | 27 | NS                             |
| <i>Fragilaria vaucheriae</i>  | Winter 83-85 vs. 86-88 | 27 | NS                             |
| <i>Gomphonema olivaceum</i>   | Winter 83-85 vs. 86-88 | 27 | NS                             |
| <i>Synedra ulna</i>           | Winter 83-85 vs. 86-88 | 27 | NS                             |



1983-85 as the "before" period and all the May and June data for 1986-89 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 in this fashion (Table 2.13). These species may prove to be sensitive indicators of potential ELF effects.

Comparisons of diversity and evenness between sites through paired t-tests indicated no significant differences in diversity or evenness between sites for 1988-89 (Table 2.3), for all data collected through 1989, or for 1983-89 data broken down into winter and summer seasons (Table 2.4). Correlation coefficients of 0.52 for diversity and 0.61 for evenness indicated the close relationship of these parameters between the two sites for 1988-89 (Table 2.3). Even so, these relationships were not as highly correlated as they were when all data were considered (Table 2.4).

Both evenness and diversity exhibit low minimum detectable differences (Table 2.5) indicating their potential value in detecting ELF effects. Stepwise multiple regression analysis of evenness on the selected physical/chemical variables failed to produce any models of value (Table 2.2). The two models that were fit had  $R^2$ 's of 0.08 and 0.10. Neither evenness or diversity correlated with any of the physical/chemical variables in last years correlation matrix. Stepwise multiple regression models fit for diversity, however, indicate the importance of discharge in predicting diversity. Discharge accounts for 77% of the explained variance in the FCD summer model and 47% in the FEX summer model (as mentioned earlier, discharge data is not available for the winter months and only the summer models have discharge as a potential variable to be fit into the model). High discharge events may act as a disturbance to the algal community, thereby keeping it at an early succesional stage with the characteristic high diversity.

Results of BACI comparisons for diversity and evenness demonstrated significant differences in means for the pooled "before" (6/83-4/86) and "after" (5/86-9/89) data (Tables 2.6, A-8, A-9). Seasonal pooled comparisons of mean differences in diversity were not significant. The only year to year comparison that was significantly different was the comparison of the summer of 83 to the summer of 87. Evenness differed from diversity in the fact that significant differences in means occurred for both summer and winter data (Tables 2.6, A-9). Summer year-to-year comparisons of evenness resulted not only in the difference between the summer of 83 and 87 that had been true for diversity, but also in a significant difference between the summer of 85 and 87. No significant differences among year-to-year comparisons existed for evenness winter data, even

Table 2.13 Results of Monthly BACI Comparisons of Dominant Diatom Species (1983-1989).

| Species                | Comparison                                  | Tukey's Test for Additivity |                 |                |             | t - test        |                     |                             |                |       |    |
|------------------------|---------------------------------------------|-----------------------------|-----------------|----------------|-------------|-----------------|---------------------|-----------------------------|----------------|-------|----|
|                        |                                             | BEFORE<br>DF                | Prob.<br>p<0.05 | Sig.<br>p<0.05 | AFTER<br>DF | Prob.<br>p<0.05 | Unpaired<br>t-value | Probability<br>(two-tailed) | Sig.<br>p<0.05 |       |    |
| Achnanthes minutissima | May & Jun 83-85/<br>May & Jun 86-89         | 3                           | 0.276           | NS             | 7           | 0.137           | NS                  | 10                          | -1.065         | 0.312 | NS |
| Cocconeis placentula   | Jul & Aug 83-85/<br>Jul & Aug 86-89         | 7                           | 0.719           | NS             | 7           | 0.137           | NS                  | 14                          | -1.320         | 0.208 | NS |
| Fragilaria vaucheriae  | Feb, Mar, Apr 84-86/<br>Feb, Mar, Apr 87-89 | 7                           | 0.479           | NS             | 5           | 0.921           | NS                  | 12                          | 0.957          | 0.357 | NS |
| Gomphonema olivaceum   | Feb & Mar 84-86/<br>Feb & Mar 87-89         | 5                           | 0.050           | NS             | 4           | 0.856           | NS                  | 9                           | 0.850          | 0.417 | NS |

though the winter pooled comparison of mean evenness differences was significant. This difference in the pooled winter data is most likely related to the fact that the 1985 transformed data, which failed Tukey's test for additivity, was included in the overall comparison. The fact that most year-to-year comparisons do not support the overall results, and that there were no differences in the summer 1989 data (the year of maximum ELF exposure to date) and any other year, suggest that the observed differences in evenness and diversity result from some factor other than ELF.

#### G. Effects of Environmental Variables on the Periphyton Community

Stepwise multiple regressions conducted on the total data set and the summer data set for each biological parameter failed to explain much of the variance in many of the cases. They did, however, identify some strong relationships that did not appear in last years correlation matrix (ie, density/silica and diversity/discharge). As a result this analysis will be conducted again next year with more variables included for model building, including some measure of ELF exposure.

In 1988 the entire set of data on physical, chemical, and biological parameters collected since 1983 was separated by site and entered for calculation of correlation coefficients. These relationships were discussed last year and used to guide variable selection for the stepwise multiple regression analysis conducted this year. Other approaches have been used in the past and will be included in future reports. A brief synopsis of some of these approaches is included here.

The multiple regressions calculated for the June 1983 to June 1985 data sets for each site were presented in the annual reports for 1984-85 and for 1985-86 and were not repeated for 1986-87 or 1987-88. Likewise, variable transformations were performed in 1985-86 to determine the linearity of variable relationships. These will not be repeated for this report but may be useful when the factor analyses are more thoroughly investigated. Our conclusion from the 1985-86 report that "an overall correlation matrix appeared to be as robust using untransformed data as any transformation attempted" was one reason for the determination of correlation coefficients on our entire data set for 1983 through 1988.

We have tried correlation matrices on transformed and untransformed data in the past and have also tried

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

#### H. Photosynthesis-Respiration Studies

A separate study was undertaken to evaluate primary production and community respiration using short term changes in dissolved oxygen concentrations during the summer period of intense algal growth. The dissolved gas procedures are advantageous because estimates of net primary production, gross primary production, and community respiration may be obtained with one technique (Bott et al. 1979). Rocks from the stream bed were placed inside each of six plexiglass chambers occupying 1/3 to 1/4 of the total chamber volume of 3-4 L. Three light and three dark chambers were run simultaneously on each date. Recirculated water was continuously recycled through the chambers using submersible pumps. Each test lasted from 0.5-2.0 hours between 1000 and 1300 hours of each test day in 1984. One site was tested during one week, and the second was tested during the following week in 1984. Even though 1984 results indicated no significant difference (t-test) between sites for net production, respiration, or gross production, the relatively large standard deviations led us to change procedures concerning exposure durations and site selection for 1985. Since 1985, production and respiration studies at FCD and FEX have been conducted on the same day with the test at each site lasting one hour. Tests were begun at one site at 1000 hours and completed at the other site by 1400 hours. Each site was tested first on alternate weeks.

The assumptions made for the purposes of production calculations considered algal periphyton to occupy only the upper half of each rock. Chlorophyll a, extracted from rocks covered by attached periphyton, was measured for each chamber with a fluorimeter. Surface area was determined by wrapping each rock in aluminum foil, straightening the foil, and determining the area of foil using a leaf area meter (LI-COR). Hourly production and respiration rates were estimated (Table 2.14) from dissolved oxygen, chlorophyll a, and rock surface area measurements.

We agree with reviewers from past years that production and respiration studies should be done for as many seasons of the year as possible. However, these procedures are labor intensive (ca. 40-50 hours per determination or 400 to 500 hours for the 10 runs per summer) and can only be done

with present level of funding during times when student technicians are available (June 15 through September 1). Thus, these determinations will be done in this period only unless additional funds are forthcoming for studies during other seasons. We also agree that  $^{14}\text{C}$  studies would be better than just monitoring changes in dissolved oxygen. Again, lack of equipment and funding to purchase such equipment precludes this as well.

Gross and net primary production and respiration were very similar between the control (FCD) and experimental (FEX) sites for 1989 (Table 2.14). The modified procedures used in 1985-89 have resulted in lower standard deviations for each parameter and in convergence of mean values between sites compared to 1984. This year we have analyzed gross primary production rates from 1984 to 1989 with the BACI technique (Tables 2.6, A-10). There were no significant differences between the two sites for either the pooled "before" and "after" data, or any year to year comparison. Additionally, we will compare results between sites using paired t-tests for each year for the final report.

## I. Summary

### 1. Chlorophyll a

Annual patterns for chlorophyll a standing crop and accrual were characterized by large year to year variability. The only consistent trend was for July-August peaks in most years and winter lows. The magnitudes of peaks also varied between years. Paired t-tests for 1988-89 data showed no differences between our control (FCD) and experimental sites (FEX), nor were there any differences for all data collected since 1983. "Before" (6/83-4/86) and "after" (5/86-9/89), control (FCD) and impact (FEX) (BACI) analyses indicate that the between site relationship in chlorophyll a has changed since May 1989 when the testing of the antenna began. However, the lack of differences between sites for the after years coupled with significant positive correlations between water temperature and chlorophyll a, the importance of water temperature as a predictor of chlorophyll a in stepwise regression models, and the increasing water temperatures during the drought periods in the spring and summer in 1986, 87, 88, and 89 lead us to believe that this change is related to weather variables and not to ELF exposure.

### 2. Organic Matter

Organic matter (AFDW-biomass) standing crop and accrual rates showed considerable year to year variability similar to chlorophyll a. These parameters have been consistently

Table 2.14 - Hourly Production and Respiration Rates for Rock Substrates of the Ford River.

| Date                         | NET PRIMARY PRODUCTION            |                         |                             | RESPIRATION*                      |                         |                             | GROSS PRIMARY PRODUCTION**        |          |                             |
|------------------------------|-----------------------------------|-------------------------|-----------------------------|-----------------------------------|-------------------------|-----------------------------|-----------------------------------|----------|-----------------------------|
|                              | mg O <sub>2</sub> /m <sup>2</sup> | mg Chl a/m <sup>2</sup> | mg O <sub>2</sub> /mg Chl a | mg O <sub>2</sub> /m <sup>2</sup> | mg Chl a/m <sup>2</sup> | mg O <sub>2</sub> /mg Chl a | mg O <sub>2</sub> /m <sup>2</sup> | mg Chl a | mg O <sub>2</sub> /mg Chl a |
| FORD CONTROL SITE (FCD)      |                                   |                         |                             |                                   |                         |                             |                                   |          |                             |
| 6/20/89                      | 142.96 ± 4.54                     | 25.35 ± 3.66            | 5.96 ± 1.11                 | 32.16 ± 10.54                     | 36.12 ± 8.15            | 0.95 ± 0.35                 | 175.12                            |          | 6.91                        |
| 6/27/89                      | 122.76 ± 5.27                     | 43.92 ± 1.36            | 2.81 ± 0.19                 | 38.35 ± 8.78                      | 42.57 ± 5.63            | 0.98 ± 0.31                 | 161.11                            |          | 3.78                        |
| 6/29/89                      | 110.24 ± 18.67                    | 41.32 ± 12.00           | 3.37 ± 0.94                 | 59.66 ± 14.46                     | 49.15 ± 14.06           | 1.42 ± 0.39                 | 177.90                            |          | 4.79                        |
| 7/6/89                       | 137.51 ± 16.62                    | 25.21 ± 5.84            | 6.00 ± 1.40                 | 37.20 ± 7.39                      | 22.77 ± 3.85            | 1.61 ± 0.09                 | 174.71                            |          | 7.61                        |
| 7/13/89                      | 80.38 ± 18.87                     | 49.43 ± 4.01            | 1.60 ± 0.28                 | 41.18 ± 6.85                      | 40.30 ± 5.20            | 1.02 ± 0.11                 | 121.56                            |          | 2.62                        |
| 7/20/89                      | 44.65 ± 14.75                     | 22.43 ± 5.27            | 2.23 ± 0.86                 | 53.54 ± 3.64                      | 26.33 ± 4.72            | 2.11 ± 0.21                 | 98.19                             |          | 4.34                        |
| 7/25/89                      | 68.03 ± 25.62                     | 22.78 ± 9.31            | 3.03 ± 0.45                 | 36.08 ± 6.12                      | 28.43 ± 4.03            | 1.26 ± 0.23                 | 102.92                            |          | 4.29                        |
| 8/1/89                       | 62.84 ± 30.79                     | 39.60 ± 3.51            | 1.60 ± 0.77                 | 20.86 ± 3.75                      | 35.33 ± 1.92            | 0.83 ± 0.14                 | 91.70                             |          | 2.43                        |
| 8/10/89                      | 72.75 ± 9.78                      | 35.21 ± 3.60            | 2.07 ± 0.25                 | 22.52 ± 1.33                      | 22.46 ± 3.35            | 1.05 ± 0.17                 | 95.27                             |          | 3.13                        |
| 8/17/89                      | 46.97 ± 31.90                     | 47.11 ± 11.66           | 0.80 ± 0.41                 | 21.16 ± 3.31                      | 32.04 ± 3.05            | 0.67 ± 0.12                 | 68.13                             |          | 1.47                        |
| Ave ± S.D.                   | 89.71 ± 37.19                     | 35.24 ± 10.50           | 2.95 ± 1.77                 | 36.95 ± 12.30                     | 33.55 ± 8.82            | 1.19 ± 0.43                 | 126.66 ± 41.50                    |          | 4.14 ± 1.94                 |
| FORD EXPERIMENTAL SITE (FEX) |                                   |                         |                             |                                   |                         |                             |                                   |          |                             |
| 6/20/89                      | 124.55 ± 6.30                     | 14.61 ± 1.37            | 8.56 ± 0.37                 | 54.86 ± 6.88                      | 28.15 ± 10.68           | 2.41 ± 0.64                 | 179.43                            |          | 10.97                       |
| 6/27/89                      | 131.25 ± 17.03                    | 47.45 ± 1.25            | 2.77 ± 0.35                 | 85.57 ± 6.36                      | 44.70 ± 11.22           | 2.09 ± 0.35                 | 216.82                            |          | 4.85                        |
| 6/29/89                      | 152.35 ± 6.97                     | 32.10 ± 10.61           | 5.63 ± 1.36                 | 72.25 ± 17.70                     | 40.82 ± 10.18           | 1.78 ± 0.06                 | 224.60                            |          | 7.41                        |
| 7/6/89                       | 114.46 ± 15.32                    | 40.35 ± 7.55            | 2.95 ± 0.35                 | 58.73 ± 1.94                      | 33.82 ± 2.31            | 1.75 ± 0.10                 | 173.18                            |          | 4.70                        |
| 7/13/89                      | 53.05 ± 14.19                     | 49.00 ± 4.37            | 1.13 ± 0.36                 | 64.92 ± 9.66                      | 34.65 ± 4.63            | 1.89 ± 0.21                 | 117.97                            |          | 3.02                        |
| 7/20/89                      | 105.39 ± 4.99                     | 18.75 ± 3.41            | 5.94 ± 0.89                 | 10.24 ± 4.94                      | 19.68 ± 3.73            | 0.69 ± 0.46                 | 115.63                            |          | 6.63                        |
| 7/25/89                      | 67.01 ± 20.11                     | 20.85 ± 0.70            | 3.28 ± 1.10                 | 59.85 ± 4.89                      | 37.91 ± 7.13            | 1.65 ± 0.22                 | 126.86                            |          | 4.93                        |
| 8/1/89                       | 49.61 ± 6.83                      | 27.96 ± 2.05            | 1.81 ± 0.33                 | 51.35 ± 1.17                      | 34.38 ± 2.80            | 1.51 ± 0.11                 | 100.95                            |          | 3.32                        |
| 8/10/89                      | 51.17 ± 2.86                      | 39.36 ± 2.67            | 1.30 ± 0.02                 | 59.45 ± 2.78                      | 34.89 ± 5.51            | 1.80 ± 0.31                 | 110.62                            |          | 3.10                        |
| 8/17/89                      | 52.58 ± 23.30                     | 29.70 ± 1.36            | 1.73 ± 0.71                 | 44.50 ± 11.33                     | 27.72 ± 4.80            | 1.65 ± 0.47                 | 97.08                             |          | 3.38                        |
| Ave ± S.D.                   | 90.14 ± 39.51                     | 32.01 ± 11.90           | 3.51 ± 2.44                 | 56.17 ± 19.72                     | 33.67 ± 7.11            | 1.72 ± 0.44                 | 146.31 ± 48.07                    |          | 5.23 ± 2.51                 |

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

\*\* = Total Metabolism = Respiration + Net Primary Production

characterized by showing no significant differences between sites since 1983. BACI analyses also showed that no difference has occurred in AFDW-organic matter accumulation since the testing of the antenna began in 1986. The only overall trend has been for a July-August peak in standing crop and accrual rates and winter time lows for both standing crop and accrual. Stepwise regression analysis failed to indicate any variable or set of variables that consistently predict standing crop. In last years correlation matrix, organic matter standing crop was correlated with water temperature (positively) and discharge and dissolved oxygen (negatively).

### 3. Diatom Cell Density

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

### 4. Total Biovolume and Individual Cell Volume

Individual cell volume comparisons of diatoms between sites showed no significant differences according to paired t-tests. Differences in the BACI analysis of biovolume are attributed to differences in the data set for the winters of 1984, 85, 86 and 88. In general, average cell volume was high in winter and low in summer, whereas total biovolume tended to be highest in summer since it is the product of average volume times density. Stepwise regression analysis indicates that water temperature is the most consistent predictor of cell volume and silica is the most consistent predictor of total biovolume. Average cell volume was negatively correlated ( $p < 0.05$ ) with water temperature and total biovolume was not correlated with any of the physical/chemical variables.

### 5. Species Diversity and Evenness

Diatom species diversity and evenness were not significantly different in 1989 or for all data collected to date according to paired t-tests. Annual trends show a high diversity and evenness during winter (except winter of 1986-87) and lower values during the summer periods. In 1989,

we calculated percent abundance for all species of diatoms and presented data for those species that achieved dominance greater than 10 % for any season. Three species, Achnanthes minutissima, Cocconeis placentula, and Fragilaria vaucheriae were found to dominate during the 1989 summer period. The dominance of Fragilaria in the summer season was atypical, caused by extremely high abundances at both sites during May 1989. Three typical species achieved dominance during the winter of 1988. BACI analyses were presented for four dominant and two non-dominant species of diatoms and showed that few differences have occurred before and after antenna testing began. Even so, overall diversity and evenness have changed significantly over that time period according to the BACI analyses. Because of the pattern of year to year differences, we suggest that these changes may be related to environmental rather than ELF effects.

#### 6. Correlation with Environmental Variables

Stepwise multiple regression analysis was conducted for each biological parameter on selected physical/chemical variables (chosen from last year's correlation matrix). In many cases the regression models agreed with the results of the correlation matrix, yet a large amount of variance was left unexplained. In some cases the regression models pointed out relationships that did not show up in the correlation matrix. Next year these models will be expanded to include more variables in an attempt to explain more of the variance.

#### 7. Photosynthesis-Respiration Studies

Net production, respiration, and gross production of the community on rock surfaces did not differ greatly between sites. BACI analyses indicate that there has been no significant differences between FEX and FCD sites for gross primary production rates for "before" and "after" data. This parameter may offer a precise means of detecting ELF effects on community metabolism.

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APPENDIX A:

BACI Analyses for Biological Parameters

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

| Comparison;<br>(Bef/Aft, Bef/Bef,<br>or Aft/Aft) | DF | Tukey's Test for Additivity* |                  |                | t - test*        |                     |                                      |
|--------------------------------------------------|----|------------------------------|------------------|----------------|------------------|---------------------|--------------------------------------|
|                                                  |    | BEFORE<br>Prob.              | Sig.<br>p < 0.05 | AFTER<br>Prob. | Sig.<br>p < 0.05 | Unpaired<br>t-value | Probability<br>(two-tailed) p < 0.05 |
| 6/83-4/86 //                                     | 38 | 0.244                        | NS               | 0.042          | S                | 2.192               | 0.032 S                              |
| 5/86-9/89                                        |    |                              |                  |                |                  |                     |                                      |
| S 83-85/86-89                                    | 19 | 0.455                        | NS               | 0.456          | NS               | 3.878               | 0.0004 S                             |
| S 83/84                                          | 5  | 0.526                        | NS               | 0.056          | NS               | 0.361               | 0.725 NS                             |
| S 83/85                                          | 5  | 0.526                        | NS               | 0.266          | NS               | -0.074              | 0.943 NS                             |
| S 83/86                                          | 5  | 0.526                        | NS               | 0.252          | NS               | -1.495              | 0.166 NS                             |
| S 83/87                                          | 5  | 0.526                        | NS               | 0.085          | NS               | -1.753              | 0.110 NS                             |
| S 83/88                                          | 5  | 0.526                        | NS               | 0.395          | NS               | -2.285              | 0.048 S                              |
| S 83/89                                          | 5  | 0.526                        | NS               | 0.014          | S                | 1.436               | 0.185 NS                             |
| S 84/85                                          | 6  | 0.056                        | NS               | 0.266          | NS               | -0.662              | 0.521 NS                             |
| S 84/86                                          | 6  | 0.056                        | NS               | 0.252          | NS               | -2.141              | 0.056 NS                             |
| S 84/87                                          | 6  | 0.056                        | NS               | 0.085          | NS               | -2.516              | 0.029 S                              |
| S 84/88                                          | 6  | 0.056                        | NS               | 0.395          | NS               | -3.090              | 0.011 S                              |
| S 84/89                                          | 6  | 0.056                        | NS               | 0.014          | S                | 2.025               | 0.070 NS                             |
| S 85/86                                          | 6  | 0.266                        | NS               | 0.252          | NS               | -1.962              | 0.076 NS                             |
| S 85/87                                          | 6  | 0.266                        | NS               | 0.085          | NS               | -2.599              | 0.025 S                              |
| S 85/88                                          | 6  | 0.266                        | NS               | 0.395          | NS               | -3.546              | 0.005 S                              |
| S 85/89                                          | 6  | 0.266                        | NS               | 0.014          | S                | 1.879               | 0.090 NS                             |
| S 86/87                                          | 5  | 0.252                        | NS               | 0.085          | NS               | -0.120              | 0.907 NS                             |
| S 86/88                                          | 5  | 0.252                        | NS               | 0.395          | NS               | -1.209              | 0.258 NS                             |
| S 86/89                                          | 5  | 0.252                        | NS               | 0.014          | S                | 0.143               | 0.889 NS                             |
| S 87/88                                          | 5  | 0.085                        | NS               | 0.395          | NS               | -1.929              | 0.086 NS                             |
| S 87/89                                          | 5  | 0.085                        | NS               | 0.014          | S                | 0.454               | 0.659 NS                             |
| S 88/89                                          | 4  | 0.395                        | NS               | 0.014          | S                | -0.574              | 0.579 NS                             |

\*Data was log (x+1) transformed

Table A-1. Results of Winter BACI Comparisons of Chlorophyll a between Control (FCD) and Experimental (FEX) Sites, 1983-88, cont.

| Comparison;<br>(Bef/Aft, Bef/Bef,<br>or Aft/Aft) | DF | Tukey's Test for Additivity* |                  |    |                | t-test*          |                     |                                      |
|--------------------------------------------------|----|------------------------------|------------------|----|----------------|------------------|---------------------|--------------------------------------|
|                                                  |    | BEFORE<br>Prob.              | Sig.<br>p < 0.05 | DF | AFTER<br>Prob. | Sig.<br>p < 0.05 | Unpaired<br>t-value | Probability<br>(two-tailed) p < 0.05 |
| W 83-85/86-88                                    | 18 | 0.020                        | S                | 10 | 0.690          | NS               | -1.525              | 0.138                                |
| W 83/84                                          | 5  | 0.086                        | NS               | 5  | 0.679          | NS               | 0.814               | 0.434                                |
| W 83/85                                          | 5  | 0.086                        | NS               | 6  | 0.012          | S                | 0.792               | 0.445                                |
| W 83/86                                          | 5  | 0.086                        | NS               | 5  | 0.821          | NS               | 0.783               | 0.452                                |
| W 83/87                                          | 5  | 0.086                        | NS               | 1  | -              | -                | 1.142               | 0.297                                |
| W 83/88                                          | 5  | 0.086                        | NS               | 3  | 0.898          | NS               | -1.373              | 0.207                                |
| W 84/85                                          | 5  | 0.679                        | NS               | 6  | 0.012          | S                | -0.285              | 0.781                                |
| W 84/86                                          | 5  | 0.679                        | NS               | 5  | 0.821          | NS               | 0.214               | 0.835                                |
| W 84/87                                          | 5  | 0.679                        | NS               | 1  | -              | -                | 1.852               | 0.114                                |
| W 84/88                                          | 5  | 0.679                        | NS               | 3  | 0.898          | NS               | -1.281              | 0.236                                |
| W 85/86                                          | 6  | 0.012                        | S                | 5  | 0.821          | NS               | 0.367               | 0.720                                |
| W 85/87                                          | 6  | 0.012                        | S                | 1  | -              | -                | 3.188               | 0.015                                |
| W 85/88                                          | 6  | 0.012                        | S                | 3  | 0.898          | NS               | -1.643              | 0.135                                |
| W 86/87                                          | 5  | 0.821                        | NS               | 1  | -              | -                | 0.572               | 0.588                                |
| W 86/88                                          | 5  | 0.521                        | NS               | 3  | 0.898          | NS               | -0.715              | 0.498                                |
| W 87/88                                          | 1  | -                            | -                | 3  | 0.898          | NS               | 0.035               | 0.974                                |

\*Data was log (x+1) transformed

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

| Comparison    | DF | Tukey's Test for Additivity* |                  |       |       | t - test*           |                             |                  |
|---------------|----|------------------------------|------------------|-------|-------|---------------------|-----------------------------|------------------|
|               |    | BEFORE                       |                  | AFTER |       | Unpaired<br>t-value | Probability<br>(two-tailed) | Sig.<br>p < 0.05 |
|               |    | Prob.                        | Sig.<br>p < 0.05 | DF    | Prob. |                     |                             |                  |
| 6/83-4/86 //  | 41 | 0.592                        | NS               | 36    | 0.033 | -2.165              | 0.034                       | S                |
| 5/86-9/89     |    |                              |                  |       |       |                     |                             |                  |
| S 83-85/86-89 | 21 | 0.507                        | NS               | 25    | 0.126 | 2.395               | 0.021                       | S                |
| S 83/84       | 9  | 0.367                        | NS               | 5     | 0.525 | -0.728              | 0.479                       | NS               |
| S 83/85       | 9  | 0.367                        | NS               | 5     | 0.287 | -0.656              | 0.523                       | NS               |
| S 83/86       | 9  | 0.367                        | NS               | 5     | 0.079 | 0.134               | 0.895                       | NS               |
| S 83/87       | 9  | 0.367                        | NS               | 7     | 0.350 | -0.101              | 0.921                       | NS               |
| S 83/88       | 9  | 0.367                        | NS               | 9     | 0.020 | 1.580               | 0.132                       | NS               |
| S 83/89       | 9  | 0.367                        | NS               | 4     | 0.710 | 1.862               | 0.085                       | NS               |
| S 84/85       | 5  | 0.525                        | NS               | 5     | 0.287 | 0.252               | 0.806                       | NS               |
| S 84/86       | 5  | 0.525                        | NS               | 5     | 0.079 | 1.586               | 0.144                       | NS               |
| S 84/87       | 5  | 0.525                        | NS               | 7     | 0.350 | 0.699               | 0.498                       | NS               |
| S 84/88       | 5  | 0.525                        | NS               | 9     | 0.020 | 2.112               | 0.053                       | NS               |
| S 84/89       | 5  | 0.525                        | NS               | 4     | 0.710 | 5.168               | 0.001                       | S                |
| S 85/86       | 5  | 0.287                        | NS               | 5     | 0.079 | 1.638               | 0.132                       | NS               |
| S 85/87       | 5  | 0.287                        | NS               | 7     | 0.350 | 0.623               | 0.545                       | NS               |
| S 85/88       | 5  | 0.287                        | NS               | 9     | 0.020 | 2.070               | 0.057                       | NS               |
| S 85/89       | 5  | 0.287                        | NS               | 4     | 0.710 | 5.962               | 0.000                       | S                |
| S 86/87       | 5  | 0.079                        | NS               | 7     | 0.350 | -0.263              | 0.797                       | NS               |
| S 86/88       | 5  | 0.079                        | NS               | 9     | 0.020 | 1.380               | 0.189                       | NS               |
| S 86/89       | 5  | 0.079                        | NS               | 4     | 0.710 | 2.958               | 0.016                       | S                |
| S 87/88       | 7  | 0.350                        | NS               | 9     | 0.020 | 1.618               | 0.125                       | NS               |
| S 87/89       | 7  | 0.350                        | NS               | 4     | 0.710 | 2.179               | 0.052                       | NS               |
| S 88/89       | 9  | 0.020                        | S                | 4     | 0.710 | -0.196              | 0.848                       | NS               |

\*Data was log(x+1) transformed

Table A-2. Results of Winter BACI Comparisons of Chlorophyll a Accrual between Control (FCD) and Experimental (FEX) Sites, 1983-88, cont.

| Comparison    | DF | Tukey's Test for Additivity* |          |       |          | L-test*  |              |          |
|---------------|----|------------------------------|----------|-------|----------|----------|--------------|----------|
|               |    | BEFORE                       | Sig.     | AFTER | Sig.     | Unpaired | Probability  | Sig.     |
|               |    | Prob.                        | p < 0.05 | DF    | p < 0.05 | t-value  | (two-tailed) | p < 0.05 |
| W 83-85/86-88 | 19 | 0.192                        | NS       | 10    | 0.994    | NS       | 29           | 0.361    |
| W 83/84       | 5  | 0.267                        | NS       | 6     | 0.868    | NS       | 11           | 0.640    |
| W 83/85       | 5  | 0.267                        | NS       | 6     | 0.003    | S        | 11           | 0.482    |
| W 83/86       | 5  | 0.267                        | NS       | 4     | 0.973    | NS       | 9            | 0.047    |
| W 83/87       | 5  | 0.267                        | NS       | 1     | -        | -        | 6            | 0.621    |
| W 83/88       | 5  | 0.267                        | NS       | 3     | 0.448    | NS       | 8            | 0.302    |
| W 84/85       | 6  | 0.868                        | NS       | 6     | 0.003    | S        | 12           | 0.149    |
| W 84/86       | 6  | 0.868                        | NS       | 4     | 0.973    | NS       | 10           | 0.038    |
| W 84/87       | 6  | 0.868                        | NS       | 1     | -        | -        | 7            | 0.766    |
| W 84/88       | 6  | 0.868                        | NS       | 3     | 0.448    | NS       | 9            | 0.387    |
| W 85/86       | 6  | 0.003                        | S        | 4     | 0.973    | NS       | 10           | 0.021    |
| W 85/87       | 6  | 0.003                        | S        | 1     | -        | -        | 7            | 0.228    |
| W 85/88       | 6  | 0.003                        | S        | 3     | 0.448    | NS       | 9            | 0.199    |
| W 86/87       | 4  | 0.973                        | NS       | 1     | -        | -        | 5            | 0.309    |
| W 86/88       | 4  | 0.973                        | NS       | 3     | 0.448    | NS       | 7            | 0.984    |
| W 87/88       | 1  | -                            | -        | 3     | 0.448    | NS       | 4            | 0.619    |

\*Data was log(x+1) transformed

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

| Comparison:<br>(Bef/Aft, Bef/Bef,<br>or Aft/Aft) |                 | Tukey's Test for Additivity* |    |                |                  | t - test* |                     |                                      |
|--------------------------------------------------|-----------------|------------------------------|----|----------------|------------------|-----------|---------------------|--------------------------------------|
| DF                                               | BEFORE<br>Prob. | Sig.<br>p < 0.05             | DF | AFTER<br>Prob. | Sig.<br>p < 0.05 | DF        | Unpaired<br>t-value | Probability<br>(two-tailed) p < 0.05 |
| <hr/>                                            |                 |                              |    |                |                  |           |                     |                                      |
| 6/83-4/86 //                                     |                 |                              |    |                |                  |           |                     |                                      |
| 5/86-9/89                                        | 38              | 0.350                        | NS | 35             | 0.565            | NS        | 73                  | 1.418                                |
|                                                  |                 |                              |    |                |                  |           |                     | 0.160                                |
|                                                  |                 |                              |    |                |                  |           |                     | NS                                   |
| S 83-85/86-89                                    | 19              | 0.027                        | S  | 24             | 0.443            | NS        | 43                  | 3.544                                |
| S 83/84                                          | 5               | 0.296                        | NS | 6              | 0.071            | NS        | 11                  | 1.699                                |
| S 83/85                                          | 5               | 0.296                        | NS | 6              | 0.314            | NS        | 11                  | -0.620                               |
| S 83/86                                          | 5               | 0.296                        | NS | 5              | 0.760            | NS        | 10                  | -1.871                               |
| S 83/87                                          | 5               | 0.296                        | NS | 5              | 0.931            | NS        | 10                  | -0.098                               |
| S 83/88                                          | 5               | 0.296                        | NS | 4              | 0.861            | NS        | 9                   | -2.225                               |
| S 83/89                                          | 5               | 0.296                        | NS | 4              | 0.889            | NS        | 9                   | 1.711                                |
| S 84/85                                          | 6               | 0.071                        | NS | 6              | 0.314            | NS        | 12                  | -2.402                               |
| S 84/86                                          | 6               | 0.071                        | NS | 5              | 0.760            | NS        | 11                  | -3.100                               |
| S 84/87                                          | 6               | 0.071                        | NS | 5              | 0.931            | NS        | 11                  | -1.871                               |
| S 84/88                                          | 6               | 0.071                        | NS | 4              | 0.861            | NS        | 10                  | -3.358                               |
| S 84/89                                          | 6               | 0.071                        | NS | 4              | 0.889            | NS        | 10                  | 2.983                                |
| S 85/86                                          | 6               | 0.314                        | NS | 5              | 0.760            | NS        | 11                  | -1.661                               |
| S 85/87                                          | 6               | 0.314                        | NS | 5              | 0.931            | NS        | 11                  | 0.580                                |
| S 85/88                                          | 6               | 0.314                        | NS | 4              | 0.861            | NS        | 10                  | -1.900                               |
| S 85/89                                          | 6               | 0.314                        | NS | 4              | 0.889            | NS        | 10                  | 1.337                                |
| S 86/87                                          | 5               | 0.760                        | NS | 5              | 0.931            | NS        | 10                  | 1.899                                |
| S 86/88                                          | 5               | 0.760                        | NS | 4              | 0.861            | NS        | 9                   | 0.590                                |
| S 86/89                                          | 5               | 0.760                        | NS | 4              | 0.889            | NS        | 9                   | -0.714                               |
| S 87/88                                          | 5               | 0.931                        | NS | 4              | 0.761            | NS        | 9                   | -2.597                               |
| S 87/89                                          | 5               | 0.931                        | NS | 4              | 0.889            | NS        | 10                  | 1.737                                |
| S 88/89                                          | 4               | 0.761                        | NS | 4              | 0.889            | NS        | 10                  | -0.647                               |

\*Data was log (x+1) transformed



Table A-3. Results of Winter BACI Comparisons of AFDW-Biomass between Control (FCD) and Experimental (FEX) Sites, 1983-1988, cont.

| Comparison:<br>(Bef/Aft, Bef/Bef,<br>or Aft/Aft) | DF | Tukey's Test for Additivity* |                  |    | t - test*      |                  |    |                     |                             |                  |
|--------------------------------------------------|----|------------------------------|------------------|----|----------------|------------------|----|---------------------|-----------------------------|------------------|
|                                                  |    | BEFORE<br>Prob.              | Sig.<br>p < 0.05 | DF | AFTER<br>Prob. | Sig.<br>p < 0.05 | DF | Unpaired<br>t-value | Probability<br>(two-tailed) | Sig.<br>p < 0.05 |
| W 83-85/86-88                                    | 18 | 0.056                        | NS               | 10 | 0.181          | NS               | 28 | -0.734              | 0.469                       | NS               |
| W 83/84                                          | 5  | 0.200                        | NS               | 5  | 0.882          | NS               | 10 | 1.216               | 0.252                       | NS               |
| W 83/85                                          | 5  | 0.200                        | NS               | 6  | 0.246          | NS               | 11 | 0.471               | 0.647                       | NS               |
| W 83/86                                          | 5  | 0.200                        | NS               | 5  | 0.834          | NS               | 10 | 0.974               | 0.353                       | NS               |
| W 83/87                                          | 5  | 0.200                        | NS               | 1  | -              | -                | 6  | 2.861               | 0.029                       | S                |
| W 83/88                                          | 5  | 0.200                        | NS               | 3  | 0.270          | NS               | 8  | -0.345              | 0.739                       | NS               |
| W 84/85                                          | 5  | 0.882                        | NS               | 6  | 0.246          | NS               | 11 | -0.505              | 0.624                       | NS               |
| W 84/86                                          | 5  | 0.882                        | NS               | 5  | 0.834          | NS               | 10 | -0.643              | 0.535                       | NS               |
| W 84/87                                          | 5  | 0.882                        | NS               | 1  | -              | -                | 6  | 1.686               | 0.143                       | NS               |
| W 84/88                                          | 5  | 0.882                        | NS               | 3  | 0.270          | NS               | 8  | 0.799               | 0.447                       | NS               |
| W 85/86                                          | 6  | 0.246                        | NS               | 5  | 0.834          | NS               | 11 | 0.111               | 0.914                       | NS               |
| W 85/87                                          | 6  | 0.246                        | NS               | 1  | -              | -                | 7  | 1.574               | 0.160                       | NS               |
| W 85/88                                          | 6  | 0.246                        | NS               | 3  | 0.270          | NS               | 9  | 0.165               | 0.872                       | NS               |
| W 86/87                                          | 5  | 0.834                        | NS               | 1  | -              | -                | 6  | 4.262               | 0.005                       | S                |
| W 86/88                                          | 5  | 0.834                        | NS               | 3  | 0.270          | NS               | 7  | 0.173               | 0.868                       | NS               |
| W 87/88                                          | 1  | -                            | -                | 3  | 0.270          | NS               | 4  | 2.707               | 0.054                       | NS               |

\*Data was log (x+1) transformed

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

| Comparison    | DF | Tukey's Test for Additivity* |          |       |          | t - test* |              |          |
|---------------|----|------------------------------|----------|-------|----------|-----------|--------------|----------|
|               |    | BEFORE                       | Sig.     | AFTER | Sig.     | Unpaired  | Probability  | Sig.     |
|               |    | Prob.                        | p < 0.05 | Prob. | p < 0.05 | t-value   | (two-tailed) | p < 0.05 |
| 6/83-4/86 //  |    |                              |          |       |          |           |              |          |
| 5/86-9/89     | 41 | 0.603                        | NS       | 0.371 | NS       | 0.466     | 0.642        | NS       |
| S 83-85/86-89 | 21 | 0.912                        | NS       | 0.340 | NS       | 0.547     | 0.587        | NS       |
| S 83/84       | 9  | 0.322                        | NS       | 0.455 | NS       | -1.435    | 0.173        | NS       |
| S 83/85       | 9  | 0.322                        | NS       | 0.772 | NS       | -0.798    | 0.438        | NS       |
| S 83/86       | 9  | 0.322                        | NS       | 0.551 | NS       | -0.144    | 0.888        | NS       |
| S 83/87       | 9  | 0.322                        | NS       | 0.581 | NS       | -0.860    | 0.403        | NS       |
| S 83/88       | 9  | 0.322                        | NS       | 0.431 | NS       | 0.186     | 0.854        | NS       |
| S 83/89       | 9  | 0.322                        | NS       | 0.756 | NS       | 0.350     | 0.732        | NS       |
| S 84/85       | 5  | 0.455                        | NS       | 0.772 | NS       | 1.575     | 0.146        | NS       |
| S 84/86       | 5  | 0.455                        | NS       | 0.551 | NS       | 1.227     | 0.248        | NS       |
| S 84/87       | 5  | 0.455                        | NS       | 0.581 | NS       | 0.997     | 0.338        | NS       |
| S 84/88       | 5  | 0.455                        | NS       | 0.431 | NS       | 2.530     | 0.024        | S        |
| S 84/89       | 5  | 0.455                        | NS       | 0.756 | NS       | 2.318     | 0.046        | NS       |
| S 85/86       | 5  | 0.772                        | NS       | 0.551 | NS       | 0.608     | 0.557        | NS       |
| S 85/87       | 5  | 0.772                        | NS       | 0.581 | NS       | -0.027    | 0.979        | NS       |
| S 85/88       | 5  | 0.772                        | NS       | 0.431 | NS       | 1.538     | 0.146        | NS       |
| S 85/89       | 5  | 0.772                        | NS       | 0.756 | NS       | 0.974     | 0.356        | NS       |
| S 86/87       | 5  | 0.551                        | NS       | 0.581 | NS       | -0.626    | 0.543        | NS       |
| S 86/88       | 5  | 0.551                        | NS       | 0.431 | NS       | 0.357     | 0.726        | NS       |
| S 86/89       | 5  | 0.551                        | NS       | 0.756 | NS       | -0.184    | 0.858        | NS       |
| S 87/88       | 7  | 0.581                        | NS       | 0.431 | NS       | 1.461     | 0.464        | NS       |
| S 87/89       | 7  | 0.581                        | NS       | 0.756 | NS       | 0.629     | 0.542        | NS       |
| S 88/89       | 9  | 0.431                        | NS       | 0.756 | NS       | -0.555    | 0.591        | NS       |

\* Data was not transformed

Table A-4. Results of Winter BACI Comparisons of AFDW-Biomass Accrual between Control (FCD) and Experimental (FEX) Sites, 1983-88, cont.

| Comparison    | DF | Tukey's Test for Additivity* |          |       |       | t - test * |              |          |
|---------------|----|------------------------------|----------|-------|-------|------------|--------------|----------|
|               |    | BEFORE                       | Sig.     | AFTER | Sig.  | Unpaired   | Probability  | Sig.     |
|               |    | Prob.                        | p < 0.05 | DF    | Prob. | t-value    | (two-tailed) | p < 0.05 |
| W 83-85/86-88 | 19 | 0.003                        | S        | 10    | 0.090 | NS         | 0.370        | NS       |
| W 83/84       | 5  | 0.077                        | NS       | 6     | 0.978 | NS         | -1.752       | NS       |
| W 83/85       | 5  | 0.077                        | NS       | 6     | 0.043 | S          | -0.395       | NS       |
| W 83/86       | 5  | 0.077                        | NS       | 4     | 0.501 | NS         | -0.829       | NS       |
| W 83/87       | 5  | 0.077                        | NS       | 1     | -     | -          | -2.444       | NS       |
| W 83/88       | 5  | 0.077                        | NS       | 3     | 0.092 | NS         | -0.509       | NS       |
| W 84/85       | 6  | 0.978                        | NS       | 6     | 0.043 | S          | 1.107        | NS       |
| W 84/86       | 6  | 0.978                        | NS       | 4     | 0.501 | NS         | 1.244        | NS       |
| W 84/87       | 6  | 0.978                        | NS       | 1     | -     | -          | -1.893       | NS       |
| W 84/88       | 6  | 0.978                        | NS       | 3     | 0.092 | NS         | 1.277        | NS       |
| W 85/86       | 6  | 0.043                        | S        | 4     | 0.501 | NS         | -0.213       | NS       |
| W 85/87       | 6  | 0.043                        | S        | 1     | -     | -          | -2.123       | NS       |
| W 85/88       | 6  | 0.043                        | S        | 3     | 0.092 | NS         | -0.030       | NS       |
| W 86/87       | 4  | 0.501                        | NS       | 1     | -     | -          | -2.274       | NS       |
| W 86/88       | 4  | 0.501                        | NS       | 3     | 0.092 | NS         | 0.375        | NS       |
| W 87/88       | 1  | -                            | -        | 3     | 0.092 | NS         | 2.004        | NS       |

\*Data was not transformed

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

| Comparison:<br>(Bef/Aft, Bef/Bef,<br>or Aft/Aft) DF |                  |    | Tukey's Test for Additivity* |                  |    | t - test*           |                                      |      |
|-----------------------------------------------------|------------------|----|------------------------------|------------------|----|---------------------|--------------------------------------|------|
| BEFORE<br>Prob.                                     | Sig.<br>p < 0.05 | DF | AFTER<br>Prob.               | Sig.<br>p < 0.05 | DF | Unpaired<br>t-value | Probability<br>(two-tailed) p < 0.05 | Sig. |
| <hr/>                                               |                  |    |                              |                  |    |                     |                                      |      |
| 6/83-4/86 //                                        |                  |    |                              |                  |    |                     |                                      |      |
| 5/86-9/89                                           | 0.203            | NS | 34                           | 0.217            | NS | 72                  | 2.686                                | S    |
| S 83-85/86-89                                       | 0.262            | NS | 22                           | 0.515            | NS | 41                  | 2.456                                | S    |
| S 83/84                                             | 0.229            | NS | 6                            | 0.803            | NS | 11                  | -0.294                               | NS   |
| S 83/85                                             | 0.229            | NS | 6                            | 0.031            | S  | 11                  | 0.014                                | NS   |
| S 83/86                                             | 0.229            | NS | 5                            | 0.720            | NS | 10                  | -1.305                               | NS   |
| S 83/87                                             | 0.229            | NS | 5                            | 0.837            | NS | 10                  | -1.787                               | NS   |
| S 83/88                                             | 0.229            | NS | 4                            | 0.057            | NS | 9                   | -2.630                               | S    |
| S 83/89                                             | 0.229            | NS | 4                            | 0.782            | NS | 9                   | 1.641                                | NS   |
| S 84/85                                             | 0.803            | NS | 6                            | 0.031            | S  | 12                  | 0.268                                | NS   |
| S 84/86                                             | 0.803            | NS | 5                            | 0.720            | NS | 11                  | -0.769                               | NS   |
| S 84/87                                             | 0.803            | NS | 5                            | 0.837            | NS | 11                  | -0.907                               | NS   |
| S 84/88                                             | 0.803            | NS | 4                            | 0.057            | NS | 10                  | -1.460                               | NS   |
| S 84/89                                             | 0.803            | NS | 4                            | 0.782            | NS | 10                  | 0.756                                | NS   |
| S 85/86                                             | 0.031            | S  | 5                            | 0.720            | NS | 11                  | -1.115                               | NS   |
| S 85/87                                             | 0.031            | S  | 5                            | 0.837            | NS | 11                  | -1.343                               | NS   |
| S 85/88                                             | 0.031            | S  | 4                            | 0.057            | NS | 10                  | -1.954                               | NS   |
| S 85/89                                             | 0.031            | S  | 4                            | 0.782            | NS | 10                  | 1.164                                | NS   |
| S 86/87                                             | 0.720            | NS | 5                            | 0.837            | NS | 10                  | -0.042                               | NS   |
| S 86/88                                             | 0.720            | NS | 4                            | 0.057            | NS | 9                   | -0.662                               | NS   |
| S 86/89                                             | 0.720            | NS | 4                            | 0.782            | NS | 9                   | -0.051                               | NS   |
| S 87/88                                             | 0.837            | NS | 4                            | 0.057            | NS | 9                   | -0.748                               | NS   |
| S 87/89                                             | 0.837            | NS | 4                            | 0.782            | NS | 9                   | -0.115                               | NS   |
| S 88/89                                             | 0.057            | NS | 4                            | 0.782            | NS | 9                   | -0.556                               | NS   |

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

Table A-5. Results of Winter BACI Comparisons of Cell Density between Control (FCD) and Experimental (FEX) Sites, 1983-88, cont.

| Comparison:<br>(Bef/Aft, Bef/Bef,<br>or Aft/Aft) | DF | Tukey's Test for Additivity* |                  |    |                | t - test*        |                     |                                      |
|--------------------------------------------------|----|------------------------------|------------------|----|----------------|------------------|---------------------|--------------------------------------|
|                                                  |    | BEFORE<br>Prob.              | Sig.<br>p < 0.05 | DF | AFTER<br>Prob. | Sig.<br>p < 0.05 | Unpaired<br>t-value | Probability<br>(two-tailed) p < 0.05 |
| W 83-85/86-88                                    | 18 | 0.654                        | NS               | 11 | 0.532          | NS               | 1.182               | 0.247                                |
| W 83/84                                          | 5  | 0.242                        | NS               | 5  | 0.216          | NS               | 2.608               | 0.026                                |
| W 83/85                                          | 5  | 0.242                        | NS               | 6  | 0.903          | NS               | 1.381               | 0.195                                |
| W 83/86                                          | 5  | 0.242                        | NS               | 5  | 0.779          | NS               | 0.191               | 0.852                                |
| W 83/87                                          | 5  | 0.242                        | NS               | 1  | -              | -                | 2.527               | 0.045                                |
| W 83/88                                          | 5  | 0.242                        | NS               | 3  | 0.130          | NS               | 0.332               | 0.749                                |
| W 84/85                                          | 5  | 0.216                        | NS               | 6  | 0.903          | NS               | 0.699               | 0.499                                |
| W 84/86                                          | 5  | 0.216                        | NS               | 5  | 0.779          | NS               | -3.096              | 0.011                                |
| W 84/87                                          | 5  | 0.216                        | NS               | 1  | -              | -                | 0.744               | 0.485                                |
| W 84/88                                          | 5  | 0.216                        | NS               | 3  | 0.130          | NS               | 2.873               | 0.021                                |
| W 85/86                                          | 6  | 0.903                        | NS               | 5  | 0.779          | NS               | -1.399              | 0.189                                |
| W 85/87                                          | 6  | 0.903                        | NS               | 1  | -              | -                | 0.928               | 0.384                                |
| W 85/88                                          | 6  | 0.903                        | NS               | 3  | 0.130          | NS               | 1.469               | 0.176                                |
| W 86/87                                          | 5  | 0.779                        | NS               | 1  | -              | -                | 3.966               | 0.007                                |
| W 86/88                                          | 5  | 0.779                        | NS               | 3  | 0.130          | NS               | 0.661               | 0.527                                |
| W 87/88                                          | 1  | -                            | -                | 3  | 0.130          | NS               | 3.113               | 0.036                                |

\*Data was log(x+1) transformed

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

| Comparison:<br>(Bef/Aft, Bef/Bef,<br>or Aft/Aft) | Tukey's Test for Additivity* |                  |    |                | t - test*        |    |                     |                                      |      |
|--------------------------------------------------|------------------------------|------------------|----|----------------|------------------|----|---------------------|--------------------------------------|------|
|                                                  | BEFORE<br>Prob.              | Sig.<br>p < 0.05 | DF | AFTER<br>Prob. | Sig.<br>p < 0.05 | DF | Unpaired<br>t-value | Probability<br>(two-tailed) p < 0.05 | Sig. |
| 6/83-4/86 //<br>5/86-9/89                        | 0.022                        | S                | 34 | 0.120          | NS               | 72 | 1.211               | 0.230                                | NS   |
| S 83-85/86-89                                    | 0.092                        | NS               | 22 | 0.669          | NS               | 41 | 1.203               | 0.236                                | NS   |
| S 83/84                                          | 0.001                        | S                | 6  | 0.278          | NS               | 11 | -0.255              | 0.803                                | NS   |
| S 83/85                                          | 0.001                        | S                | 6  | 0.001          | S                | 11 | -1.355              | 0.203                                | NS   |
| S 83/86                                          | 0.001                        | S                | 5  | 0.848          | NS               | 10 | -0.368              | 0.720                                | NS   |
| S 83/87                                          | 0.001                        | S                | 5  | 0.279          | NS               | 10 | -0.169              | 0.869                                | NS   |
| S 83/88                                          | 0.001                        | S                | 4  | 0.197          | NS               | 9  | -0.822              | 0.433                                | NS   |
| S 83/89                                          | 0.001                        | S                | 4  | 0.863          | NS               | 9  | 0.534               | 0.606                                | NS   |
| S 84/85                                          | 0.278                        | NS               | 6  | 0.001          | S                | 12 | -1.247              | 0.236                                | NS   |
| S 84/86                                          | 0.278                        | NS               | 5  | 0.848          | NS               | 11 | -0.170              | 0.868                                | NS   |
| S 84/87                                          | 0.278                        | NS               | 5  | 0.279          | NS               | 11 | 0.118               | 0.908                                | NS   |
| S 84/88                                          | 0.278                        | NS               | 4  | 0.197          | NS               | 10 | -0.643              | 0.534                                | NS   |
| S 84/89                                          | 0.278                        | NS               | 4  | 0.863          | NS               | 10 | 0.930               | 0.374                                | NS   |
| S 85/86                                          | 0.001                        | S                | 5  | 0.848          | NS               | 11 | 0.877               | 0.399                                | NS   |
| S 85/87                                          | 0.001                        | S                | 5  | 0.279          | NS               | 11 | 1.502               | 0.161                                | NS   |
| S 85/88                                          | 0.001                        | S                | 4  | 0.197          | NS               | 10 | 0.803               | 0.441                                | NS   |
| S 86/89                                          | 0.001                        | S                | 4  | 0.863          | NS               | 10 | 0.846               | 0.417                                | NS   |
| S 86/87                                          | 0.848                        | NS               | 5  | 0.279          | NS               | 10 | 0.276               | 0.788                                | NS   |
| S 86/88                                          | 0.848                        | NS               | 4  | 0.197          | NS               | 9  | -0.331              | 0.748                                | NS   |
| S 87/89                                          | 0.848                        | NS               | 4  | 0.863          | NS               | 9  | 0.312               | 0.762                                | NS   |
| S 87/88                                          | 0.279                        | NS               | 4  | 0.197          | NS               | 9  | -1.022              | 0.333                                | NS   |
| S 87/89                                          | 0.279                        | NS               | 4  | 0.863          | NS               | 9  | 0.847               | 0.419                                | NS   |
| S 88/89                                          | 0.197                        | NS               | 4  | 0.863          | NS               | 9  | -0.382              | 0.711                                | NS   |

\*Data was not transformed

Table A-6. Results of Winter BACI Comparisons of Cell Volume between Control (FCD) and Experimental (FEX) Sites, 1983-88, cont.

| Comparison:<br>(Bef/Aft, Bef/Bef,<br>or Aft/Aft) | DF | Tukey's Test for Additivity* |       |                  |    | t - test* |                     |                                      |
|--------------------------------------------------|----|------------------------------|-------|------------------|----|-----------|---------------------|--------------------------------------|
|                                                  |    | BEFORE                       | Prob. | Sig.<br>p < 0.05 | DF | AFTER     | Prob.               | Sig.<br>p < 0.05                     |
|                                                  |    |                              |       |                  |    |           | Unpaired<br>t-value | Probability<br>(two-tailed) p < 0.05 |
| W 83-85/86-88                                    | 18 | 0.285                        |       | NS               | 11 | 0.434     | 1.179               | 0.248                                |
| W 83/84                                          | 5  | 0.872                        |       | NS               | 5  | 0.288     | -0.645              | 0.534                                |
| W 83/85                                          | 5  | 0.872                        |       | NS               | 6  | 0.272     | -0.911              | 0.382                                |
| W 83/86                                          | 5  | 0.872                        |       | NS               | 5  | 0.630     | -0.844              | 0.418                                |
| W 83/87                                          | 5  | 0.872                        |       | NS               | 1  | -         | -0.704              | 0.508                                |
| W 83/88                                          | 5  | 0.872                        |       | NS               | 3  | 0.593     | 1.071               | 0.315                                |
| W 84/85                                          | 5  | 0.288                        |       | NS               | 6  | 0.272     | -0.502              | 0.626                                |
| W 84/86                                          | 5  | 0.288                        |       | NS               | 5  | 0.630     | -0.633              | 0.541                                |
| W 84/87                                          | 5  | 0.288                        |       | NS               | 1  | -         | -1.188              | 0.280                                |
| W 84/88                                          | 5  | 0.288                        |       | NS               | 3  | 0.593     | 1.744               | 0.119                                |
| W 85/86                                          | 6  | 0.272                        |       | NS               | 5  | 0.630     | -0.550              | 0.593                                |
| W 85/87                                          | 6  | 0.272                        |       | NS               | 1  | -         | -0.359              | 0.730                                |
| W 85/88                                          | 6  | 0.272                        |       | NS               | 3  | 0.593     | 0.606               | 0.559                                |
| W 86/87                                          | 5  | 0.630                        |       | NS               | 1  | -         | 0.210               | 0.841                                |
| W 86/88                                          | 5  | 0.630                        |       | NS               | 3  | 0.593     | -0.285              | 0.783                                |
| W 87/88                                          | 1  | -                            |       | -                | 3  | 0.593     | 0.207               | 0.846                                |

\*Data was not transformed

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

| Comparison:<br>(Bef/Aft, Bef/Bef,<br>or Aft/Aft) | DF | Tukey's Test for Additivity* |                  |    | t - test*      |                  |    |                     |                                      |      |
|--------------------------------------------------|----|------------------------------|------------------|----|----------------|------------------|----|---------------------|--------------------------------------|------|
|                                                  |    | BEFORE<br>Prob.              | Sig.<br>p < 0.05 | DF | AFTER<br>Prob. | Sig.<br>p < 0.05 | DF | Unpaired<br>t-value | Probability<br>(two-tailed) p < 0.05 | Sig. |
| 6/83-4/86 //<br>5/86-9/89                        | 38 | 0.199                        | NS               | 34 | 0.132          | NS               | 72 | 2.551               | 0.013                                | S    |
| S 83-85/86-89                                    | 19 | 0.948                        | NS               | 22 | 0.080          | NS               | 41 | 1.203               | 0.234                                | NS   |
| S 83/84                                          | 5  | 0.640                        | NS               | 6  | 0.593          | NS               | 11 | 0.602               | 0.559                                | NS   |
| S 83/85                                          | 5  | 0.640                        | NS               | 6  | 0.328          | NS               | 11 | 0.270               | 0.792                                | NS   |
| S 83/86                                          | 5  | 0.640                        | NS               | 5  | 0.443          | NS               | 10 | -0.178              | 0.863                                | NS   |
| S 83/87                                          | 5  | 0.640                        | NS               | 5  | 0.056          | NS               | 10 | 0.384               | 0.709                                | NS   |
| S 83/88                                          | 5  | 0.640                        | NS               | 4  | 0.058          | NS               | 9  | -1.112              | 0.295                                | NS   |
| S 83/89                                          | 5  | 0.640                        | NS               | 4  | 0.699          | NS               | 9  | 0.534               | 0.606                                | NS   |
| S 84/85                                          | 6  | 0.593                        | NS               | 6  | 0.328          | NS               | 12 | -0.493              | 0.631                                | NS   |
| S 84/86                                          | 6  | 0.593                        | NS               | 5  | 0.443          | NS               | 11 | -0.695              | 0.501                                | NS   |
| S 84/87                                          | 6  | 0.593                        | NS               | 5  | 0.056          | NS               | 11 | 0.319               | 0.755                                | NS   |
| S 84/88                                          | 6  | 0.593                        | NS               | 4  | 0.058          | NS               | 10 | -1.388              | 0.195                                | NS   |
| S 84/89                                          | 6  | 0.593                        | NS               | 4  | 0.699          | NS               | 10 | 0.930               | 0.374                                | NS   |
| S 85/86                                          | 6  | 0.328                        | NS               | 5  | 0.443          | NS               | 11 | -0.428              | 0.677                                | NS   |
| S 85/87                                          | 6  | 0.328                        | NS               | 5  | 0.056          | NS               | 11 | 0.189               | 0.854                                | NS   |
| S 85/88                                          | 6  | 0.328                        | NS               | 4  | 0.058          | NS               | 10 | -1.476              | 0.171                                | NS   |
| S 85/89                                          | 6  | 0.328                        | NS               | 4  | 0.699          | NS               | 10 | 0.846               | 0.417                                | NS   |
| S 86/87                                          | 5  | 0.443                        | NS               | 5  | 0.056          | NS               | 10 | 0.502               | 0.627                                | NS   |
| S 86/88                                          | 5  | 0.443                        | NS               | 4  | 0.058          | NS               | 9  | -0.850              | 0.418                                | NS   |
| S 86/89                                          | 5  | 0.443                        | NS               | 4  | 0.699          | NS               | 9  | 0.312               | 0.762                                | NS   |
| S 87/88                                          | 5  | 0.056                        | NS               | 4  | 0.058          | NS               | 9  | -1.389              | 0.198                                | NS   |
| S 87/89                                          | 5  | 0.056                        | NS               | 4  | 0.699          | NS               | 9  | 0.847               | 0.419                                | NS   |
| S 88/89                                          | 4  | 0.058                        | NS               | 4  | 0.699          | NS               | 9  | -0.382              | 0.711                                | NS   |

\*Data was log (x + 1) transformed



Table A-7. Results of Winter BACI Comparisons of Biovolume between Control (FCD) and Experimental (FEX) Sites, 1983-88.  
cont.

| Comparison:<br>(Bef/Aft, Bef/Bef,<br>or Aft/Aft) | Tukey's Test for Additivity* |                  |    |                | t - test*        |    |                     |                                      |
|--------------------------------------------------|------------------------------|------------------|----|----------------|------------------|----|---------------------|--------------------------------------|
|                                                  | BEFORE<br>Prob.              | Sig.<br>p < 0.05 | DF | AFTER<br>Prob. | Sig.<br>p < 0.05 | DF | Unpaired<br>t-value | Probability<br>(two-tailed) p < 0.05 |
| W 83-85/86-88                                    | 0.392                        | NS               | 11 | 0.677          | NS               | 29 | 2.228               | 0.034                                |
| W 83/84                                          | 0.276                        | NS               | 5  | 0.552          | NS               | 10 | 2.048               | 0.065                                |
| W 83/85                                          | 0.276                        | NS               | 6  | 0.232          | NS               | 11 | 1.386               | 0.193                                |
| W 83/86                                          | 0.276                        | NS               | 5  | 0.412          | NS               | 10 | -0.241              | 0.815                                |
| W 83/87                                          | 0.276                        | NS               | 1  | -              | -                | 6  | 1.370               | 0.220                                |
| W 83/88                                          | 0.276                        | NS               | 3  | 0.982          | NS               | 8  | 1.584               | 0.152                                |
| W 84/85                                          | 0.552                        | NS               | 6  | 0.232          | NS               | 11 | -1.542              | 0.151                                |
| W 84/86                                          | 0.552                        | NS               | 5  | 0.412          | NS               | 10 | -2.607              | 0.026                                |
| W 84/87                                          | 0.552                        | NS               | 1  | -              | -                | 6  | 0.032               | 0.975                                |
| W 84/88                                          | 0.552                        | NS               | 3  | 0.982          | NS               | 8  | 2.922               | 0.019                                |
| W 85/86                                          | 0.232                        | NS               | 5  | 0.412          | NS               | 11 | -1.831              | 0.094                                |
| W 85/87                                          | 0.232                        | NS               | 1  | -              | -                | 7  | 1.298               | 0.235                                |
| W 85/88                                          | 0.232                        | NS               | 3  | 0.982          | NS               | 9  | 2.686               | 0.025                                |
| W 86/87                                          | 0.412                        | NS               | 1  | -              | -                | 6  | 1.689               | 0.142                                |
| W 86/88                                          | 0.412                        | NS               | 3  | 0.982          | NS               | 8  | 1.481               | 0.177                                |
| W 87/88                                          | -                            | -                | 3  | 0.982          | NS               | 4  | 1.639               | 0.176                                |

\*Data was log (x + 1) transformed

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

| Comparison:<br>(Bef/Aft., Bef/Bef,<br>or Aft/Aft) | Tukey's Test for Additivity* |                  |    |                | t - test*        |    |                     |                                      |
|---------------------------------------------------|------------------------------|------------------|----|----------------|------------------|----|---------------------|--------------------------------------|
|                                                   | BEFORE<br>Prob.              | Sig.<br>p < 0.05 | DF | AFTER<br>Prob. | Sig.<br>p < 0.05 | DF | Unpaired<br>t-value | Probability<br>(two-tailed) p < 0.05 |
| 6/83-4/86 //<br>5/86-9/89                         | 0.835                        | NS               | 34 | 0.480          | NS               | 72 | -2.380              | 0.020                                |
| S 83-85/86-89                                     | 0.896                        | NS               | 22 | 0.440          | NS               | 41 | -1.881              | 0.067                                |
| S 83/84                                           | 0.984                        | NS               | 6  | 0.917          | NS               | 11 | 1.686               | 0.120                                |
| S 83/85                                           | 0.984                        | NS               | 6  | 0.957          | NS               | 11 | 0.575               | 0.577                                |
| S 83/86                                           | 0.984                        | NS               | 5  | 0.753          | NS               | 10 | 1.624               | 0.136                                |
| S 83/87                                           | 0.984                        | NS               | 5  | 0.396          | NS               | 10 | 2.762               | 0.020                                |
| S 83/88                                           | 0.984                        | NS               | 4  | 0.802          | NS               | 9  | 1.542               | 0.157                                |
| S 83/89                                           | 0.984                        | NS               | 4  | 0.895          | NS               | 9  | -1.164              | 0.274                                |
| S 84/85                                           | 0.917                        | NS               | 6  | 0.957          | NS               | 12 | -0.997              | 0.338                                |
| S 84/86                                           | 0.917                        | NS               | 5  | 0.753          | NS               | 11 | -0.122              | 0.905                                |
| S 84/87                                           | 0.917                        | NS               | 5  | 0.396          | NS               | 11 | 1.050               | 0.316                                |
| S 84/88                                           | 0.917                        | NS               | 4  | 0.802          | NS               | 10 | -0.125              | 0.903                                |
| S 84/89                                           | 0.917                        | NS               | 4  | 0.895          | NS               | 10 | 0.628               | 0.544                                |
| S 85/86                                           | 0.957                        | NS               | 5  | 0.753          | NS               | 11 | 0.894               | 0.390                                |
| S 85/87                                           | 0.957                        | NS               | 5  | 0.396          | NS               | 11 | 1.927               | 0.080                                |
| S 85/88                                           | 0.957                        | NS               | 4  | 0.802          | NS               | 10 | 0.835               | 0.423                                |
| S 85/89                                           | 0.957                        | NS               | 4  | 0.895          | NS               | 10 | -0.447              | 0.664                                |
| S 86/87                                           | 0.753                        | NS               | 5  | 0.396          | NS               | 10 | 1.259               | 0.237                                |
| S 86/88                                           | 0.753                        | NS               | 4  | 0.802          | NS               | 9  | -0.009              | 0.993                                |
| S 86/89                                           | 0.753                        | NS               | 4  | 0.895          | NS               | 9  | 0.558               | 0.591                                |
| S 87/88                                           | 0.396                        | NS               | 4  | 0.802          | NS               | 9  | -1.238              | 0.247                                |
| S 87/89                                           | 0.396                        | NS               | 4  | 0.895          | NS               | 9  | 1.916               | 0.088                                |
| S 88/89                                           | 0.802                        | NS               | 4  | 0.895          | NS               | 9  | 0.736               | 0.48                                 |

\*Data was not transformed

Table A-8. Results of Winter BACI Comparisons of Diversity between Control (FCD) and Experimental (FEX) Sites, 1983-88, cont.

| Comparison:<br>(Bef/Aft, Bef/Bef,<br>or Aft/Aft) | DF | Tukey's Test for Additivity* |                  |    | L - test*      |                  |    |                     |                                      |      |
|--------------------------------------------------|----|------------------------------|------------------|----|----------------|------------------|----|---------------------|--------------------------------------|------|
|                                                  |    | BEFORE<br>Prob.              | Sig.<br>p < 0.05 | DF | AFTER<br>Prob. | Sig.<br>p < 0.05 | DF | Unpaired<br>t-value | Probability<br>(two-tailed) p < 0.05 | Sig. |
| W 83-85/86-88                                    | 18 | 0.961                        | NS               | 11 | 0.103          | NS               | 29 | -0.977              | 0.337                                | NS   |
| W 83/84                                          | 5  | 0.528                        | NS               | 5  | 0.742          | NS               | 10 | -0.046              | 0.964                                | NS   |
| W 83/85                                          | 5  | 0.528                        | NS               | 6  | 0.132          | NS               | 11 | 0.193               | 0.850                                | NS   |
| W 83/86                                          | 5  | 0.528                        | NS               | 5  | 0.599          | NS               | 10 | 1.270               | 0.233                                | NS   |
| W 83/87                                          | 5  | 0.528                        | NS               | 1  | -              | -                | 6  | 0.360               | 0.731                                | NS   |
| W 83/88                                          | 5  | 0.528                        | NS               | 3  | 0.232          | NS               | 8  | -0.129              | 0.900                                | NS   |
| W 84/85                                          | 5  | 0.742                        | NS               | 6  | 0.132          | NS               | 11 | 0.194               | 0.850                                | NS   |
| W 84/86                                          | 5  | 0.742                        | NS               | 5  | 0.599          | NS               | 10 | 0.975               | 0.352                                | NS   |
| W 84/87                                          | 5  | 0.742                        | NS               | 1  | -              | -                | 6  | 0.242               | 0.817                                | NS   |
| W 84/88                                          | 5  | 0.742                        | NS               | 3  | 0.232          | NS               | 8  | -0.124              | 0.904                                | NS   |
| W 85/86                                          | 6  | 0.132                        | NS               | 5  | 0.599          | NS               | 11 | 0.945               | 0.365                                | NS   |
| W 85/87                                          | 6  | 0.132                        | NS               | 1  | -              | -                | 7  | 0.150               | 0.885                                | NS   |
| W 85/88                                          | 6  | 0.132                        | NS               | 3  | 0.232          | NS               | 9  | 0.056               | 0.957                                | NS   |
| W 86/87                                          | 5  | 0.599                        | NS               | 1  | -              | -                | 6  | -0.546              | 0.604                                | NS   |
| W 86/88                                          | 5  | 0.599                        | NS               | 3  | 0.232          | NS               | 8  | 0.967               | 0.362                                | NS   |
| W 87/88                                          | 1  | -                            | -                | 3  | 0.232          | NS               | 4  | 0.225               | 0.833                                | NS   |

\*Data was not transformed

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

| Comparison:<br>(Bef/Aft., Bef/Bef,<br>or Aft/Aft) | DF | Tukey's Test for Additivity* |                  |    |                | t - test*        |    |                     |                                      |      |
|---------------------------------------------------|----|------------------------------|------------------|----|----------------|------------------|----|---------------------|--------------------------------------|------|
|                                                   |    | BEFORE<br>Prob.              | Sig.<br>p < 0.05 | DF | AFTER<br>Prob. | Sig.<br>p < 0.05 | DF | Unpaired<br>t-value | Probability<br>(two-tailed) p < 0.05 | Sig. |
| 6/83-4/86 //                                      | 38 | 0.163                        | NS               | 34 | 0.145          | NS               | 72 | -3.671              | 0.0005                               | S    |
| 5/86-9/89                                         |    |                              |                  |    |                |                  |    |                     |                                      |      |
| S 83-85/86-89                                     | 19 | 0.497                        | NS               | 22 | 0.031          | S                | 41 | -2.360              | 0.023                                | S    |
| S 83/84                                           | 5  | 0.563                        | NS               | 6  | 0.371          | NS               | 11 | 1.904               | 0.083                                | NS   |
| S 83/85                                           | 5  | 0.563                        | NS               | 6  | 0.711          | NS               | 11 | 0.565               | 0.584                                | NS   |
| S 83/86                                           | 5  | 0.563                        | NS               | 5  | 0.935          | NS               | 10 | 1.372               | 0.200                                | NS   |
| S 83/87                                           | 5  | 0.563                        | NS               | 5  | 0.092          | NS               | 10 | 2.829               | 0.018                                | S    |
| S 83/88                                           | 5  | 0.563                        | NS               | 4  | 0.865          | NS               | 9  | 2.147               | 0.060                                | NS   |
| S 83/89                                           | 5  | 0.563                        | NS               | 4  | 0.666          | NS               | 9  | -1.277              | 0.234                                | NS   |
| S 84/85                                           | 6  | 0.371                        | NS               | 6  | 0.711          | NS               | 12 | -1.323              | 0.211                                | NS   |
| S 84/86                                           | 6  | 0.371                        | NS               | 5  | 0.935          | NS               | 11 | -0.324              | 0.752                                | NS   |
| S 84/87                                           | 6  | 0.371                        | NS               | 5  | 0.092          | NS               | 11 | 1.525               | 0.155                                | NS   |
| S 84/88                                           | 6  | 0.371                        | NS               | 4  | 0.865          | NS               | 10 | 0.625               | 0.546                                | NS   |
| S 84/89                                           | 6  | 0.371                        | NS               | 4  | 0.666          | NS               | 10 | 0.445               | 0.666                                | NS   |
| S 85/86                                           | 6  | 0.711                        | NS               | 5  | 0.935          | NS               | 11 | 0.863               | 0.406                                | NS   |
| S 85/87                                           | 6  | 0.711                        | NS               | 5  | 0.092          | NS               | 11 | 2.418               | 0.034                                | S    |
| S 85/88                                           | 6  | 0.711                        | NS               | 4  | 0.865          | NS               | 10 | 1.661               | 0.120                                | NS   |
| S 85/89                                           | 6  | 0.711                        | NS               | 4  | 0.666          | NS               | 10 | -0.764              | 0.462                                | NS   |
| S 86/87                                           | 5  | 0.935                        | NS               | 5  | 0.092          | NS               | 10 | 1.564               | 0.149                                | NS   |
| S 86/88                                           | 5  | 0.935                        | NS               | 4  | 0.865          | NS               | 9  | 0.799               | 0.445                                | NS   |
| S 86/89                                           | 5  | 0.935                        | NS               | 4  | 0.666          | NS               | 9  | 0.092               | 0.929                                | NS   |
| S 87/88                                           | 5  | 0.092                        | NS               | 4  | 0.865          | NS               | 9  | -0.853              | 0.416                                | NS   |
| S 87/89                                           | 5  | 0.092                        | NS               | 4  | 0.666          | NS               | 9  | 1.663               | 0.131                                | NS   |
| S 88/89                                           | 4  | 0.865                        | NS               | 4  | 0.666          | NS               | 9  | 0.980               | 0.353                                | NS   |

\*Data was log(x+1) transformed

Table A-9. Results of Winter BACI Comparisons of Evenness between Control (FCD) and Experimental (FEX) Sites, 1983-88, cont.

| Comparison:<br>(Bef/Aft, Bef/Bef,<br>or Aft/Aft) | DF | Tukey's Test for Additivity* |                  |    | L-test*        |                  |    |                     |                             |                  |
|--------------------------------------------------|----|------------------------------|------------------|----|----------------|------------------|----|---------------------|-----------------------------|------------------|
|                                                  |    | BEFORE<br>Prob.              | Sig.<br>p < 0.05 | DF | AFTER<br>Prob. | Sig.<br>p < 0.05 | DF | Unpaired<br>t-value | Probability<br>(two-tailed) | Sig.<br>p < 0.05 |
| W 83-85/86-88                                    | 18 | 0.098                        | NS               | 11 | 0.313          | NS               | 29 | -2.440              | 0.021                       | S                |
| W 83/84                                          | 5  | 0.590                        | NS               | 5  | 0.719          | NS               | 10 | -0.165              | 0.872                       | NS               |
| W 83/85                                          | 5  | 0.590                        | NS               | 6  | 0.036          | S                | 11 | -1.013              | 0.333                       | NS               |
| W 83/86                                          | 5  | 0.590                        | NS               | 5  | 0.639          | NS               | 10 | 1.106               | 0.295                       | NS               |
| W 83/87                                          | 5  | 0.590                        | NS               | 1  | -              | -                | 6  | 1.230               | 0.265                       | NS               |
| W 83/88                                          | 5  | 0.590                        | NS               | 3  | 0.018          | S                | 8  | -1.021              | 0.337                       | NS               |
| W 84/85                                          | 5  | 0.719                        | NS               | 6  | 0.036          | S                | 11 | -0.880              | 0.398                       | NS               |
| W 84/86                                          | 5  | 0.719                        | NS               | 5  | 0.639          | NS               | 10 | 1.191               | 0.261                       | NS               |
| W 84/87                                          | 5  | 0.719                        | NS               | 1  | -              | -                | 6  | 1.385               | 0.215                       | NS               |
| W 84/88                                          | 5  | 0.719                        | NS               | 3  | 0.018          | S                | 8  | -1.144              | 0.286                       | NS               |
| W 85/86                                          | 6  | 0.036                        | S                | 5  | 0.639          | NS               | 11 | 1.712               | 0.115                       | NS               |
| W 85/87                                          | 6  | 0.036                        | S                | 1  | -              | -                | 7  | 1.652               | 0.142                       | NS               |
| W 86/88                                          | 6  | 0.036                        | S                | 3  | 0.018          | S                | 9  | -1.677              | 0.128                       | NS               |
| W 86/87                                          | 5  | 0.639                        | NS               | 1  | -              | -                | 6  | -0.141              | 0.893                       | NS               |
| W 86/80                                          | 5  | 0.639                        | NS               | 3  | 0.018          | S                | 8  | 0.274               | 0.791                       | NS               |
| W 87/88                                          | 1  | -                            | -                | 3  | 0.018          | S                | 4  | 0.097               | 0.927                       | NS               |

\*Data was log(x+1) transformed

Table A-10. Results of BACI Comparisons of Gross Primary Production between Control (FCD) and Experimental (FEX) Sites.  
1984-1989.

| Comparison   | DF | Tukey's Test for Additivity* |                  |    |                | t - test*        |                     |                                      |
|--------------|----|------------------------------|------------------|----|----------------|------------------|---------------------|--------------------------------------|
|              |    | BEFORE<br>Prob.              | Sig.<br>p < 0.05 | DF | AFTER<br>Prob. | Sig.<br>p < 0.05 | Unpaired<br>t-value | Probability<br>(two-tailed) p < 0.05 |
| 7/84-8/85 // | 10 | 0.513                        | NS               | 34 | 0.596          | NS               | -0.106              | 0.916                                |
| 6/86-8/89    |    |                              |                  |    |                |                  |                     |                                      |
| 84/85        | 3  | 0.950                        | NS               | 6  | 0.620          | NS               | -0.745              | 0.475                                |
| 84/86        | 3  | 0.950                        | NS               | 8  | 0.661          | NS               | -0.657              | 0.524                                |
| 84/87        | 3  | 0.950                        | NS               | 5  | 0.103          | NS               | -0.661              | 0.527                                |
| 84/88        | 3  | 0.950                        | NS               | 9  | 0.951          | NS               | -1.073              | 0.305                                |
| 84/89        | 3  | 0.950                        | NS               | 9  | 0.814          | NS               | -0.427              | 0.677                                |
| 85/86        | 6  | 0.620                        | NS               | 8  | 0.661          | NS               | 0.537               | 0.600                                |
| 85/87        | 6  | 0.620                        | NS               | 5  | 0.103          | NS               | 0.099               | 0.923                                |
| 85/88        | 6  | 0.620                        | NS               | 9  | 0.951          | NS               | 0.108               | 0.916                                |
| 85/89        | 6  | 0.620                        | NS               | 9  | 0.814          | NS               | 0.726               | 0.479                                |
| 86/87        | 8  | 0.661                        | NS               | 5  | 0.103          | NS               | -0.407              | 0.691                                |
| 86/88        | 8  | 0.661                        | NS               | 9  | 0.951          | NS               | -0.750              | 0.464                                |
| 86/89        | 8  | 0.661                        | NS               | 9  | 0.814          | NS               | 0.328               | 0.747                                |
| 87/88        | 5  | 0.103                        | NS               | 9  | 0.951          | NS               | -0.043              | 0.966                                |
| 87/89        | 5  | 0.103                        | NS               | 9  | 0.814          | NS               | 0.595               | 0.562                                |
| 88/89        | 9  | 0.951                        | NS               | 9  | 0.814          | NS               | 0.984               | 0.338                                |

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

APPENDIX B:

BACI Analyses for Diatom Abundance

Table B-1. Results of BACI Comparisons of *Achnanthes minutissima* (Summer 1983-1989).

| Species                       | Comparison    | Tukey's Test for Additivity |      |    |       | t - test |                  |                                 |
|-------------------------------|---------------|-----------------------------|------|----|-------|----------|------------------|---------------------------------|
|                               |               | BEFORE                      | Sig. | DF | AFTER | Sig.     | Unpaired t-value | Probability (two-tailed) p<0.05 |
| <i>Achnanthes minutissima</i> | S 83-85/86-89 | 0.064                       | NS   | 13 | 0.182 | NS       | 0.998            | 0.325                           |
|                               | S 83/84       | -                           | -    | 1  | 0.383 | NS       | -0.658           | 0.535                           |
|                               | S 83/85       | -                           | -    | 1  | 0.106 | NS       | 0.348            | 0.740                           |
|                               | S 83/86       | -                           | -    | 1  | 0.598 | NS       | -0.862           | 0.422                           |
|                               | S 83/87       | -                           | -    | 1  | 0.354 | NS       | -0.386           | 0.713                           |
|                               | S 83/88       | -                           | -    | 1  | 0.606 | NS       | 0.079            | 0.940                           |
|                               | S 83/89       | -                           | -    | 1  | 0.001 | S        | 0.446            | 0.667                           |
|                               | S 84/85       | 0.383                       | NS   | 5  | 0.106 | NS       | 1.349            | 0.207                           |
|                               | S 84/86       | 0.383                       | NS   | 5  | 0.598 | NS       | -0.528           | 0.609                           |
|                               | S 84/87       | 0.383                       | NS   | 5  | 0.354 | NS       | 0.034            | 0.974                           |
|                               | S 84/88       | 0.383                       | NS   | 5  | 0.606 | NS       | 0.986            | 0.350                           |
|                               | S 84/89       | 0.383                       | NS   | 5  | 0.001 | S        | -0.659           | 0.526                           |
|                               | S 85/86       | 0.106                       | NS   | 5  | 0.598 | NS       | -1.685           | 0.123                           |
|                               | S 85/87       | 0.106                       | NS   | 5  | 0.354 | NS       | -0.934           | 0.372                           |
|                               | S 85/88       | 0.106                       | NS   | 5  | 0.606 | NS       | -0.358           | 0.728                           |
|                               | S 85/89       | 0.106                       | NS   | 5  | 0.001 | S        | 0.623            | 0.549                           |
|                               | S 86/87       | 0.598                       | NS   | 5  | 0.354 | NS       | 0.448            | 0.664                           |
|                               | S 86/88       | 0.598                       | NS   | 5  | 0.606 | NS       | 1.335            | 0.215                           |
|                               | S 86/89       | 0.598                       | NS   | 5  | 0.001 | S        | -1.056           | 0.318                           |
|                               | S 87/88       | 0.354                       | NS   | 5  | 0.606 | NS       | 0.649            | 0.533                           |
|                               | S 87/89       | 0.354                       | NS   | 5  | 0.001 | S        | -0.438           | 0.672                           |
|                               | S 88/89       | 0.606                       | NS   | 4  | 0.001 | S        | -0.004           | 0.997                           |



Table B-2. Results of BACI Comparisons of *Cocconeis* placentula (Summer 1983-1989).

| Species                        | Comparison    | Tukey's Test for Additivity |        |       |        | t - test |              |        |
|--------------------------------|---------------|-----------------------------|--------|-------|--------|----------|--------------|--------|
|                                |               | BEFORE                      | Sig.   | AFTER | Sig.   | Unpaired | Probability  | Sig.   |
|                                |               | DF                          | p<0.05 | DF    | p<0.05 | t-value  | (two-tailed) | p<0.05 |
| <i>Cocconeis</i><br>placentula | S 83-85/86-89 | 13                          | 0.515  | 22    | NS     | 38       | 0.288        | NS     |
|                                | S 83/84       | 1                           | -      | 5     | NS     | 6        | 0.040        | S      |
|                                | S 83/85       | 1                           | -      | 5     | NS     | 6        | 0.059        | NS     |
|                                | S 83/86       | 1                           | -      | 5     | NS     | 6        | 0.055        | NS     |
|                                | S 83/87       | 1                           | -      | 5     | NS     | 6        | 0.330        | NS     |
|                                | S 83/88       | 1                           | -      | 4     | NS     | 5        | 0.189        | NS     |
|                                | S 83/89       | 1                           | -      | 4     | NS     | 8        | 0.470        | NS     |
|                                | S 84/85       | 5                           | 0.629  | 5     | NS     | 10       | 0.848        | NS     |
|                                | S 84/86       | 5                           | 0.629  | 5     | NS     | 10       | 0.346        | NS     |
|                                | S 84/87       | 5                           | 0.529  | 5     | NS     | 10       | 0.272        | NS     |
|                                | S 84/88       | 5                           | 0.629  | 4     | NS     | 9        | 0.332        | NS     |
|                                | S 84/89       | 5                           | 0.629  | 4     | NS     | 9        | 0.379        | NS     |
|                                | S 85/86       | 5                           | 0.410  | 5     | NS     | 10       | 0.302        | NS     |
|                                | S 85/87       | 5                           | 0.410  | 5     | NS     | 10       | 0.344        | NS     |
|                                | S 85/88       | 5                           | 0.410  | 4     | NS     | 9        | 0.305        | NS     |
|                                | S 85/89       | 5                           | 0.410  | 4     | NS     | 9        | 0.410        | NS     |
|                                | S 86/87       | 5                           | 0.836  | 5     | NS     | 10       | 0.117        | NS     |
|                                | S 86/88       | 5                           | 0.836  | 4     | NS     | 9        | 0.650        | NS     |
|                                | S 86/89       | 5                           | 0.836  | 4     | NS     | 9        | 0.123        | NS     |
|                                | S 87/88       | 5                           | 0.710  | 4     | NS     | 9        | 0.163        | NS     |
|                                | S 87/89       | 5                           | 0.710  | 4     | NS     | 9        | 0.714        | NS     |
|                                | S 88/89       | 4                           | 0.285  | 4     | NS     | 9        | 0.368        | NS     |

Table B-3. Results of BACI Comparisons of *Achnanthes minutissima* (Winter 1983-1988).

| Species                       | Comparison    | DF | Tukey's Test for Additivity |        |       |        | t-test   |              |        |
|-------------------------------|---------------|----|-----------------------------|--------|-------|--------|----------|--------------|--------|
|                               |               |    | BEFORE                      | Sig.   | AFTER | Sig.   | Unpaired | Probability  | Sig.   |
|                               |               |    | Prob.                       | p<0.05 | Prob. | p<0.05 | t-value  | (two-tailed) | p<0.05 |
| <i>Achnanthes minutissima</i> | W 83-85/86-88 | 16 | 0.084                       | NS     | 0.468 | NS     | 0.133    | 0.896        | NS     |
|                               | W 83/84       | 5  | 0.199                       | NS     | 0.031 | S      | 3.217    | 0.012        | S      |
|                               | W 83/85       | 5  | 0.199                       | NS     | 0.013 | S      | -2.254   | 0.046        | NS     |
|                               | W 83/86       | 5  | 0.199                       | NS     | 0.370 | NS     | 1.339    | 0.210        | NS     |
|                               | W 83/87       | 5  | 0.199                       | NS     | -     | -      | -1.768   | 0.127        | NS     |
|                               | W 83/88       | 5  | 0.199                       | NS     | 0.009 | S      | -0.057   | 0.956        | NS     |
|                               | W 84/85       | 3  | 0.031                       | S      | 0.013 | S      | -4.318   | 0.002        | S      |
|                               | W 84/86       | 3  | 0.031                       | S      | 0.370 | NS     | -2.273   | 0.053        | NS     |
|                               | W 84/87       | 3  | 0.031                       | S      | -     | -      | -2.318   | 0.081        | NS     |
|                               | W 84/88       | 3  | 0.031                       | S      | 0.009 | S      | 1.375    | 0.218        | NS     |
|                               | W 85/86       | 6  | 0.013                       | S      | 0.370 | NS     | 3.067    | 0.011        | S      |
|                               | W 85/87       | 6  | 0.013                       | S      | -     | -      | 0.065    | 0.950        | NS     |
|                               | W 85/88       | 6  | 0.013                       | S      | 0.009 | S      | -0.757   | 0.468        | NS     |
|                               | W 86/87       | 5  | 0.370                       | NS     | -     | -      | -1.945   | 0.100        | NS     |
|                               | W 86/88       | 5  | 0.370                       | NS     | 0.009 | S      | 0.382    | 0.712        | NS     |
|                               | W 87/88       | 1  | -                           | -      | 0.009 | S      | -0.367   | 0.732        | NS     |

Table B-4. Results of BACI Comparisons of *Fragilaria vaucheriae* (Winter 1983-1988).

| Species                      | Comparison    | DF | Tukey's Test for Additivity |        |       |        | t - test |              |        |
|------------------------------|---------------|----|-----------------------------|--------|-------|--------|----------|--------------|--------|
|                              |               |    | BEFORE                      | Sig.   | AFTER | Sig.   | Unpaired | Probability  | Sig.   |
|                              |               |    | Prob.                       | p<0.05 | Prob. | p<0.05 | t-value  | (two-tailed) | p<0.05 |
| <i>Fragilaria vaucheriae</i> | W 83-85/86-88 | 16 | 0.668                       | NS     | 0.881 | NS     | 0.607    | 0.549        | NS     |
|                              | W 83/84       | 5  | 0.044                       | S      | 0.299 | NS     | -2.437   | 0.041        | S      |
|                              | W 83/85       | 5  | 0.044                       | S      | 0.697 | NS     | 0.474    | 0.645        | NS     |
|                              | W 83/86       | 5  | 0.044                       | S      | 0.001 | S      | 0.896    | 0.391        | NS     |
|                              | W 83/87       | 5  | 0.044                       | S      | -     | -      | -0.053   | 0.960        | NS     |
|                              | W 83/88       | 5  | 0.044                       | S      | 0.115 | NS     | 1.505    | 0.171        | NS     |
|                              | W 84/85       | 3  | 0.299                       | NS     | 0.697 | NS     | 0.924    | 0.380        | NS     |
|                              | W 84/86       | 3  | 0.299                       | NS     | 0.001 | S      | 1.684    | 0.131        | NS     |
|                              | W 84/87       | 3  | 0.299                       | NS     | -     | -      | 1.511    | 0.205        | NS     |
|                              | W 84/88       | 3  | 0.299                       | NS     | 0.115 | NS     | -0.927   | 0.390        | NS     |
|                              | W 85/86       | 6  | 0.697                       | NS     | 0.001 | S      | 0.822    | 0.428        | NS     |
|                              | W 85/87       | 6  | 0.697                       | NS     | -     | -      | -0.421   | 0.687        | NS     |
|                              | W 85/88       | 6  | 0.697                       | NS     | 0.115 | NS     | 2.153    | 0.060        | NS     |
|                              | W 86/87       | 5  | 0.001                       | S      | -     | -      | -0.519   | 0.622        | NS     |
|                              | W 86/88       | 5  | 0.001                       | S      | 0.115 | NS     | 0.399    | 0.701        | NS     |
|                              | W 87/88       | 1  | -                           | -      | 0.115 | NS     | 1.671    | 0.170        | NS     |

Table B-5. Results of BACI Comparisons of Gomphonema olivaceum (Winter 1983-1988).

| Species                 | Comparison    | DF | Tukey's Test for Additivity |       |                |       | Sig.<br>p<0.05 | DF | t - test            |                             |                |
|-------------------------|---------------|----|-----------------------------|-------|----------------|-------|----------------|----|---------------------|-----------------------------|----------------|
|                         |               |    | BEFORE                      | Prob. | Sig.<br>p<0.05 | AFTER | Prob.          |    | Unpaired<br>t-value | Probability<br>(two-tailed) | Sig.<br>p<0.05 |
| Gomphonema<br>olivaceum | W 83-85/86-88 | 16 | 0.313                       |       | NS             | 0.499 |                | 11 | 1.548               | 0.133                       | NS             |
|                         | W 83/84       | 5  | 0.986                       |       | NS             | 0.693 |                | 3  | 0.847               | 0.429                       | NS             |
|                         | W 83/85       | 5  | 0.986                       |       | NS             | 0.108 |                | 6  | -0.418              | 0.688                       | NS             |
|                         | W 83/86       | 5  | 0.986                       |       | NS             | 0.841 |                | 5  | -1.824              | 0.095                       | NS             |
|                         | W 83/87       | 5  | 0.986                       |       | NS             | -     |                | 1  | 1.481               | 0.213                       | NS             |
|                         | W 83/88       | 5  | 0.986                       |       | NS             | 0.793 |                | 3  | 2.467               | 0.039                       | S              |
|                         | W 84/85       | 3  | 0.693                       |       | NS             | 0.108 |                | 6  | 2.066               | 0.073                       | NS             |
|                         | W 84/86       | 3  | 0.693                       |       | NS             | 0.841 |                | 5  | 2.661               | 0.026                       | S              |
|                         | W 84/87       | 3  | 0.693                       |       | NS             | -     |                | 1  | 1.213               | 0.271                       | NS             |
|                         | W 84/88       | 3  | 0.693                       |       | NS             | 0.793 |                | 3  | 2.155               | 0.075                       | NS             |
|                         | W 85/86       | 6  | 0.108                       |       | NS             | 0.841 |                | 5  | 1.546               | 0.153                       | NS             |
|                         | W 85/87       | 6  | 0.108                       |       | NS             | -     |                | 1  | 2.580               | 0.026                       | S              |
|                         | W 85/88       | 6  | 0.108                       |       | NS             | 0.793 |                | 3  | 1.279               | 0.233                       | NS             |
|                         | W 86/87       | 5  | 0.841                       |       | NS             | -     |                | 1  | 0.178               | 0.863                       | NS             |
|                         | W 86/88       | 5  | 0.841                       |       | NS             | 0.793 |                | 3  | 2.069               | 0.072                       | NS             |
|                         | W 87/88       | 1  | -                           |       | -              | 0.793 |                | 3  | 1.104               | 0.331                       | NS             |

Table B-6. Results of BACI Comparisons of *Cymbella minuta* (Summer 1983-1989).

| Species                | Comparison    | Tukey's Test for Additivity |        |       |        | t - test |              |        |
|------------------------|---------------|-----------------------------|--------|-------|--------|----------|--------------|--------|
|                        |               | BEFORE                      | Sig.   | AFTER | Sig.   | Unpaired | Probability  | Sig.   |
|                        |               | Prob.                       | p<0.05 | Prob. | p<0.05 | t-value  | (two-tailed) | p<0.05 |
|                        |               | DF                          |        | DF    |        | DF       |              |        |
| <i>Cymbella minuta</i> | S 83-85/86-89 | 15                          | NS     | 22    | NS     | 37       | 0.088        | 0.930  |
|                        | S 83/84       | 3                           | NS     | 5     | NS     | 8        | 0.178        | 0.863  |
|                        | S 83/85       | 3                           | NS     | 5     | NS     | 8        | 0.014        | 0.989  |
|                        | S 83/86       | 3                           | NS     | 5     | NS     | 8        | 1.253        | 0.246  |
|                        | S 83/87       | 3                           | NS     | 5     | S      | 8        | 0.600        | 0.565  |
|                        | S 83/88       | 3                           | NS     | 5     | NS     | 8        | -0.821       | 0.436  |
|                        | S 83/89       | 3                           | NS     | 4     | S      | 7        | -0.731       | 0.488  |
|                        | S 84/85       | 5                           | NS     | 5     | NS     | 10       | -0.135       | 0.896  |
|                        | S 84/86       | 5                           | NS     | 5     | NS     | 10       | 1.466        | 0.173  |
|                        | S 84/87       | 5                           | NS     | 5     | S      | 10       | 0.645        | 0.534  |
|                        | S 84/88       | 5                           | NS     | 5     | NS     | 10       | -1.182       | 0.265  |
|                        | S 84/89       | 5                           | NS     | 4     | S      | 9        | -1.201       | 0.260  |
|                        | S 85/86       | 5                           | NS     | 5     | NS     | 10       | 1.197        | 0.259  |
|                        | S 85/87       | 5                           | NS     | 5     | S      | 10       | 0.638        | 0.538  |
|                        | S 85/88       | 5                           | NS     | 5     | NS     | 10       | -0.895       | 0.392  |
|                        | S 85/89       | 5                           | NS     | 4     | S      | 9        | -0.644       | 0.524  |
|                        | S 86/87       | 5                           | NS     | 5     | S      | 10       | -0.323       | 0.754  |
|                        | S 86/88       | 5                           | NS     | 5     | NS     | 10       | -2.008       | 0.072  |
|                        | S 86/89       | 5                           | NS     | 4     | S      | 9        | -2.199       | 0.055  |
|                        | S 87/88       | 5                           | S      | 5     | NS     | 10       | -1.379       | 0.198  |
|                        | S 87/89       | 5                           | S      | 4     | S      | 9        | -1.210       | 0.257  |
|                        | S 88/89       | 5                           | NS     | 4     | S      | 9        | 0.389        | 0.706  |



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

Changes from workplan - None.

Rationale

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

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

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

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

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



dramatically alter the algal species abundances in the periphyton.

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

#### Objective

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

#### Materials and Methods

Small microcosm streamside flow-through artificial streams were used for monitoring effects of grazers on periphyton. These plexiglass streams were constructed from 1.27 cm thick plexiglass and were 1 m long with three 15 cm wide channels fed from a common reservoir. This reservoir was filled by pumping water from the Ford River through a 300 micron mesh filter into the reservoir. The reservoir also contained polyester fibers as an additional filter to remove suspended sediments. This double filter system proved necessary because of excessive settling of suspended particles on substrates in its absence. The pumps were powered by a heavy duty, marine 12 volt battery, which was exchanged and recharged daily. Two of these

streams were constructed so that identical studies could be conducted at both FEX and FCD sites simultaneously.

Each set of streamside channels was fed from a common water source, and the three channels were subdivided into four chambers per channel using plastic screen dividers (Fig. 3.1). Since all three channels were fed from a common water source, the 12 chambers represented 12 replicates. This design duplicated use of 12 separate chambers placed in the Ford River and avoided the problem of pseudoreplication as much as possible given the need to use the Ford River as a common water source. Use of additional stream channels would simply increase the replicates without solving the problem of the common water source. In 1987 and 1988, only 6 of these chambers were used per stream (3 controls and 3 experimental chambers), since we concluded that only one grazer level was needed. We used 4 controls and 4 experimental chambers in 1989.

In 1985, 86, 87 and 88 ceramic tiles (3.6 cm <sup>2</sup>) were placed in the river 25-30 days prior to experiments to allow time for algal colonization. Twenty randomly selected tiles were then placed in one of the four separated chambers along each of the three channels of the artificial streams. Each chamber was separated from the next by plastic screen with fine mesh to prevent exchange of grazers between chambers. Tiles were taken at random from each control and treatment chamber at the end of each experiment for determination of chlorophyll a, (n=8 per chamber), organic matter biomass (n=8), and diatom species determinations (n=4). Each level of grazing was always replicated at least three times. The colonized tiles were exposed to grazing for a total of 6 or 7 days (usually 7 except in 1986 when a storm event caused the experiment to be terminated one day earlier than planned).

As indicated in the 1988 annual report, the above protocol was slightly changed for the 1989 experiment. In 1989 the grazer study was conducted for 14 days instead of 7 days as in previous years. This change was incorporated because of the possibility that 7 days is too short for some grazer effects to show up. Many of the studies in the literature, as reviewed above, lasted 14 days or longer. Four replicates of 2 grazer treatments (0 and 30 grazers/chamber) with 20 tiles/chamber were set up at each site on July 28. One half of the tiles (5 for chlorophyll a and 5 for species determination) were collected on August 4 and replaced with 10 colonized tiles of a slightly different size. On August 11 all 20 tiles in each chamber were collected and separated into 14 day tiles and a second set of 7 day tiles. These were used for chlorophyll a and species determinations as mentioned above.

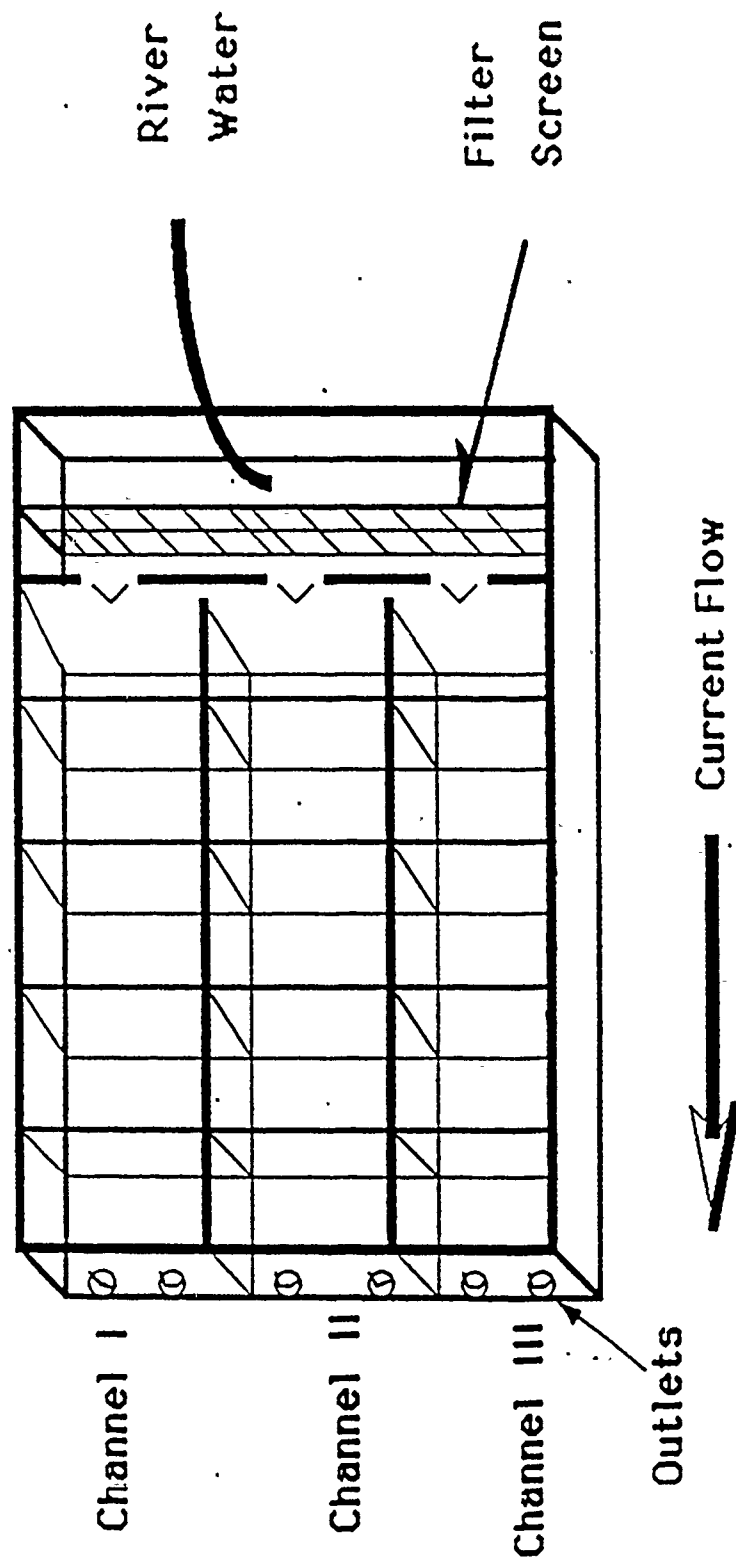


Figure 3.1 Experimental stream used in grazer studies.  
Not drawn to scale.

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

In 1986, the studies at FEX contrasted the effects of grazing by limpets with the effects of grazing by the insect larva, Glossosoma. The results of this study were presented in the 1987 annual report (AE-071). We plan additional analyses of these data and will include them in future annual reports.

In both 1987 and 1988, two levels of tricopteran larvae grazer (Glossosoma nigrior) were used (0 and 30 per chamber). The results of the 1987 study were discussed in the 1988 annual report and the results of the 1988 study are discussed in full here. Data analysis for the 1989 study is in preliminary stages and will be discussed in full next year.

### Results and Discussion

Three level nested ANOVA comparisons using results from both sites showed significant differences between FEX and FCD AFDW-organic matter accumulation (Table 3.1 and Table 3.2). Within a site however, comparing treatments at FEX separately from treatments at FCD, no significant differences were detected between AFDW-organic matter accumulation of control against grazed tiles, i.e. between control and grazed tiles at FEX and between control and grazed tiles at FCD.

Chlorophyll a comparisons indicated no significant differences between sites or treatments (Table 3.2). Thus, no overall clear evidence for grazing significantly altering either chlorophyll a or AFDW-organic matter accumulation levels was evident for the 1988 experiments.

Chlorophyll a and AFDW-organic matter accumulation levels appear not to be very sensitive to grazing induced changes. This may be particularly noticeable in short term experiments run over the course of several days. The same results may not occur in grazing experiments allowed to continue for several weeks. Hill and Knight (1987) observed significant reductions in AFDW-organic matter

accumulation and increases in chlorophyll a after 23 days of grazing pressure. This pattern of ambiguous results for significant and consistent changes in either chlorophyll a or AFDW-organic matter accumulation levels as a result of grazing, is precisely the pattern observed in all previously run experiments (see Annual Reports AE-045, AE-058, AE-071 and AE-084 for 1985, 1986, 1987 and 1988).

Several different aspects of diatom community structure were measured or calculated. These included the Shannon-Wiener index of species diversity, Simpson's index of evenness, as well as determinations of cell density, average individual cell volume, and total biovolume, a crude index of algal biomass. As with organic matter, evenness and diversity showed more variation between sites and replicates than between treatments (Table 3.1). This is consistent with our previous studies and only Dickman and Gochbauer (1978) have documented a grazer effect on the diversity of the periphyton community. In that study, grazers acted to increase the diversity of the community but only after 3-4 weeks of exposure to grazers. The 7 day duration of our study may not have been long enough to allow us to detect a grazer effect on species diversity. Cell density, mean cell volume and total cell biovolume all decreased due to grazing (Tables 3.1 and 3.2). The decrease in cell density is probably a direct result of grazing while the decrease in mean cell volume may be due to the decrease in dominance of Achnanthes minutissima caused by grazing (Fig. 3.2). A. minutissima is the most dominant species on the grazed and ungrazed tiles, and with the exception of C. placentula is one of the larger species present.

In the previous grazer studies, the primary grazer effect (present in 1985 and 86 but not in 87) was a decrease in Cocconeis placentula and an increase in Achnanthes minutissima. It was hypothesized that the grazers selected the larger Cocconeis over Achnanthes allowing Achnanthes to increase in dominance due to decreased competition with Cocconeis. In 1988 the grazers had a significant effect on all 6 of the most dominant species of algae (Table 3.3 and Fig. 3.2). The primary result, however, is that A. minutissima dominance rank decreased due to grazing (slightly at FCD and dramatically at FEX) while C. placentula either increased (FCD) or was unaffected (FEX) due to grazing.

As mentioned in last years annual report we had a problem with silt covering the tiles used as algal substrates in the experimental streams. The silt problem was caused by a storm that increased the turbidity of the Ford river over the course of this study. Even though the experimental streams were cleaned daily, the silt may be

Table 3.1 Results of 3 level nested ANOVA test on 1988 Biological Parameters from the grazer studies.

| Year<br>Parameter    | Source of Variance (level)   |                                           |                                              |
|----------------------|------------------------------|-------------------------------------------|----------------------------------------------|
|                      | Among Sites<br>(FEX and FCD) | Among Treatments<br>(Grazed and Ungrazed) | Among Replicates<br>(3 replicates/Treatment) |
| 1988                 |                              |                                           |                                              |
| Organic matter       | P< 0.01                      | NS                                        | P< 0.05                                      |
| Chlorophyll <u>a</u> | NS                           | NS                                        | NS                                           |
| Evenness             | P< 0.001                     | NS                                        | P< 0.001                                     |
| Diversity            | P< 0.001                     | NS                                        | P< 0.001                                     |
| Cell Density         | P< 0.001                     | P< 0.001                                  | P< 0.001                                     |
| Cell Volume          | NS                           | P< 0.01                                   | P< 0.05                                      |
| Biovolume            | P< 0.01                      | P< 0.001                                  | P< 0.001                                     |

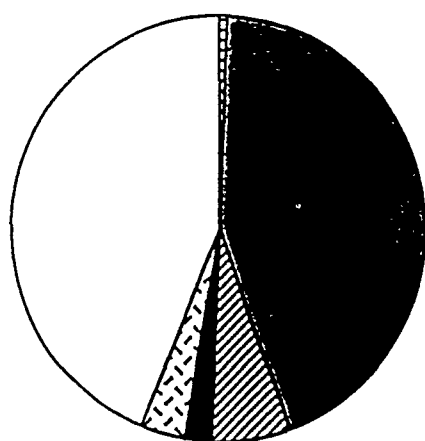
Table 3.2 Means  $\pm$  S.E. of Biological Parameters measured from the Glossosoma grazer study in 1988. Chlorophyll  $a$  =  $\text{mg/m}^2$ , Cell density =  $\text{cells/m}^2 \times 10^8$ , Cell volume =  $\text{microns}^3$  and Total biovolume =  $\text{microns}^3/\text{m}^2 \times 10^{11}$ .  $N = 3$ .

| Parameter         | FCD               |                   |  | FEX               |                   |
|-------------------|-------------------|-------------------|--|-------------------|-------------------|
|                   | Grazed            | Ungrazed          |  | Grazed            | Ungrazed          |
| Organic Matter    | $3.37 \pm 0.42$   | $3.28 \pm 0.55$   |  | $4.97 \pm 0.62$   | $5.15 \pm 0.19$   |
| Chlorophyll $a$   | $9.00 \pm 0.20$   | $9.17 \pm 0.53$   |  | $10.00 \pm 0.59$  | $9.11 \pm 0.47$   |
| Shannon Evenness  | $0.58 \pm 0.01$   | $0.58 \pm 0.01$   |  | $0.70 \pm 0.01$   | $0.69 \pm 0.01$   |
| Shannon Diversity | $2.00 \pm 0.02$   | $1.97 \pm 0.03$   |  | $2.45 \pm 0.04$   | $2.48 \pm 0.02$   |
| Cell Density      | $43.90 \pm 1.57$  | $44.37 \pm 0.57$  |  | $45.14 \pm 2.09$  | $56.21 \pm 1.57$  |
| Cell Volume       | $104.15 \pm 3.41$ | $124.78 \pm 3.14$ |  | $113.13 \pm 4.41$ | $117.59 \pm 7.66$ |
| Cell Biovolume    | $0.94 \pm 0.02$   | $1.11 \pm 0.03$   |  | $1.02 \pm 0.06$   | $1.34 \pm 0.12$   |

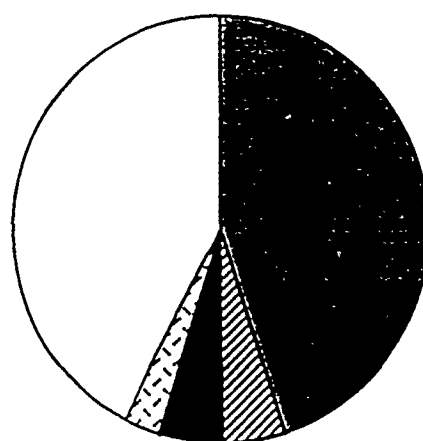
Table 3.3 Results of 3 level nested ANOVA performed on arcsine transformed proportions of the six most dominant diatom species on grazed and ungrazed tiles at FEX and FCD for the 1988 grazer study.

| Species                                                  | Source of Variance |                  |                  |
|----------------------------------------------------------|--------------------|------------------|------------------|
|                                                          | Among Sites        | Among Treatments | Among Replicates |
| <u>Achantheses linearis</u><br>var. <u>linearis</u>      | p< 0.001           | p< 0.01          | p< 0.001         |
| <u>Achnanthes minutissima</u><br>var. <u>minutissima</u> | P< 0.001           | p< 0.001         | p< 0.001         |
| <u>Cocconeis placentula</u>                              | p< 0.001           | p< 0.05          | p< 0.001         |
| <u>Cymbella minuta</u><br>var. <u>minuta</u>             | p< 0.001           | p< 0.001         | NS               |
| <u>Gomphonema parvulum</u><br>var. <u>parvulum</u>       | NS                 | p< 0.001         | p< 0.001         |
| <u>Fragilaria vaucheriae</u><br>var. <u>vaucheriae</u>   | p< 0.001           | p< 0.01          | NS               |

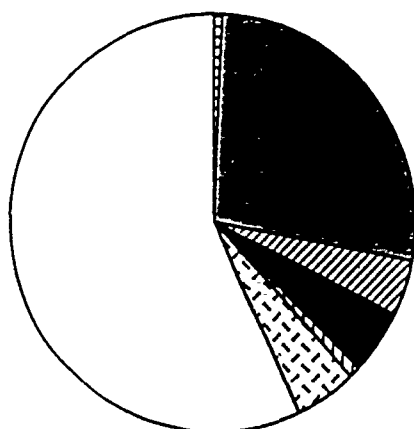




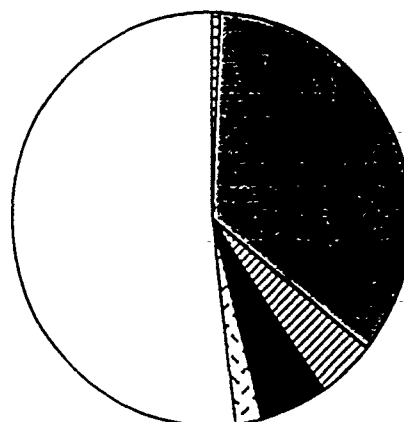
FCD GRAZED



FCD UNGRAZED



FEX GRAZED



FEX UNGRAZED

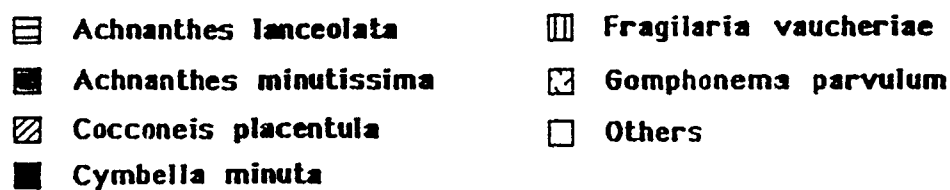


Figure 3.2 Proportion of Total Community Composition of the Six Most Dominant Diatom Species on Grazed and Ungrazed Tiles from the 1988 Grazer Study.

responsible for a large part of the variation experienced between sites (the degree of siltation was different at each site), and between replicates (some chambers were more prone to siltation than others). Siltation may also explain the conflicting results from the 1988 study versus the 1985 and 86 studies. The negative response by A. minutissima to grazing in 1988 may be due to decreased production caused by the silt. As mentioned above, under low light conditions (as would be experienced with high turbidity and silt) the algal community is more susceptible to snail grazer effects than under high light conditions (Lamberti et al. 1989). In previous experiments A. minutissima was able to increase in dominance under grazing pressure because of reduced competition with Cocconeis (even though Achnanthes was also grazed). The silt in 1988 may have limited the ability of A. minutissima to respond positively to grazing as it has in the past.

Due to problems experienced during the course of this study in 1987 and 1988 (we had silt problems in both years) we are hesitant to draw any firm conclusions about the effects of Glossosoma grazers on periphyton communities, or on the effects of ELF radiation on the grazer/periphyton interaction. We do, however, feel that the grazer study has value and will hold off drawing conclusions until the results from 1989 can be analysed. As mentioned earlier, the 1989 study was of a longer duration (14 days) than past experiments and may allow us to detect more subtle grazer effects (such as an increase in diversity as detected by Dickman and Gochbauer (1978)). In addition, the weather remained favorable throughout the 14 days of the experiment, and there were no siltation problems in 1989. We expect to complete analyses of the 1989 grazer studies early in the coming year and will include grazer studies in 1990 only if these results are promising. Otherwise, this work element will be discontinued and additional effort will be diverted to more exhaustive analyses of data in elements 1 and 2. The 1989 data will be presented in the 1990 annual report.

### Summary

Grazing macroinvertebrates can change the composition of the diatom community at densities equal to or greater than densities found in the Ford River. Specifically, Glossoma nigrior, a grazing caddisfly, caused a shift in dominance within the diatom community in 1985 and 1986 with Cocconeis decreasing in abundance and Achnanthes increasing in abundance as grazing pressure increased. Such shifts in community structure occurred at both FEX and FCD despite no significant changes in community based parameters such as chlorophyll a or AFDW-organic matter biomass accumulation.

Results from 1985 were somewhat different from results from 1986. In 1986, the trend towards decreased abundance of Cocconeis and increased abundance of Achnanthes occurred at both sites but was not as significant as in 1985. In 1987, there was no measurable impact of grazers on any aspect of the periphyton community with the possible exception of shifts in dominance of a couple of minor taxa at FEX. In 1988, there was a grazer impact on the dominance of Achnanthes but this impact resulted in a decrease in dominance (opposite the results of 1985 and 86). Between year differences in the impact of grazers on the periphyton communities in our streamside channels may be due to variation in the silt load encountered during the course of the studies. We made some minor modifications in our procedures to avoid such potential confounding problems in 1989 and await final analyses of these data before deciding whether, or how, to proceed with this element.

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

Changes from Original Synopsis - None.

##### *Objectives*

1) To determine whether structural community parameters (diversity, evenness, richness, numbers of individuals) and functional community parameters (total insect biomass, biomass according to functional feeding groups) are affected by E.L.F. electromagnetic fields, and 2) to determine whether growth rates, as monitored by changes in mean dry weight per individual values (MDW/IND) of six species of aquatic insects are altered after E.L.F. activation.

##### *Rationale*

Extremely low frequency electromagnetic fields may affect structural and functional community parameters (A.I.B.S. 1985, Halberg et al. 1975) as well as life-histories of insects (Walters and Carstensen 1986). Although a number of terrestrial animals, including insects (Bindokas et al. 1989, Kirschvink 1989) have been studied with regard to impacts of electromagnetic fields on their behavior, no studies (other than this one) have been done regarding potential E.L.F. effects on stream insects. Because aquatic biota, including bacteria (Frankel et al. 1978) and several species of aquatic vertebrates (Kirschvink 1989) contain magnetite, and some of those species respond to E.L.F. fields in water, it is possible that aquatic insects can detect E.L.F. fields and alter their responses accordingly.

As E.L.F. fields do not appear to operate in biological systems in ways similar to other anthropogenic agents, it is difficult to determine proper measures of exposure (e.g., intensity, frequency, electromagnetic excursions during activation and deactivation periods) for relating those exposures to biotic responses (O.T.A. 1989). One may not make simple assumptions regarding dose-response curves. However, as a first approximation, it may not be unreasonable to accumulate gauss-days for each year of our study to at least see whether any pattern emerges for the biological parameters since E.L.F. activation. As yet, quantitative data on gauss-days each year are not available. Since July of 1986 when E.L.F. was first activated, there has been an increasing frequency and increasing duration of E.L.F. fields. Full power began in the fall of 1989. In an attempt to see whether there was any pattern following a dose-response curve, we have plotted some of our data against years. Assumptions are many, as described above; however, even for

heuristic purposes, we feel illustrations of this type are now appropriate since we have accumulated over two years of pre-operational and over three years of post-operational data.

### *Materials and Methods*

From November of 1983 through September of 1989, 60 micron mesh-lined half cylinder 18 x 28 x 10 cm substrate plastic sampler baskets were filled with benthic substrata and buried flush with the stream bottom at FEX and FCD. From May through September each year, seven replicates for each site were collected monthly, with replacement. Each September, sufficient samplers were placed at the sites to allow for late fall, winter, and early spring collections. (After 1986, January through March collections were excluded, owing to past sampling difficulties.) Meier et al. (1979) showed that 30 to 39 days' incubation of samples in substrates in southern Michigan showed the maximum numbers of individuals colonizing substrates. Our colonization studies in 1983 showed that 30 days' incubation was the most parsimonious incubation period (1984 Annual Report).

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

Statistical analyses for structural and functional community parameters included power tests, coefficient of variation values, Student-t tests, linear regressions, 2-Way and 3-Way ANOVAS, and ANCOVAS. Species overlaps between the two sites were also computed for each month, then for each season (spring, summer, and fall), and finally for each year. In the 1988 Annual Report for this element, MDW/IND values were plotted against

chronological time and/or against physiological time. All six species monitored for changes in MDW/IND values have major growth periods during the summer months. Data for 1989 have been processed only through July, so results for those analyses will appear in the 1990 Annual Report. (The person who identified the insects for the past four years was replaced in September of 1989; therefore, fewer samples were completed during the transition period.)

## Results and Discussion

### Structural Community Indices

Taxon diversity, evenness, richness, and number of individuals were first analyzed with 3-Way ANOVA tests to see whether there were month, year, and site effects in addition to interactions between and among the factors (Table 4.1). It is obvious, both from Table 4.1 and from figures 4.1 through 4.4 that seasonal differences were highly significant for each of these community parameters. Certainly, aquatic insect species in the community have diverse life history patterns. Some are univoltine, many are bivoltine. Times of emergence vary as well as rates of growth. Responses to strong fluctuations in water temperature and velocities during the spring and fall months are also different than responses to relatively stable temperature and velocity regimes during the summer months. As spring, summer, and fall seasons differ from one another, structural community data were segregated according to season for a more detailed analysis.

TABLE 4.1  
3-Way ANOVA Tests for Structural Community Parameters

| Source         | d.f. | F VALUES, LEVELS OF SIGNIFICANCE |          |          |              |
|----------------|------|----------------------------------|----------|----------|--------------|
|                |      | Diversity                        | Evenness | Richness | No. Individ. |
| Mo., Yr., Site | 28   | 2.85***                          | 2.37***  | 2.03***  | 7.84***      |
| Mo., Yr        | 28   | 8.23***                          | 6.80***  | 14.22*** | 16.72***     |
| Mo., Site      | 7    | 13.16***                         | 18.29*** | 2.75**   | 39.53***     |
| Month          | 7    | 59.71***                         | 44.71*** | 26.65*** | 75.91***     |
| Yr. Site       | 4    | 1.93 n.s.                        | 4.71***  | 5.09***  | 17.00***     |
| Year           | 4    | 18.10***                         | 33.98*** | 87.41*** | 40.20***     |
| Site           | 1    | 51.12***                         | 29.59*** | 54.65*** | 40.23***     |
| Error          | 320  |                                  |          |          |              |

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



FIGURE 4.1

# DIFFERENCE VALUES(FEX - FCD), DIVERSITY

H', 1983 - 1989

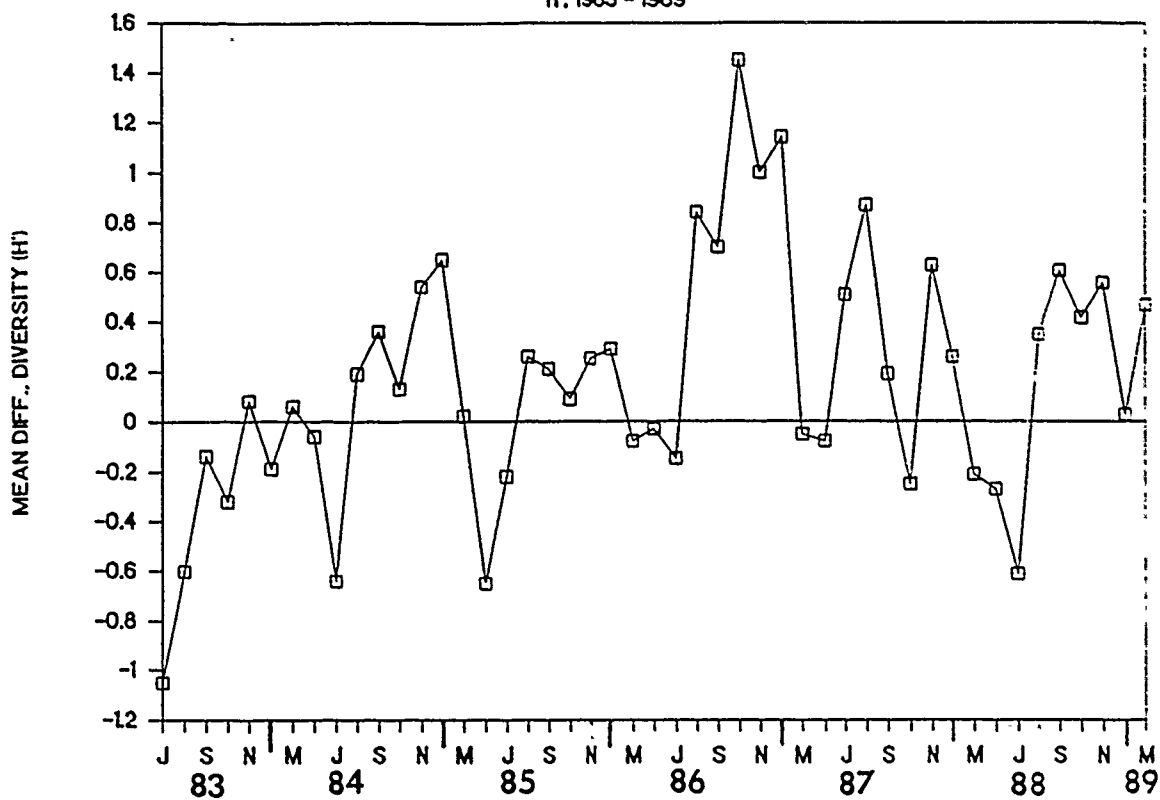


Figure 4.1. Differences in mean taxon diversity, FEX minus FCD. July - Nov., 1983; April through Nov., 1984 - 1988; April, May, 1989.

FIGURE 4.2

# DIFFERENCE VALUES(FEX - FCD), EVENNESS

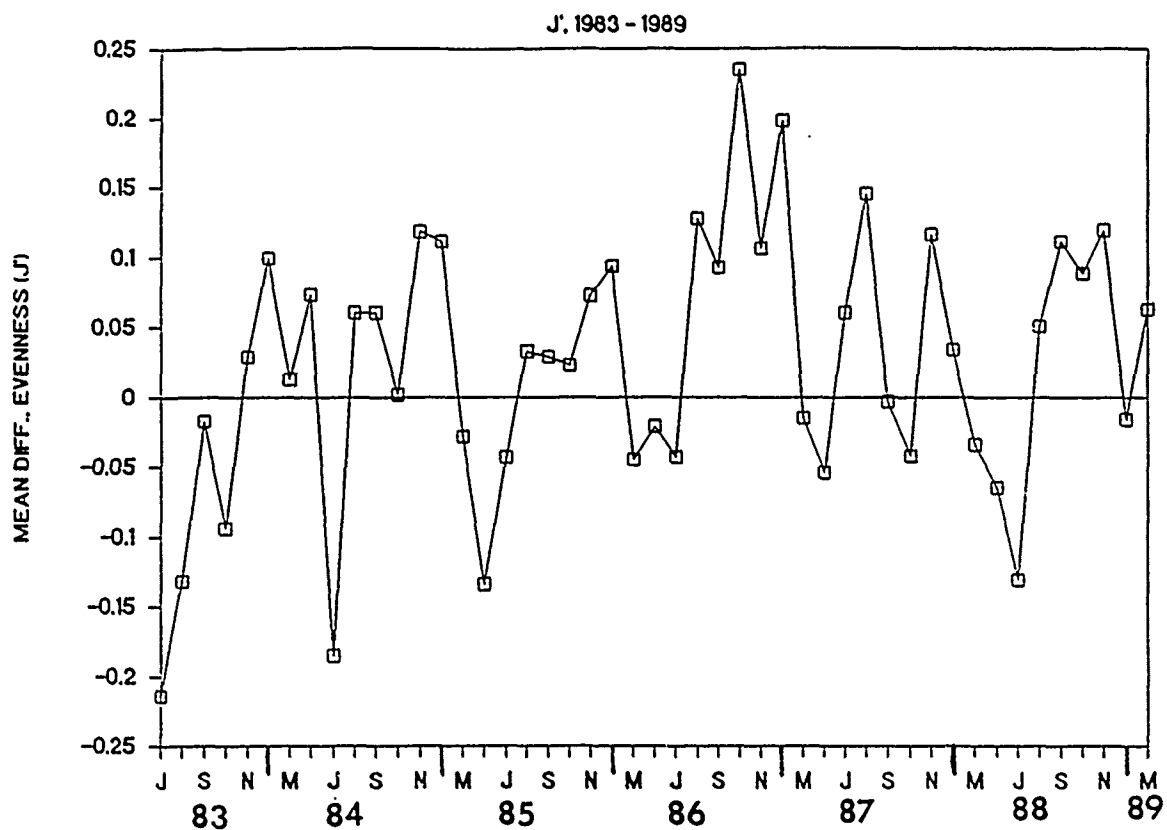


Figure 4.2. Differences in mean taxon evenness, FEX minus FCD. July - Nov., 1983; April through Nov., 1984 - 1988; April, May, 1989.

FIGURE 4.3

# DIFFERENCE VALUES(FEX - FCD), RICHNESS

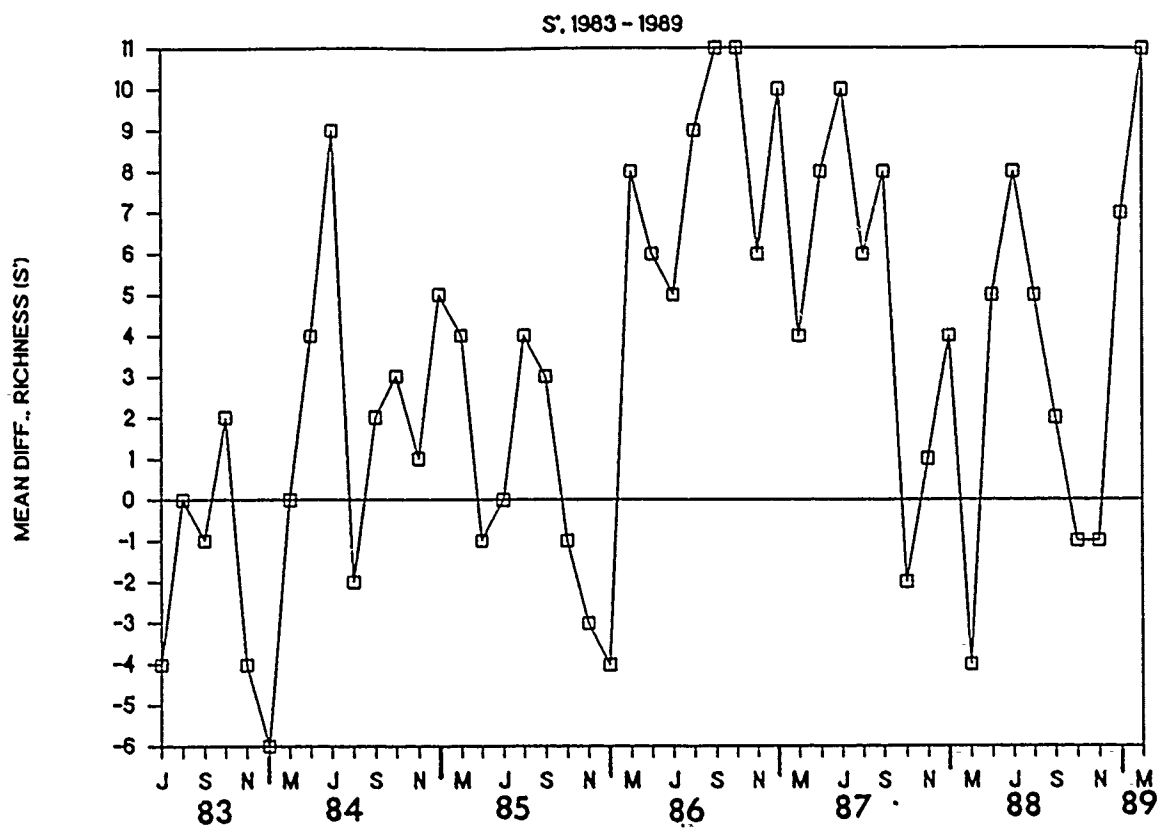


Figure 4.3. Differences in mean taxon richness, FEX minus FCD. July - Nov., 1983; April through Nov., 1984 - 1988; April, May, 1989.

FIGURE 4.4

# DIFFERENCE VALUES(FEX - FCD). INDIVID.

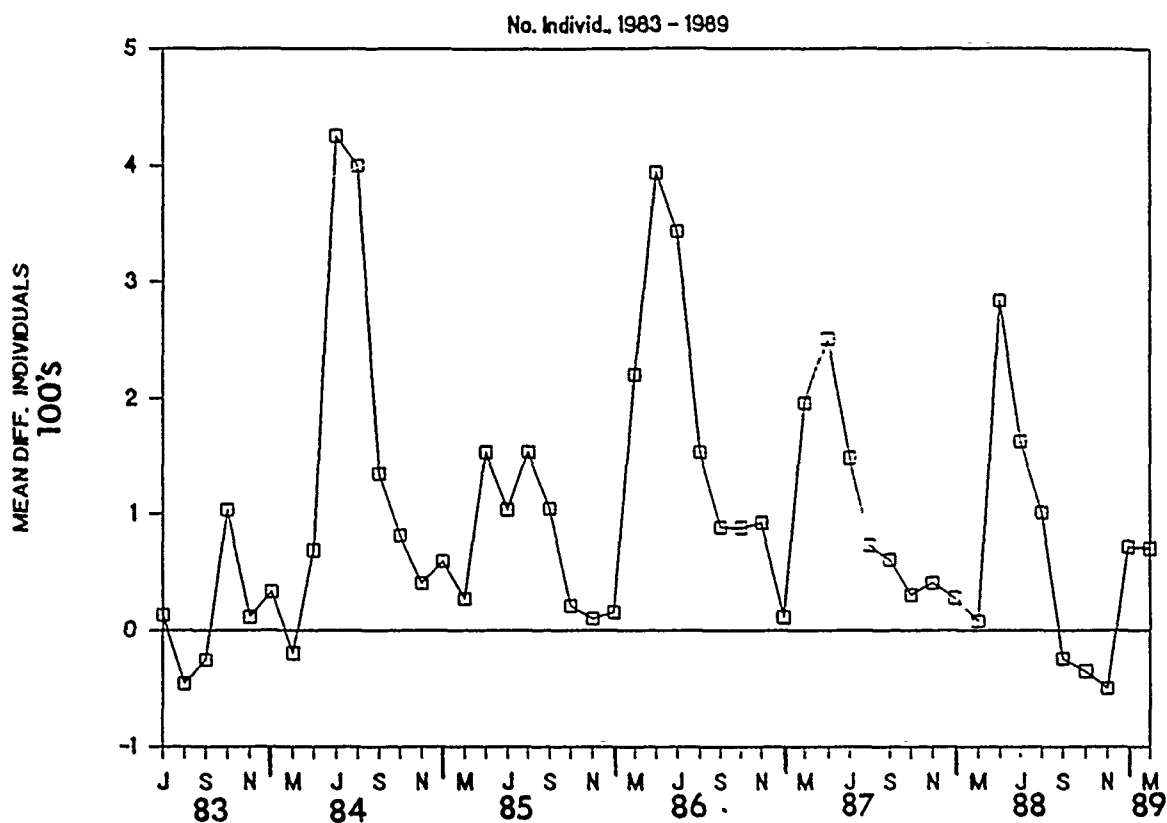


Figure 4.4. Differences in mean number of individuals, FEX minus FCD.  
 July - Nov., 1983; April through Nov., 1984 - 1988; April, May, 1989.

Figures 4.1 through 4.4 are graphs of relative differences between FEX and FCD rather than actual values for each parameter. By presenting the data in this form, possible site differences are more easily visualized. However, actual values were used in 2-Way ANOVA tests for evaluating site, year, and site-year interactions for each parameter.

Taxon diversity ( $H'$ ) and taxon evenness ( $J'$ ) were usually higher at FEX than at FCD during the spring months (April-May). During the summer months (June - August),  $H'$  and  $J'$  values were not consistently higher at one site than at the other. In the fall (September - November),  $H'$  and  $J'$  were almost always higher at FEX than at FCD (Figures 4.1, 4.2). Table 4.2 shows that only the summer months had no site differences for  $H'$ . Although the spring months had significant site and year effects for  $H'$  and  $J'$ , there were no significant site x year interactions. The fall season is the most difficult time period to interpret, as there are site, year, and site x year effects. Although the FEX usually had a more diverse and equitable community, the actual and relative values for these two indices fluctuated greatly from year to year during that season. This is a transition period for many insects. Some have emerged in late summer; some are just beginning development; and many are in the process of maximum growth during the fall months. (See Mean Dry Weight/Individual discussion at the end of this element and at the end of Element 6.) It is also the time when water temperatures are falling. Not only are there significant main effects and interaction effects for  $H'$  and  $J'$  during this season, but significant results occur for all structural parameters analyzed.

Taxon richness ( $S$ ) values were not significantly different between the sites during the spring months; however, there were significant site effects for the summer and fall months. Richness was almost always higher at FEX than at FCD from June through November each year. There were significant year effects each season for this parameter as well. Figure 4.3 illustrates the strong see-saw pattern for this parameter over the five complete years for data analysis (1984 - 1988). The more heterogeneous substrate at FEX appears to support a richer community during the summer and fall months.

The parameter that is almost always higher at FEX than at FCD among seasons and over all the years is total number of individuals, Figure 4.4. It thus, was to be expected that there were site differences for the spring, summer, and fall seasons. In addition, numbers of individuals fluctuated greatly over the years. This is reflected in significant year effects. Numbers of individuals are also characterized by having the highest Coefficient of Variation (CV) values of any parameter under study. Unless there were dramatic losses in numbers of individuals as a function of ELF, this parameter would not be useful as a detection for ELF effects.

TABLE 4.2

2-Way ANOVAS for Structural Community Parameters  
Spring, Summer and Fall Seasons

| Parameter,<br>Source       | d.f. | Spring    | Summer    | Fall     |
|----------------------------|------|-----------|-----------|----------|
|                            |      | F-value   | F-value   | F-value  |
| DIVERSITY                  |      |           |           |          |
| Site                       | 1    | 5.18*     | 0.18 n.s. | 30.13*** |
| Year                       | 4    | 4.86**    | 2.80 *    | 11.63*** |
| Site x Yr.                 | 4    | 1.29 n.s. | 4.53 **   | 3.75**   |
| EVENNESS, arcsin transform |      |           |           |          |
| Site                       | 1    | 5.79*     | 0.71 n.s. | 30.34*** |
| Year                       | 4    | 3.78**    | 8.88***   | 19.35*** |
| Site x Yr.                 | 4    | 0.91 n.s. | 3.48**    | 3.21*    |
| RICHNESS                   |      |           |           |          |
| Site                       | 1    | 1.32 n.s. | 30.76***  | 6.97**   |
| Year                       | 4    | 12.22***  | 16.05***  | 27.67*** |
| Site x Yr.                 | 4    | 1.13 n.s. | 1.64 n.s. | 2.72*    |
| NO. INDIVIDUALS            |      |           |           |          |
| Site                       | 1    | 5.26*     | 184.98*** | 34.83*** |
| Year                       | 4    | 12.65***  | 18.98***  | 17.27*** |
| Site x Yr.                 | 4    | 3.48*     | 5.84**    | 7.19***  |

Error, d.f. = 90 for spring; 140 for summer; 140 for fall

Taxon richness overlap values were computed by month, by season (Spring = March - May, Summer = June - August, and Fall = September - November) and by year (1984 through 1988). Figures 4.5A, B, and C are plots of numbers of taxa found at FEX, at FCD, and numbers in common at both sites. The high numbers of taxa in 1986 are reflected by the highest values for FEX in all seasons. The most dramatic increase that year occurred in the fall (Figure 4.5C). The only period when numbers of taxa were higher at FCD than at FEX was in the spring of 1984; otherwise, FEX supported a higher richness of taxa regardless of season or year. The substrates at FEX contain a more heterogeneous substrate than do the substrates at FCD; i.e., FCD contains more sand and finer particles than does FEX (See 1983 Annual Report). The heterogeneous nature of the substrates at FEX probably supports a more diverse community.

FIGURE 4.5A

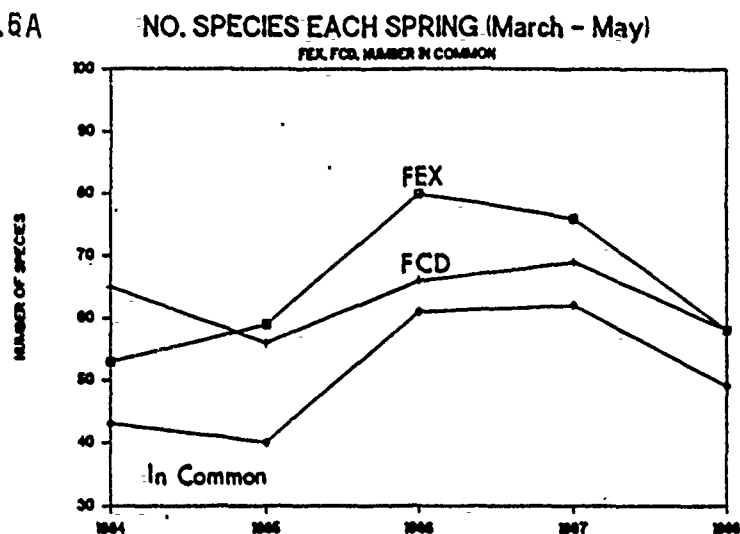


FIGURE 4.5B

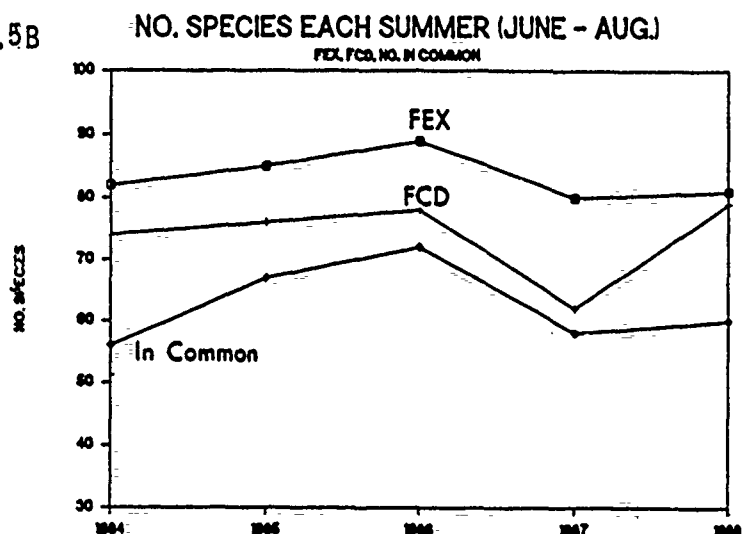


FIGURE 4.5C

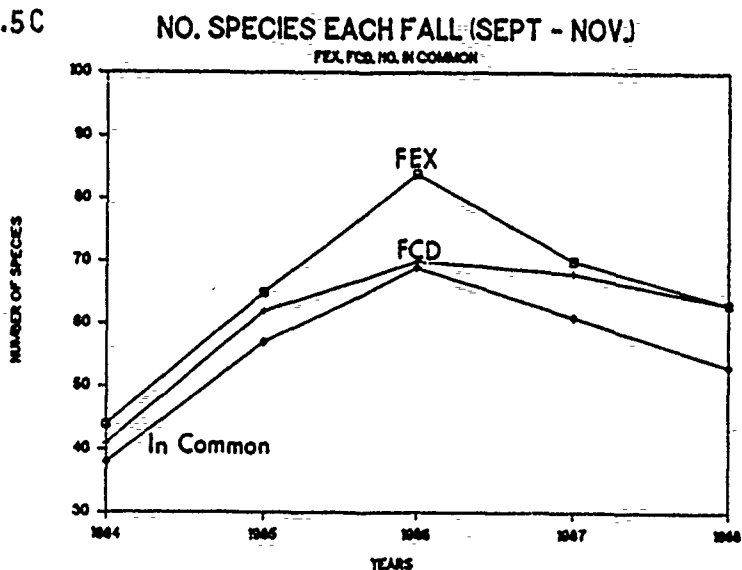


Figure 4.5. Number of species at FEX, FCD, and those held in common.  
 4.5A: Spring  
 4.5B: Summer  
 4.5C: Fall

As stated earlier, after activation of E.L.F. in July of 1986, in each succeeding year both the intensity and frequency of E.L.F. fields increased. If there is a dose-response curve associated with E.L.F. fields, one would expect a deviation in one or more parameters affected by E.L.F. at FEX that would not be matched by that (those) parameter(s) at FCD. Given the (albeit) tenuous assumptions about relationships between biotic parameters and gauss-days (intensity x duration) values, for those parameters not affected by E.L.F. in a linear fashion, one would expect similar linear responses over time at FEX and at FCD (Figure 4.6A). If the response was exponential and the biological parameter was, again, not affected by E.L.F., the parameter would change exponentially at FEX and FCD in similar directions (Figure 4.6B). If there was a response to E.L.F. fields by some biological parameter, either linearly or exponentially, that parameter would differ between FEX and FCD (Figure 4.7A, B). These are two general types of responses, if a dose-response curve applies to E.L.F. effects. Of course, additional types of responses beyond the linear or exponential cases could apply.

We had said in the 1988 Annual Report that we would perform B.A.C.I. (Before and After, Control and Impact) analyses for comparing differences between FEX and FCD sites before and after antenna operation (see Stewart-Oaten et al. 1986) on the structural community parameters. Given the fact that each year of antenna operation has been different, both in intensity and frequency, we feel that analyses using gauss-days which will incorporate both intensity and frequency may be a better alternative to the B.A.C.I. method. The latter method does not take into account the year-to-year differences. We plan on studying both methodologies after the 1990 data are completed. In the event that we select B.A.C.I., we will have a sufficient number of years after antenna operation to have more robust analyses.

A factor that has been shown to affect many of our biotic parameters is water temperature (pp. 163-166 of 1988 Annual Report). We now have water temperatures for the sites over a seven year period. Figures 4.8A and 4.8B show cumulative degree day deviations from the grand mean over the seven years at FEX (Figure 4.8A) and at FCD (Figure 4.8B). The accumulated water degrees (base = 2 °C) on the 15th of every month from April through October each year was calculated. A mean of the seven values for each month was used, and the deviations from those means were plotted for each month and year. Water temperatures were similar at FEX and at FCD until June of 1989. If the ambient monitoring system was accurate at both sites that year, more ground water and/or cooler waters from tributaries below FEX resulted in FCD water temperatures accumulating many fewer degrees over the season. In fact, at FCD, the deviations are slightly and consistently below the grand mean (zero line). In contrast, the curve at FEX became the second-highest recorded after July that year (compare figures 4.7A and 4.7B). Water temperatures at



FIGURE 4.6A

# **A General Dose-Response Case: Linear Change, with no Deviation**

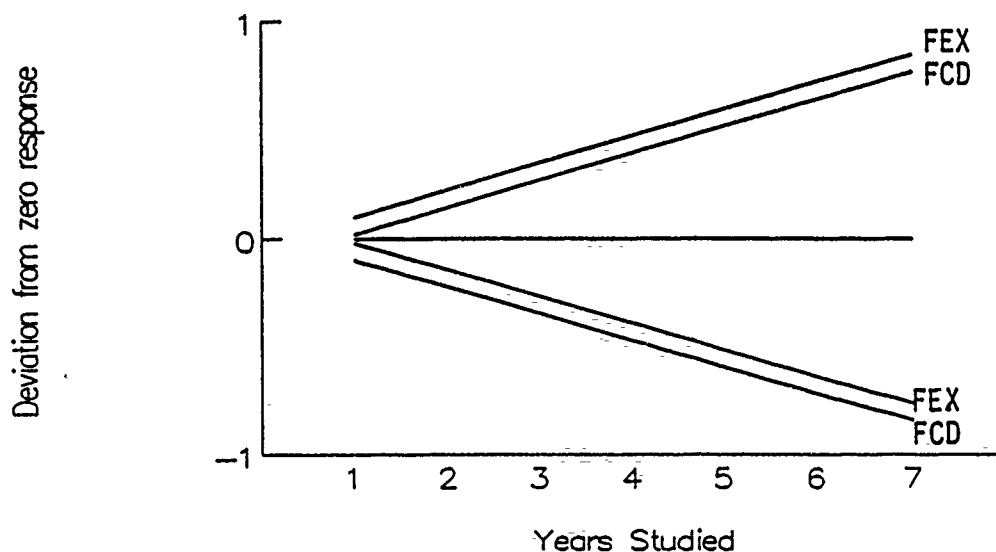


FIGURE 4.6B

# **A General Dose-Response Case: Exponential Change, with no Deviation**

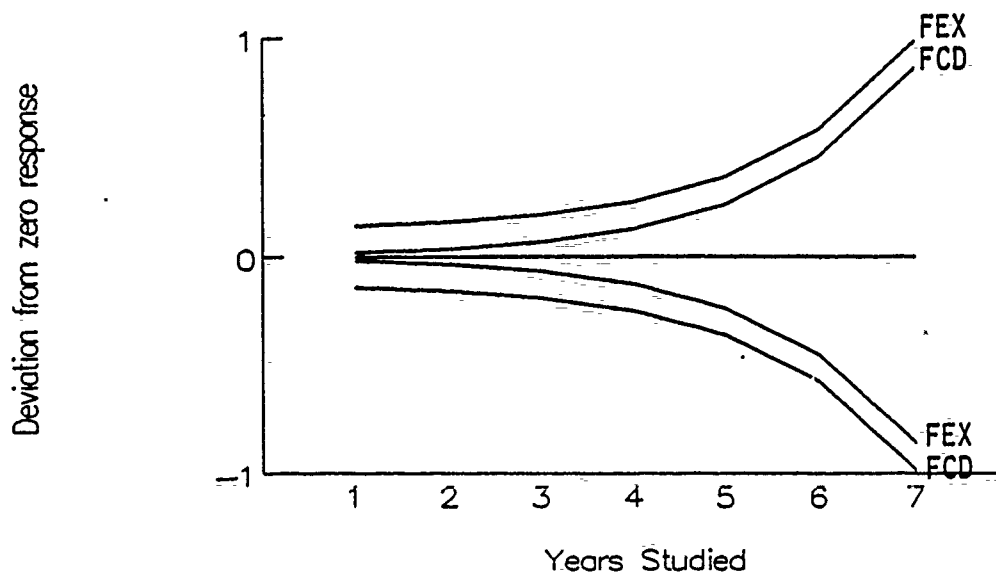


Figure 4.6. A theoretical model for a dose-response curve with no deviation between FEX and FCD: no effect. Either both are increasing or both are decreasing with gauss-days (in this graph, years). A:Linear; B:Exponential.

FIGURE 4.7-A

# **A General Dose-Response Case: Linear Change, with Deviation**

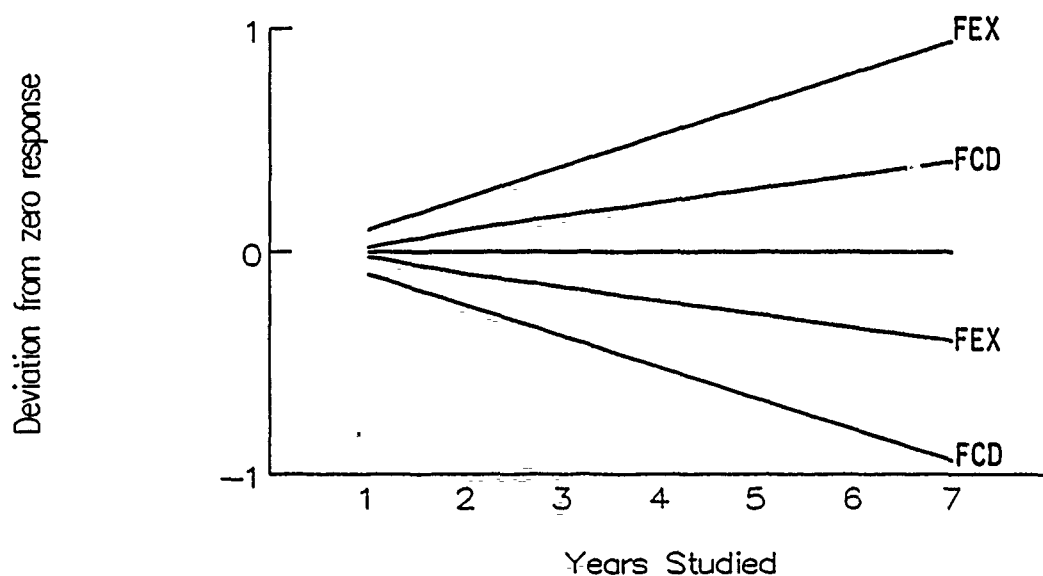


FIGURE 4.7-B

# **A General Dose-Response Case: Exponential Change, with Deviation**

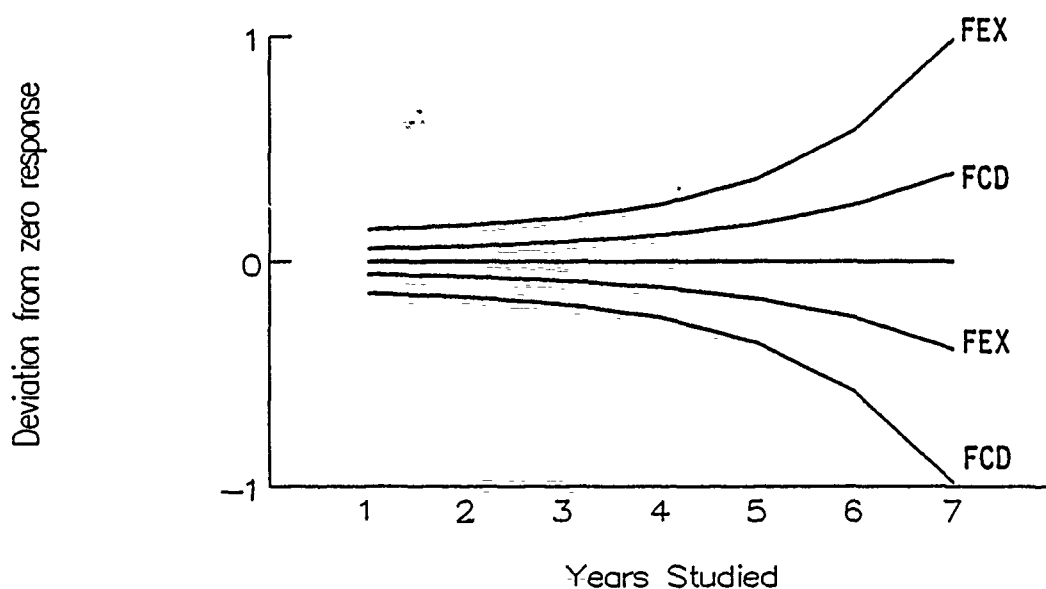


Figure 47. A theoretical model for a dose-response curve where parameter  $x$  at FEX deviates significantly from parameter  $x$  at FCD, with increasing gauss-days (in this case years). A: Linear; B: Exponential Cases.

FIGURE 4.8A DEVIATIONS IN MEAN VALUES, DEGREE-DAYS  
fex, 1983 - 1989

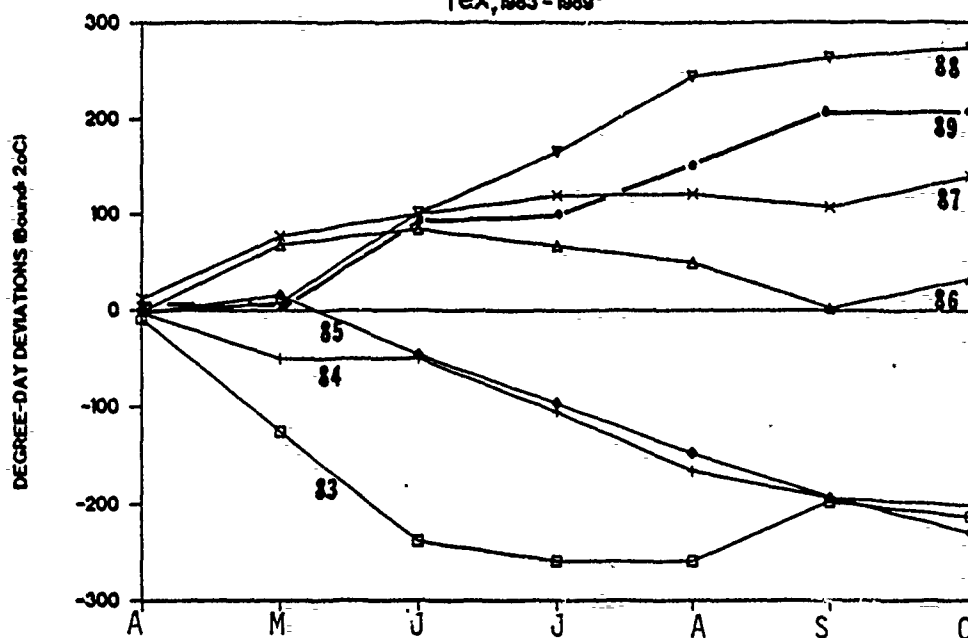


FIGURE 4.8B DEVIATIONS IN MEAN VALUES, DEGREE-DAYS  
fcd, 1983 - 1989

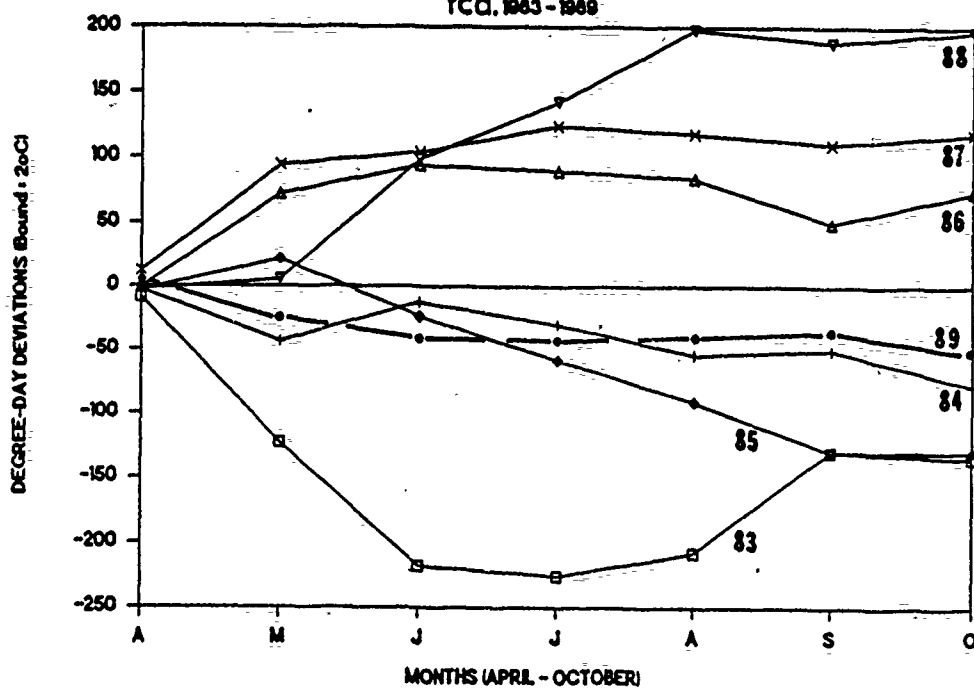


Figure 4.8. Deviations from grand mean (zero line) for cumulative degree days, April through October, 1983 - 1989 (threshold value: 20 C).

4.8A: FEX

4.8B: FCD

FEX are consistently higher over the years as compared with FCD (note different y-axes on the graphs). There are several beaver ponds above FEX. Warmer water flowing over the beaver impoundments probably increases water temperatures at FEX. Beaver ponds are lacking within 1000 m of the ambient monitoring system at FCD.

When cumulative degree days are used as an independent variable, as for changes in MDW/IND values for species of aquatic insects, the degree days used are those that accumulated at the sample collection date.

### Functional Community Indices

#### Total Insect Mass and Functional Feeding Group Mass:

Total insect mass was significantly different among years, months, and between sites (Table 4.3). All interaction terms were also significant at the  $p = 0.05$  level, except for the month by site interaction, which was only slightly above the 0.05 level.

TABLE 4.3

3-Way ANOVA for Differences in Total Mass of Aquatic Insects at FEX and FCD from November 1983 to May 1989  
(April - November for all Complete Years, 1984 - 1988)

| Source              | SS<br>(gms.) | d.f. | MSS<br>(gms.) | F-ratio  |
|---------------------|--------------|------|---------------|----------|
| Years               | 858.53       | 4    | 214.63        | 30.7 *** |
| Months              | 1,044.12     | 7    | 149.12        | 21.4 *** |
| Site                | 412.17       | 1    | 412.17        | 59.0 *** |
| Years, Months       | 1,079.42     | 28   | 38.55         | 5.5 ***  |
| Years, Months, Site | 399.34       | 28   | 14.26         | 2.04 **  |
| Months, Site        | 98.95        | 7    | 14.14         | 2.02 ns  |
| Years, Site         | 238.94       | 4    | 59.74         | 8.6 ***  |
| Error               | 2,235.46     | 320  | 6.99          |          |

Figure 4.9, a plot of the mean difference between FEX and FCD for total insect mass, shows that peak differences between the two sites occurred at least once a year, even though the amplitude and duration of the differences varied. The peak differences also usually occurred during the summer

FIGURE 4.9

# DIFFERENCE VALUES(FEX - FCD), TOT.BIO.

MEAN TOTAL INSECT BIO., 1983 - 1989

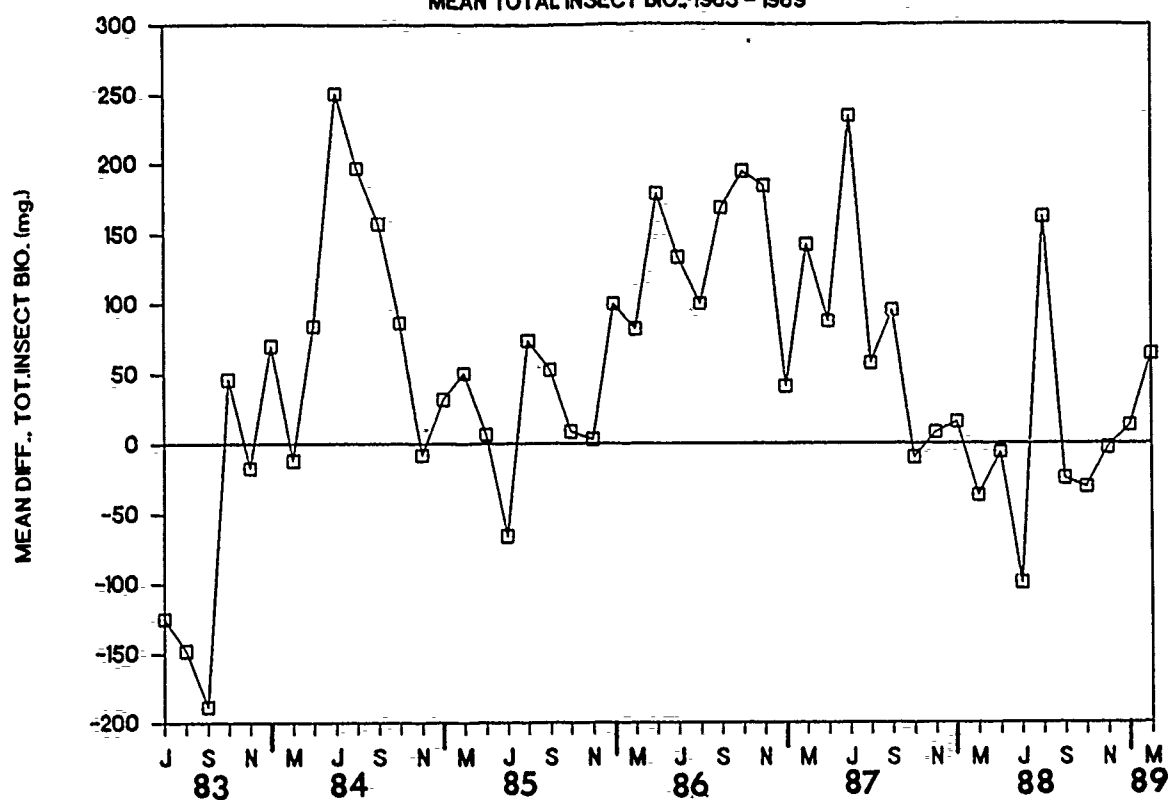


Figure 4.9. Differences in mean total insect mass (mg.), FEX minus FCD. July - Nov., 1983; April through Nov. 1984 - 1988; April, May, 1989.

months. The majority of the points occur above the zero line and indicate that total insect mass is often higher at FEX than at FCD. During the fall and mild winter of 1986 - 1987, the difference between FEX and FCD remained high. Even though FEX usually supported a higher mass of insects, no distinct pattern was evident before versus after E.L.F. activation (Figure 4.9).

As there were seasonal differences for total biomass values at the two sites, 2-Way ANOVAs were run to test for site, year and possible site x year differences (Table 4.4).

TABLE 4.4  
2-Way ANOVA for Differences in Total Mass of Aquatic  
Insects by Season, FEX vs. FCD  
1984 - 1988

| Source     | d.f. | F VALUES, LEVEL OF SIGNIFICANCE |           |          |
|------------|------|---------------------------------|-----------|----------|
|            |      | Spring                          | Summer    | Fall     |
| Site       | 1    | 1.82 n.s.                       | 0.70 n.s. | 25.98*** |
| Year       | 4    | 6.99***                         | 0.98 n.s. | 27.34*** |
| Site x Yr. | 4    | 1.14 n.s.                       | 1.03 n.s. | 10.84*** |
| Error, df. | 90   | 140                             | 140       |          |

By separating the data into seasons, several patterns emerged that had been obscured by treating all the months together (Table 4.2). In the spring months of 1986 and 1987 total mass of insects was higher than for springs in other years. This was reflected in year differences for the spring months. During the summer months, the site differences and year differences were not significant. It is during these times that total insect mass is usually at its highest. As for structural community parameter data, total insect mass fluctuated between sites and among years during the fall period. These fluctuations, if incorporated in an analysis such as appears in Table 4.2, could confound the results for spring and summer analyses.

Total insect mass was analyzed according to functional feeding groups, including collector-gatherers, collector-filter-feeders, shredders and predators. The relationship between predators and their potential prey is biologically meaningful in community analyses. Given that, 3-Way and 2-Way ANOVAS were performed on predator/prey ratios to see if any changes had occurred after 1986 when ELF activation was initiated. Table 4.5 presents the 3-WAY ANOVA for looking at site, year and month effects.

TABLE 4.5

3-Way ANOVA for Differences in Predator/Prey Mass (Arcsin Transformation) at FEX and FCD, Nov., 1983 - May, 1989  
(April - November for all Complete Years)

| Source              | SS        | d.f. | MSS       | F-ratio  |
|---------------------|-----------|------|-----------|----------|
| Site                | 14,694.90 | 1    | 14,594.90 | 23.14*** |
| Years               | 8,556.82  | 4    | 2,139.21  | 3.37*    |
| Months              | 16,303.65 | 7    | 2,329.09  | 3.67**   |
| Years, Months       | 31,871.25 | 28   | 1,138.26  | 1.79***  |
| Years, Months, Site | 58,127.07 | 28   | 2,075.97  | 3.27***  |
| Months, Site        | 9,080.29  | 7    | 1,297.18  | 2.04*    |
| Years, Site         | 6,850.88  | 4    | 1,712.72  | 2.70*    |
| Error               | 635.18    | 320  |           |          |

In order to unconfound seasonal differences, a 2-WAY ANOVA was performed for the spring, summer and fall months separately for 1984 through 1988 data, Table 4.6A. This ratio showed site differences during the spring and summer months, but no site differences for the fall months. In the summer months, not only was the predator/prey ratio significantly different between the two sites, but there were significant year and site x year interaction differences. In April of 1986, a very large number of predators relative to prey were collected at FEX. The predators, for the most part were dragonfly naiads of Ophiogomphus colubrinus, the predator we use in our mark-recapture studies (Element 5). In the summer of 1986, a period when insect biomass was at its highest for the entire period of the study, a consistently higher biomass of predators relative to prey were collected at FCD as compared with FEX (See Figure 4.10). (The predator/prey ratio index was the only data set where FCD often had a higher ratio than did FEX.) In order to see whether the unusual year of 1986 (in terms of low rainfall, mild fall, and high numbers of aquatic insects) affected the analysis dramatically, an additional 2-Way ANOVA was performed without data from 1986 (Table 4.6B). When 1986 was excluded, only the summer months' analyses differed substantially; there were no significant site nor site x yr interaction differences. This ratio, as well as total insect mass values will be important parameters to monitor during the course of the study, as they encompass much data regarding community dynamics. Given that results for both are usually not confounded by site x year interactions, these parameters will continue to be valuable in our monitoring program.

FIGURE  
4.10

# DIFFERENCES IN PREDATOR-PREY RATIOS

FEX - FCD, 1984 - 1988

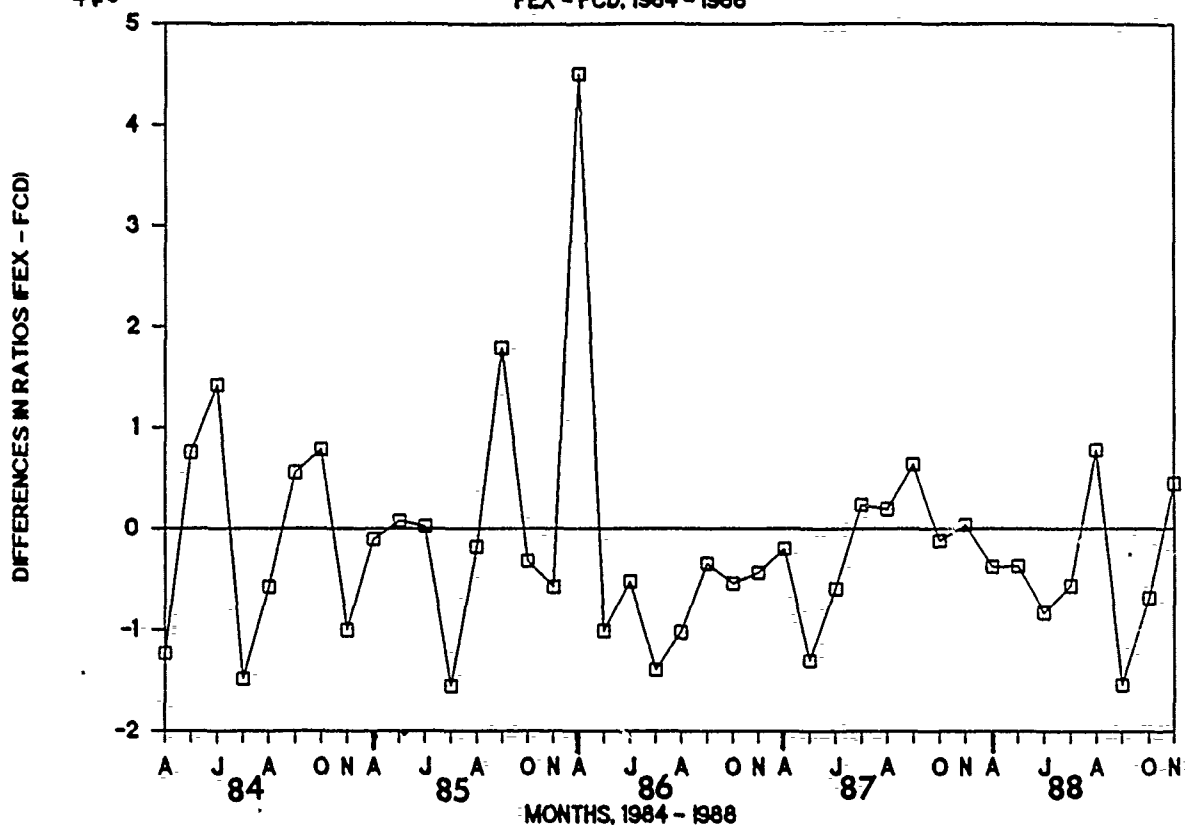


Figure 4.10. Differences in Predator/Prey ratios, FEX minus FCD.  
April - November, 1984 - 1988.



TABLE 4.6A,B

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

| A. 1984 - 1988                                 |      |                                 |           |           |
|------------------------------------------------|------|---------------------------------|-----------|-----------|
| Source                                         | d.f. | F-VALUES, LEVEL OF SIGNIFICANCE |           |           |
|                                                |      | Spring                          | Summer    | Fall      |
| Site                                           | 1    | 9.82**                          | 10.61**   | 1.55 n.s. |
| Year                                           | 4    | 0.91 n.s.                       | 2.58*     | 2.69*     |
| Site x Year                                    | 4    | 0.84 n.s.                       | 2.72*     | 2.17 n.s. |
| Error                                          |      |                                 |           |           |
| d.f. = 90 spg d.f. = 140 summ; d.f. = 140 fall |      |                                 |           |           |
| -----                                          |      |                                 |           |           |
| B. 1984, 1985, 1987, 1988                      |      |                                 |           |           |
| Site                                           | 1    | 9.32**                          | 3.07 n.s. | 0.98 n.s. |
| Year                                           | 3    | 0.82 n.s.                       | 2.70*     | 3.15*     |
| Site x Year                                    | 3    | 1.15 n.s.                       | 1.53 n.s. | 1.74 n.s. |
| Error                                          |      |                                 |           |           |
| d.f. = 72 spg d.f. = 112 summ; d.f. = 112 fall |      |                                 |           |           |

Discharge rate and water temperature were two physical parameters associated with biological parameters, including total insect biomass and periphyton density. Table 4.7 gives correlation coefficient values for those parameters from April through October each year.

TABLE 4.7

Correlation Coefficients for Biological  
and Physical Parameters from April or May  
through October or November, 1983 - 1989.

|                                           | Ln Perif.<br>Density<br>No/M2 X 10-8 | Ln Insect<br>Biomass<br>mg X 10-1 | Water<br>Temp.<br>°C. | Discharge<br>Rate<br>M3/Sec. |
|-------------------------------------------|--------------------------------------|-----------------------------------|-----------------------|------------------------------|
| Ln Perif.                                 | 1.00                                 |                                   |                       |                              |
| Ln Insect                                 | .50                                  | 1.00                              |                       |                              |
| Water                                     | .51                                  | .61                               | 1.00                  |                              |
| Discharge                                 | -.47                                 | -.57                              | -.61                  | 1.00                         |
| Critical value (1-tail, .05) = $\pm$ 0.26 |                                      |                                   |                       |                              |
| Critical value (2-tail, .05) = $\pm$ 0.31 |                                      |                                   |                       |                              |

Figures 4.11A and 4.11B show the negative relationship between discharge rate and insect biomass and between discharge rate and periphyton density. May is a month when both insect biomass and periphyton density have a potential for being high. However, discharge intensities can fluctuate during that month, depending on past snow cover and the timing of the influx of melt waters. For those reasons, values in the plots for May are marked, along with the years. Before 1989, the relationship between discharge and insect biomass values each May was clearly linear. In May of 1989, even though discharge was relatively low, insect biomass was also low, unlike for the years 1986 through 1988 (Figure 4.11A). No explanation for the difference can be given at this time. The relationship between discharge and periphyton density in 1989 fell closer to a regression line when only May data are considered. Discharge rates in the spring could be a good index for insect and periphyton mass at that time in the Ford River.

FEX and FCD sites were treated separately in a linear regression analysis of natural log values of the mean insect biomass versus the mean discharge that the animals had experienced prior to their collection. When April through October data from 1984 through 1988 were analyzed, insect mass at FEX was shown to be more highly correlated with discharge than insect mass at FCD (Table 4.8). As for prior analyses, data were separated according to season to see whether there were seasonal differences in the relationship between insect mass and discharge (Table 4.8).

TABLE 4.8

Linear Regressions for Mean Total Insect Mass (Ln) versus  
Mean Discharge ( $m^3$  /Sec), 1984 - 1988

| Time Period           | Slope | $r^2$ | T-value, signif. |
|-----------------------|-------|-------|------------------|
| 1984-1988, Ap. - Oct. |       |       |                  |
| FEX                   | -.403 | .575  | -6.48***         |
| FCD                   | -.266 | .244  | -3.27**          |
| Spring, Ap.- May      |       |       |                  |
| FEX                   | -.453 | .706  | -4.39**          |
| FCD                   | -.252 | .339  | -2.03 n.s.       |
| Summer, J,J, Aug.     |       |       |                  |
| FEX                   | -.355 | .214  | -1.88 n.s.       |
| FCD                   | -.392 | .225  | -1.94 n.s.       |
| Fall, Sept. - Oct.    |       |       |                  |
| FEX                   | -.349 | .392  | -2.273*          |
| FCD                   | -.336 | .465  | -2.638*          |

FIGURE 4.11A DISCHARGE VS. LN INSECT BIOMASS

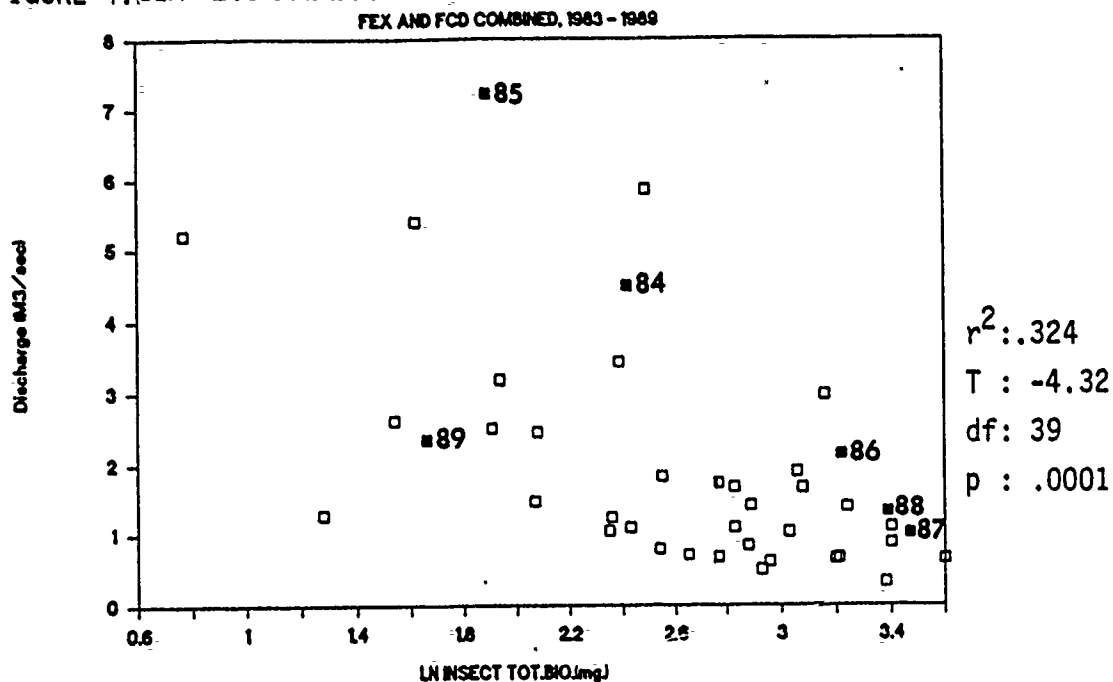


FIGURE 4.11B DISCHARGE VS. LN PERIPHYTON DENSITY

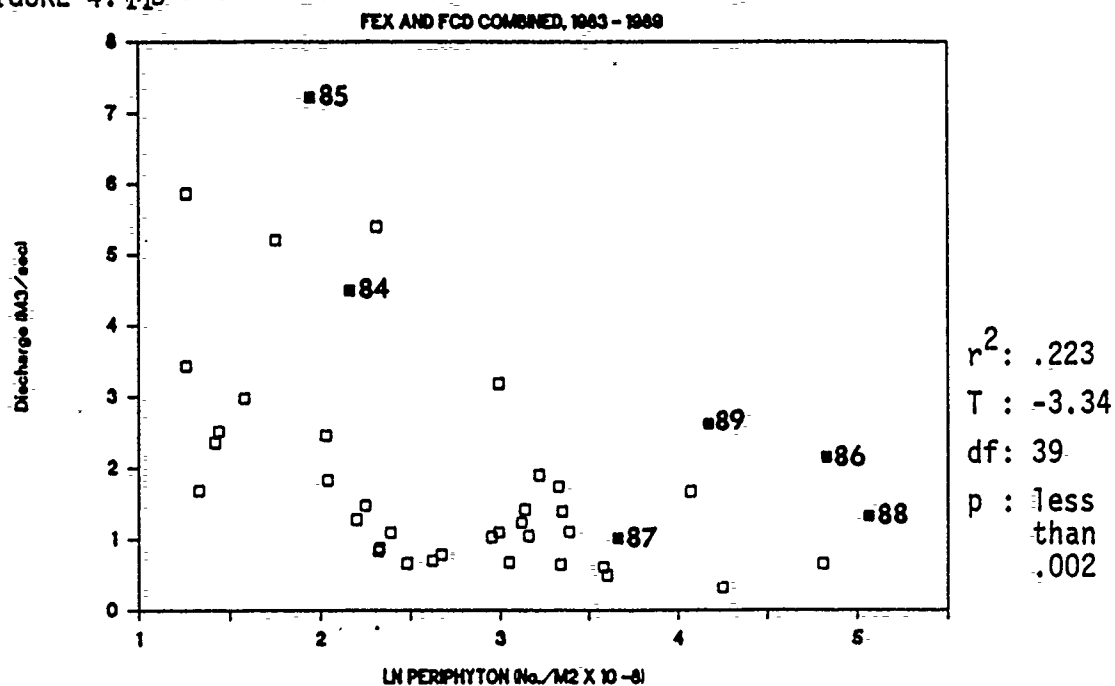


Figure 4.11A Relationship between discharge at combined sites and Ln Insect Total Biomass. Late spring through summer each year, 1983-89. Filled squares: each May.

4.11B Relationship between discharge at combined sites and Ln Periphyton Density.

In the spring seasons when discharge values were at their highest values, the regression coefficient for FEX was high. During the summer months, when discharge values are low relative to spring and fall periods, the regression coefficients for both sites were low and T-values were not significant.

As ln total insect mass was linearly related to mean discharge values, ANCOVAs were performed, using discharge as the covariate and total insect mass as the variate (Table 4.9). These analyses were performed for the spring, summer, and fall months separately and replicates rather than sample means were used.

TABLE 4.9

ANCOVAs for Ln Total Insect Mass (gm.) and  
Mean Discharge (m<sup>3</sup>). Spring, Summer, Fall  
1984 - 1988

| Season, Source           | d.f. | SS      | MS     | F, sign.              |
|--------------------------|------|---------|--------|-----------------------|
| <b>SPRING</b>            |      |         |        |                       |
| Diff. between adj. means |      |         |        |                       |
| Adj. Means               | 1    | .01037  | .01037 | .014 n.s.             |
| Error                    | 97   | 72.5247 | .7477  |                       |
| Diff. between slopes     |      |         |        |                       |
| Slopes                   | 1    | 3.2139  | 3.2139 | 4.451*                |
| Sum group dev.           | 96   | 69.3198 | .7220  |                       |
|                          |      |         |        | Common slope: -.41450 |
| <b>SUMMER</b>            |      |         |        |                       |
| Diff. between adj. means |      |         |        |                       |
| Adj. Means               | 1    | 6.3662  | 6.3662 | 20.127***             |
| Error                    | 147  | 46.4953 | .3163  |                       |
| Diff. between slopes     |      |         |        |                       |
| Slopes                   | 1    | .0934   | .0934  | .294 n.s.             |
| Sum group dev.           | 146  | 46.4019 | .3178  |                       |
|                          |      |         |        | Common slope: -.44640 |
| <b>FALL</b>              |      |         |        |                       |
| Diff. between adj. means |      |         |        |                       |
| Adj. Means               | 1    | 8.8281  | 8.8281 | 18.858***             |
| Error                    | 97   | 45.4101 | .4682  |                       |
| Diff. between slopes     |      |         |        |                       |
| Slopes                   | 1    | .0148   | .0148  | .031 n.s.             |
| Sum group dev.           | 96   | 45.3953 | .4729  |                       |
|                          |      |         |        | Common slope: -.3392  |

The ANCOVAS showed that the pattern for the spring months differed from the summer and fall months. In the spring, the adjusted mean values between the sites did not differ, but the slopes differed significantly. As discharge increased during the spring (up to  $6.27 \text{ m}^3$ ), insect mass was more substantially reduced at FEX. During the summers, mean discharge values never exceeded  $2.66 \text{ m}^3$ . During that period, the insect mass at FEX was higher than at FCD, resulting in a significantly higher adjusted mean value at FEX. The fall period showed the same pattern as the summer period with respect to significantly higher adjusted mean values for insect mass, given a mean value for discharge, at FEX even though there were some years (1984, 1985) when the fall mean discharge was very high (up to  $5.26 \text{ m}^3$ ). There were no differences between slopes for the two sites during the summer and fall months, indicating that although insect mass was higher at FEX, the response by the insects to increased flows at the two sites was similar.

#### Changes in Mean Dry Weights Per Individual:

Six species of collector-gatherers have been selected for studies on changes in MDW/IND values each year. These include three mayflies, Paraleptophlebia mollis, Ephemerella invaria, and Ephemerella subvaria; two caddisflies, Glossosoma nigrior and Protophila sp.; and one coleopteran, Optioservus sp. These species show very discrete generations (except for the coleopteran) and are abundant at both sites. They are the only species for this element that fulfill those two important criteria.

Major growth periods for these species can occur in May, June, or July. June of 1989 samples were only recently identified in the laboratory. When those data and data for July and August are fully analyzed, this portion of the element will be completed. Figures 4.15 through 4.21 for the 1988 Annual Report show those definite patterns (pp.177 - 185). Here, results for Paraleptophlebia mollis from 1984 to 1988, using chronological time and physiological time, are presented to the reader for heuristic purposes (figures 4.12, 4.13A, 4.13B), with the caveat that this species, along with the remaining five species, will include 1989 data in the next writing.

#### Future Plans for This Element

The same design and accumulation of data will continue as in the past. 2-Way and 3-Way ANOVA analyses will continue to be used, along with figures showing difference values for FEX and FCD for structural and functional community indices. Principle effects and their interaction terms, coupled with graphical presentations of relative site differences, allow for detailed analysis.

FIGURE 4.12

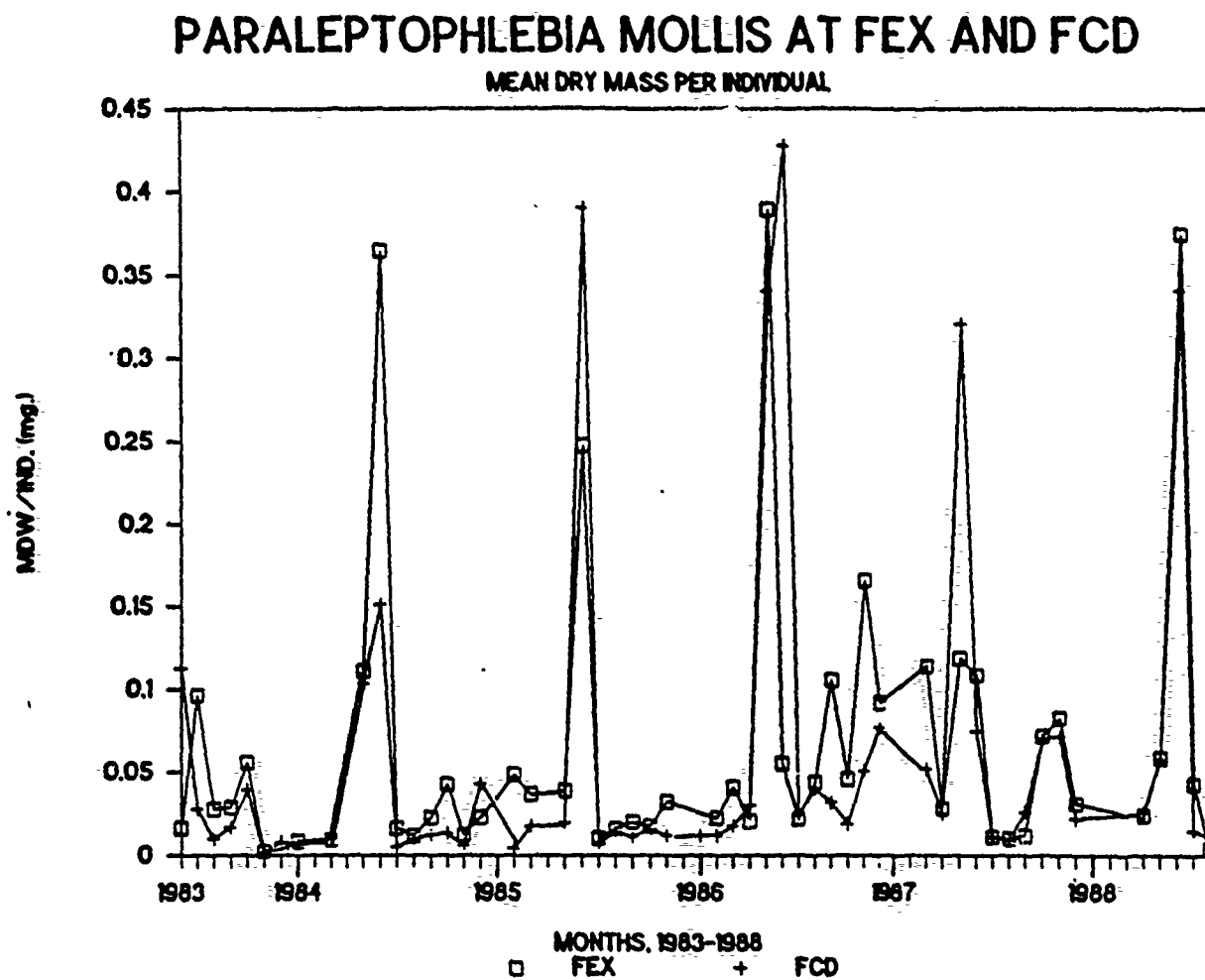


Figure 4.12. Mean Dry Weight per Individual (MDW/IND) for Paraleptophlebia mollis at FEX (squares) and FCD from June, 1983 to August 1988.

FIGURE 4.13A.

A.

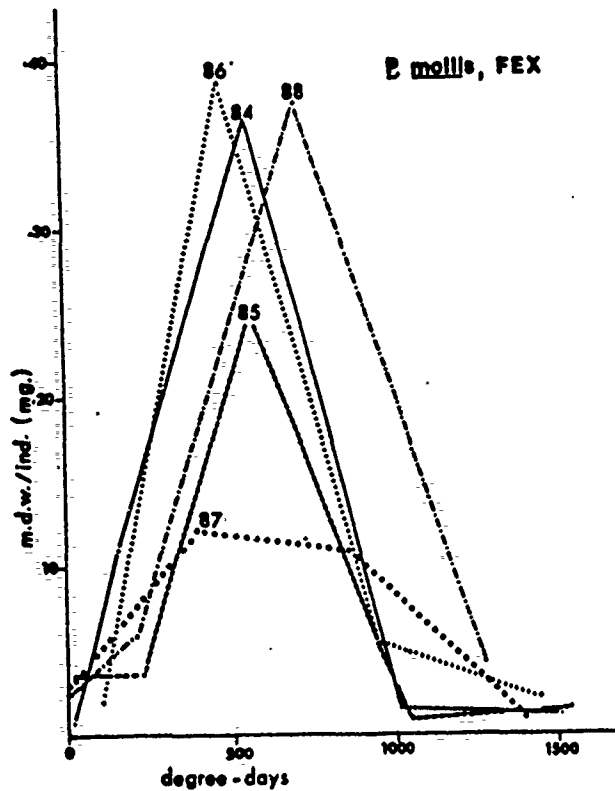


FIGURE 4.13B

B.

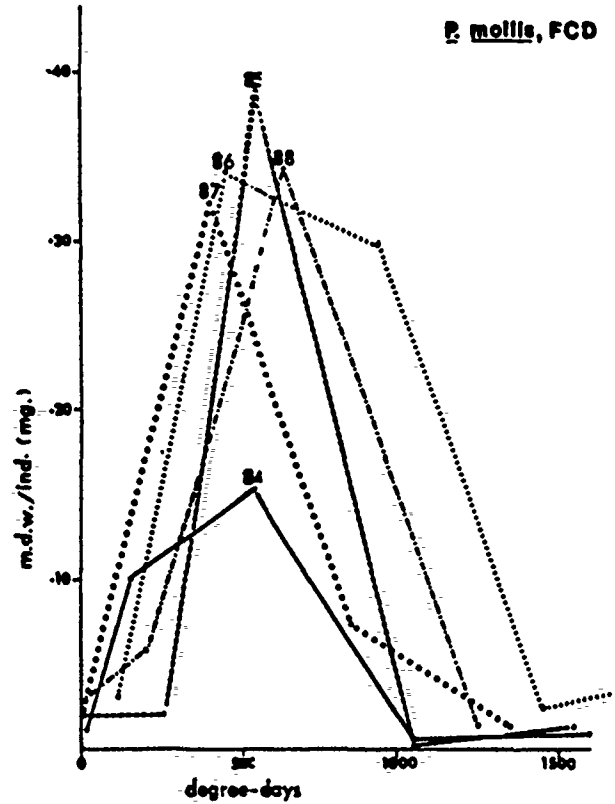


Figure 4.13A. Mean Dry Weight per Individual (MDW/IND) against Cumulative Degree Days (threshold = 2 oC). Paraleptophlebia mollis at FEX. Springs and early Summers of 1984 - 1988.

Figure 4.13B. Mean Dry Weight per Individual (MDW/IND) against Cumulative Degree Days (threshold = 2 oC). Paraleptophlebia mollis at FCD. springs and early Summers of 1984 - 1988.

As it appears that cumulative degree days is a better independent variable for changes in MDW/IND values for the six species studied, degree days rather than chronological time will be used for determining whether E.L.F. has any effect on changes in growth rates. Although we are not specifically monitoring rare species, losses of rare species can be determined by our taxon similarity overlap analyses -- whether they were absent one year and then reappeared or whether they were lost only at one site (e.g., FEX) after E.L.F. activation. The analysis also includes numbers of individuals, so that significant reductions of certain species could be analyzed using our methods. Because the similarity breakdowns were done month by month, season by season, and year by year, alterations as a function of E.L.F. that could be better detected on a seasonal rather than on a yearly basis can also be done. The taxa identified thus far at FEX and at FCD appear in Appendix I of this Report.

We will obtain gauss-days data since activation of E.L.F., which will be used to see whether there is a relationship between gauss-days and any of our biotic parameters. We will also use the B.A.C.I. method for analyzing the data to see whether the gauss-days method or the B.A.C.I. method is the most sensitive for determining possible ELF effects.

### Summary

Taxon diversity ( $H'$ ) and taxon evenness ( $J'$ ) did not show differences between sites during the summer months; however, there were significant yearly differences. In the spring and fall seasons, there were significant site and year effects. The only season where there were significant interactions between sites and years was in the fall. The yearly significant differences for  $H'$  and  $J'$  were not related to ELF effects, as determined by graphical analysis. Taxon richness ( $S'$ ) showed no site effects in the spring season. This was not the case for the summer and fall seasons. During those seasons, richness was higher at FEX than at FCD. Substrates at FEX are more heterogeneous and this probably contributes to the higher taxon richness at the experimental site. Numbers of individuals vary greatly and CV values for that parameter always exceed 20%, which is the maximum percentage where we can detect a + or - 40% difference in mean values with 95% confidence at a p level of 0.05. Numbers of individuals showed site, year and site x year significant differences for each of the three seasons. Unless there are dramatic losses in numbers of individuals associated with ELF activation, we will not be able to detect ELF effects, if they exist, for this parameter.

A theoretical dose-response curve for potential E.L.F. effects was presented, along with cautions for using this method of analysis. Even though E.L.F. effects, if they occur, may not operate in a dose-response manner, we do not know this for a fact. Thus far, our use of years as an approximation of



E.L.F. intensities, etc. show no relationships. Gauss-days will give us numerical data by which to apply the model.

Cumulative degree data for water temperatures at FEX and at FCD show that, overall, water at FEX is warmer than at FCD. In fact, the years 1987 through 1989 were above the grand mean for cumulative degrees at FEX. In contrast, only 1987 through 1988 were above the grand mean at FCD. Cumulative degree data represents physiological time rather than chronological time, and it is more useful, especially for growth rate studies, than is chronological time.

Total insect biomass showed significant site, month and year effects as well as significant interaction effects. However, when total insect biomass was analyzed according to seasons, there were no site nor site x year effects during the spring and summer seasons. It was only during the fall season when there were significant main and interaction effects. It appears that the spring and summer seasons will be the most sensitive seasons for data analyses, as the fall period reflects the high variance associated with this transition time for aquatic insects in the Ford River.

Predator/prey biomass ratios showed no significant interactions between site and year for any of the three seasons. However, there were significant site effects in the spring and summer months. In 1986 when the weather was dry and hot and the fall was mild, the predator/prey ratio differed from other years, as seen from graphical analysis. When that year was excluded from analysis, there were no site nor year effects for the ratio during the summer seasons.

Discharge was shown to be linearly related to total insect mass. ANCOVA analyses, with mean discharge as the covariate, showed that in the spring months the negative relationship between insect mass and discharge was very strong at the experimental site. The mean values of insect mass, adjusted to the mean discharge value, were not significantly different during that season. Both the summer and fall seasons had a significantly higher mass of insects at FEX than at FCD; however, the patterns of responses to increasing velocities were similar at the two sites.

An update in changes in mean dry weight per individual (MDW/IND) values for six species is currently not available. When the data for June, July, and August of 1989 are fully analyzed, they will be incorporated into the report (revised).

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## APPENDIX I

### List of Taxa of Aquatic Insects From FEX and FEX, Ford River EPHEMEROPTERA

#### TRICORYTHIDAE

Tricorythodes Ulmer

#### CAENIDAE

Drunella cornutella McDunnough  
Dannella simplex McDunnough  
Ephemerella invaria (Walker)  
E. needhami McDunnough  
E. rotunda Morgan  
E. subvaria McDunnough  
Serratella deficiens (Morgan)  
S. sordida (McDunnough)  
Eurylophella bicolor (Clemens)

#### BAETIDAE

Baetis flavistriga McDunnough  
B. vagans McDunnough  
B. macdunnoughi Ide  
B. pygmaeus (Hagen)  
Pseudocloeon parvulum McDunnough  
P. punctiventris (McDunnough)  
Centropilum cf. rufostrigatum McDunnough

#### OLIGONEURIIDAE

Isonychia Eaton

#### SIPHONURIDAE

Siphonorus rapidus McDunnough

#### LEPTOPHLEBIIDAE

Paraleptophlebia mollis (Eaton)  
Leptophlebia cupida (Say)

#### HEPTAGENIIDAE

Epeorus vitrea (Walker)  
Rhithrogena jejuna Eaton  
Stenonema vicarium (Walker)  
S. modestum (Banks) (= S. rubrum McDunnough)  
S. exiguum Travel (= S. quinquespinum Lewis)  
S. pulchellum (Walsh)  
Leucrocuta hebe (McDunnough) (= Heptagenia hebe)

Nixe lucidipennis (Clemens) (= Heptagenia lucidipennis)  
Stenacron interpunctatum (Say)

BAETISCIDAE

Baetisca laurentina McDunnough

EPHEMERIDAE

Ephemera simulans Walker  
Hexagenia limbata (Serville)

ODONATA

GOMPHIDAE

Ophiogomphus colubrinus Selys  
O. carolus Needham  
Gomphus (Stylurus) scudderi Selys  
G. (Gomphus) lividus Selys  
Dromogomphus spinosus Selys  
Hagenius brevistylus Selys

AESCHNIDAE

Boyeria vinosa Say

CORDULEGASTERIDAE

Cordulegaster maculatus Selys

CALOPTERYGIDAE

Calopteryx sp. Leach

PLECOPTERA

CAPNIIDAE

Allocapnia Claassen  
Paracapnia Hanson  
Capnia Pictet

CHLOROPERLIDAE

Haploperla Navas  
Alloperla Banks  
Suwallia Ricker

PERLIDAE

Acroneuria lycorias (Newman)  
A. abnormis (Newman)  
Paragnetina media (Walker)

PERLODIDAE

Isogenoides Klapalek  
I. olivaceous (Walker)  
Isoperla transmarina (Newman)  
I. slossonae (Banks)

NEMOURIDAE

Amphinemura Ris  
Paranemoura (Walker)

PTERONARCIDAE

Pteronarcys Newman

TAENIOPTERYGIDAE

Taeniopteryx nivalis (Fitch)

HEMIPTERA

BELOSTOMATIDAE

Belostoma flumineum Latreille  
Lethocerus Mayr

TRICHOPTERA

BRACHYCENTRIDAE

Brachycentrus numerosus (Say)

GLOSSOSOMATIDAE

Glossosoma intermedium (Klapalek)  
G. nigrilor (Banks)  
Protoptila tenebrosa (Walker)

LIMNEPHILIDAE

Anabolia Stephens  
Hydatophylax argus? Wallengren  
Platycentropus Ulmer  
Pycnopsyche subfasciata (Say)  
Neophylax nacatus Denning

HYDROPSYCHIDAE

Ceratopsyche morosa (befida form)  
C. sparna (Ross)  
Cheumatopsyche analis (Banks)  
Potamyia Banks

HYDROPTILIDAE

Hydroptila Dalman  
Leucotrichia pictipes (Banks)  
Neotrichia Morton  
Oxyethria Eaton

LEPIDOSTOMATIDAE

Lepidostoma Rambur

LEPTOCERIDAE

Oecetis avara (Banks)  
Ceraclea angustus (Banks)  
Triaenodes tarda Milne  
Nystacides Berthold  
Setodes incertus (Walker)

ODONTOCERIDAE

Psilotreta indecisa Banks

MOLANNIDAE

Molanna Curtis

PHILOPOTAMIDAE

Chimarra aterrima (Hagen)  
Dolophilodes distinctus (Walker)

PHRYGANEIDAE

Ptilostomis Kolenati

POLYCENTROPODIDAE

Neureclipsis crepuscularis (Walker)  
Nyctiophylax moestus (Banks)

PSYCHOMYIIDAE

Psychomyia flavida (Hagen)  
Lype diversa (Banks)

HELICOPSYCHIDAE

Helicopsyche borealis (Hagen)

COLEOPTERA

ELMIDAE

Ancyronyx variegata Erichson

Optioservus Sanderson  
O. fastiditus (Le Conte)  
O. trivittatus (Brown)  
Macronychus glabratus Say  
Dubiraphia Sanderson

DRYOPIDAE

Helichus lithophilus (Germar)

GYRINIDAE

Gyrinus Geoffroy in) Muller

DYTISCIDAE

Celina Aube  
Dytiscus harrisi Kirby  
Laccophilus Leach

HYDROPHILIDAE

Paracymus subcupreus (Say)

MEGALOPTERA

CORYDALIDAE

Nigronia Banks

SIALIDAE

Sialis Latreille

DIPTERA

DOLICHOPODIDAE

Rhaphium Meigen

EMPIDIDAE

Hemerodromia Meigen  
Clinocera Meigen  
Chelifera Macquart

BLEPHARICERIDAE

Blepharicera Macquart

TABANIDAE

Tabanus Linnaeus  
Chrysops Meigen



## TIPULIDAE

Antocha Osten Sacken  
Tipula Linnaeus  
T. abdominalis (Say)  
Hexatoma (erlocera) c.f. spinosa (Osten Sacken)  
Dicranota Zetterstedt  
Hesperoconopa Alexander

## CERATOPOGONIIDAE

Probezzia Kieffer  
Culicoides Latreille

## CHIRONOMIDAE

### TANYTARSINI

Tanytarsus van der Wulp  
Rheotanytarsus Theinemann and Bause  
Microspectra Kieffer  
Stempellinella Brundin  
Stempellina Thienemann and Bause

### TANYPODINAE

Ablabesymia Johannsen  
Pentaneura Philippi  
Thienemannimyia group (sensu Simpson & Bode, 1980)  
Labrundina Fittkau  
Procladius Skuse  
Procladius cf. sublettei Roback  
Nilotanypus Kieffer

## ORTHOCLADIINAE

Brillia flavifrons Johannsen  
Parametrlocnemus Goetghebuer  
Corynoneura Winnertz  
Eukiefferiella Thienemann  
E. devonica group (sensu Lehman, 1972)  
E. claripennis group (sensu Bode, 1983)  
Rheocricotopus Thienemann and Harnisch  
Cricotopus van der Wulp  
Thienemanniella Kieffer  
Synorthocladius Thienemann  
Orthocladius (Eurthocladikus) Thienemann (in part)  
Ivetenia bavarica group (sensu Saether & Halvorsen, 1981)  
T. discoloripes group (sensu Saether & Halvorsen, 1981)  
Diplocladius Kieffer  
Lopescladius Oliveira  
Nannocladius Kieffer

Chaetocladius Kieffer  
Symptocladius Kieffer and Zavrel  
Heterotrissocladius marcidus (Walker)  
Xylotopus par (Coquillett)

#### CHIRONOMINI

Polypedilum cfd. lonvictum (Walker)  
P. cf. scalaenum (Schränk)  
P. cf. halterale (Coquillett)  
P. cf. aviceps Townes  
Robackia Saether  
R. demeljerei (Krusemann, 1933)  
Microtendipes caelum Townes  
Stenochironomus Kieffer  
Cryptochironomus Kieffer  
Saetheria Jackson  
Parachironomus Lenz  
Chironomus Meigen  
Cryptotendipes Lenz  
Xenochironomus xenolabis Kieffer  
Paraleuterborniella Lenz

#### DIAMESINAE

Potthastia Kieffer  
Pagastia Oliver

#### ATHERICIDAE

Atherix variegata Walker

#### SIMULLIDAE

Cnephia mutata (Malloch)  
Simulium (Eusimulium) euryadminiculum Davies  
S. corbis Twinn  
S. quebecense Twinn  
S. venustum (Say)  
S. rugglesi Nicholson and Mickel  
S. jenningsi Malloch  
S. tuberosum (Lundstrom)  
Prosimulium mixtum Syme and Davies  
P. mysticum Peterson  
Ectemnia invenusta (Walker)

## ***Element 5 - Movement Patterns of Ophiogomphus colubrinus***

Changes from the Original Synopsis - None.

### **Objectives**

1) To compare short-term movement patterns of a dominant insect predator, Ophiogomphus colubrinus, at the experimental site, FEX, with the reference site, FCD; 2) to determine whether E.L.F. activation has altered movement patterns and distances travelled by the predator.

### **Rationale**

Extremely low frequency electromagnetic fields have been shown to affect honeybee behavior and orientation (Bindokas et al. 1989, Walker and Bitterman 1989), homing pigeons (Bookman 1978) and several species of marine vertebrates (Kalmijn 1978). Magnetite, a biogenic compound which is associated with geomagnetic sensitivity, has been found in a myriad of organisms, including freshwater bacteria (Frankel and Blakemore 1989, Kalmijn and Blakemore 1978) and eukaryotic algae (Kirschvink 1989). Tenforde (1989) reported that "...weak electrical and magnetic fields of aquatic organisms are sensed by potential predators". The dragonfly naiad we are monitoring for orientation and movement patterns (O. colubrinus) is a predator. If those animals use electrical and magnetic fields to find their prey, E.L.F. activation may alter movements or orientation of this aquatic insect.

On the other hand, random effects associated with the flow of water over surfaces may overshadow any potential E.L.F. influences. If differences between FEX and FCD with respect to movement patterns of this animal can be detected under field conditions, which are rife with background environmental variables, then more controlled, laboratory experiments with this predator will be fully warranted. As yet, no studies regarding the presence or absence of magnetite or the responses of rheophilic insects to electromagnetic fields have been done.

### **Materials and Methods**

Since 1985, mark-recapture studies have been done on Ophiogomphus colubrinus at FEX and FCD. The same riffles at each site have been used over the years, and physical data regarding flow directions, depths, velocities, water temperatures, and rainfall have been recorded.

At the beginning of each field season, 1.0 meter grids were measured and flagged, and animals were collected using a 1 meter wide kickscreen sampler.

Approximately 300 individuals were then marked with Testors paint. As an entire day was required to recapture marked animals, marking activities at the two sites were alternated by one (48 hr experiments) to two days (24 hr experiments). Each marking period every year had a unique color so that each date of marking could be distinguished from other dates.

After 24 or 48 hr, animals were recaptured with the kickscreen sampler. The numbers of animals collected, locations of recaptured animals, and percent recapture success were recorded for each experiment, along with the locations of animals marked on previous occasions.

Over the years, some improvements in techniques were made. Although changes in methods can alter results, those changes were deemed of sufficient worth to justify their use. In 1987 and 1988, rock piles were placed upstream of the release site so that released animals could more easily gain "footing" on the substrate. In June of 1989, when water levels were high, we added another alteration by constructing wooden baffles in front of the release sites. Baffles were removed after the released animals had settled (usually 10 minutes). These additions greatly facilitated replacement of the animals and minimized possible washing downstream of marked animals. All changes were implemented simultaneously at FEX and FCD.

Possible yearly differences owing to these technique alterations could potentially occur; however, techniques employed at the two sites were always the same for each pair of experiments each year.

Initially, studies included 24, 48, and 72 hr recapture experiments. After analyzing the data, it was decided to delete the 72 hr experiments, as variances in distances travelled were high and recapture success was low. This was done after the field season of 1987. We also excluded any experiments where the sites were disturbed for other experiments; e.g., a 48 hr experiment where animals had been disturbed during the previous 24 hr for a 24 hr recapture study. The data presented herein represent all those 24 and 48 hr experiments over the years which suffered no intervening disturbances, including severe rainfall and the concomitant higher water velocities. Those events were shown to significantly increase distances travelled (see prior Annual Reports).

Finally, because release techniques were altered as previously described, Chi Square tests were used to test for any differences. The advantage of using the Chi Square test was that we were able to partition the total sums of squares into an orthogonal array of many smaller Chi Squares, each with contributing degrees of freedom. In doing so, we could investigate all interaction terms of importance.

## Results and Discussion

### 1. 24 Hour Recaptures

For the overall Chi Square matrix, numbers of animals recaptured at the two sites were categorized into distances from the release point for each year. That matrix appears in Table 5.1. Some years had fewer numbers in each cell, owing to the fact that fewer recapture series were done those years (e.g., 1985 and 1989). For any one year, the same number of 24 hr recapture experiments was performed at each site.

TABLE 5.1  
Differences Between Observed and Expected Numbers of  
Recaptured Animals at Various Distances from  
Release at FEX and FCD after 24 Hours  
1985 - 1989

| Years | Site | Distance Downstream From Release (m) |        |         |         |
|-------|------|--------------------------------------|--------|---------|---------|
|       |      | 0 - 2                                | 3 - 10 | 11 - 20 | 21 - 40 |
| 1985  | FEX  | -36                                  | +120   | - 8     | 0       |
|       | FCD  | -47                                  | + 77   | +27     | + 4     |
| 1986  | FEX  | -133                                 | +196   | +65     | -14     |
|       | FCD  | -137                                 | +227   | -52     | +69     |
| 1987  | FEX  | +154                                 | - 18   | - 3     | 0       |
|       | FCD  | - 39                                 | + 80   | +23     | +19     |
| 1988  | FEX  | +238                                 | -105   | -23     | - 8     |
|       | FCD  | +277                                 | - 55   | -28     | -26     |
| 1989  | FEX  | - 28                                 | -34    | +36     | +22     |
|       | FCD  | - 5                                  | +10    | + 7     | - 2     |

Chi Square = 670,  $p < < 0.001$ ; d.f. - 27

The whole table (years, sites, and distances combined) shows significant differences, Chi Square = 670, d.f. = 27,  $p < < 0.001$ . There also appears to be no regular pattern for + and - signs (observed minus expected values). Orthogonal subsets were selected apriori from the table to see whether there were differences in distances travelled among or between years and for differences in distances travelled between sites. The results appear in Table 5.2.

TABLE 5.2

Chi Square Tests for Mark-Recaptures of Ophiogomphus  
colubrinus after 24 Hours, 1985 through 1989

| Test Description                                                   | Chi Square | d.f. | P Level |
|--------------------------------------------------------------------|------------|------|---------|
| <u>Yearly Differences for Distances Travelled, Sites Collapsed</u> |            |      |         |
| 1989 vs. 1985-1988                                                 | 90         | 3    | <0.001  |
| 1985 vs. 1986-1988                                                 | 50         | 3    | <0.001  |
| 1986 vs. 1987-1988                                                 | 233        | 3    | <0.001  |
| 1987 vs. 1988                                                      | 11         | 3    | <0.01   |
| <u>Distances Moved by Years (1985-1989), Sites Collapsed</u>       |            |      |         |
| 3-10 M vs. 11-40 M                                                 | 68         | 4    | <0.001  |
| 11-20 M vs. 21-40 M                                                | 14         | 4    | <0.01   |
| <u>Site Differences, Moved vs. Not Moved</u>                       |            |      |         |
| 1985 - 1989                                                        | 8.23       | 1    | <0.05   |
| 1985                                                               | 2.90       | 1    | >0.05   |
| 1986                                                               | 1.98       | 1    | >0.10   |
| 1987                                                               | 139.50     | 1    | <0.001  |
| 1988                                                               | 5.73       | 1    | <0.025  |
| 1989                                                               | 0.07       | 1    | >0.50   |

There were yearly differences for distances travelled by the animals. (This was especially evident when 1986 is compared with 1987 - 1988.) 1985 was the only year when the E.L.F. lines were not operational. The pre-operational year was compared with post-operational years (excluding 1989, when baffles were used). There were significant differences in distances moved between the two sets of years (sites combined).

Distances moved were separated into two categories to determine whether the animals that were moving were moving at similar rates over the years. Once again, there were significant differences in distances moved throughout the years.

However, when distances travelled were categorized into those not moved (remaining within 2 m of the release point) versus those moved (all remaining categories in Table 5.1 together) there were no site differences in 1985, 1986 and 1989. In 1987, significantly more animals remained stationary at FEX than expected, as compared with FCD. In 1988, significantly more animals moved at FEX than expected. Even though these comparisons -- not moved versus moved animals -- show no differences between sites for some years, there are two years when there were site differences. It appears the yearly variations in distances moved at FEX and FCD are sufficiently great that only a large E.L.F. effect would be detected using the 24 hr experiments for this predator.

## 2. 48 Hour Recaptures

The 48 hr recapture experiments were analyzed following the same methods described for the 24 hr experiments. Major efforts were placed on the 48 hr experiments rather than on 24 hr experiments in 1989 because we felt that by leaving the insects in the stream for 48 hr, we might reduce the variance problems associated with having many of the animals remaining at the release site during the first 24 hr. Three pairs of experiments were performed in July; two in August, and one in September. The differences between the two sites in percent return for animals recaptured within two meters of the release site were very small (Table 5.3, figures 5.1A, B, 5.2). Percent recapture success was very high (FEX; mean: 75.5%, sd: 6.0. FCD; mean: 71.8%, sd: 6.4). Comparison of figures 5.1A, B and 5.2 (1989 data) with figures 5.3A, B (1985 through 1988 data) show that indeed, distances travelled in 1989 by the dragonfly naiads at FEX and FCD were very similar as compared with prior years. In 1988 there was a very low number of marked animals recaptured at FEX for one of the two series. In 1985 through 1987, a lower percentage were recaptured near the release sites than in 1988 and 1989, indicating that improved 'settling' techniques were effective. In 1988 rock baffles were used and in 1989 taller, wooden baffles were used. One can also see that, in general, a higher percentage of marked animals were recaptured near the release site at FEX as compared with FCD throughout the years until 1989.

In July and August of 1989, most of the marked animals were recovered within 2 m of the release site. In September some animals at FCD moved almost twice as far as those at FEX, and many animals were found more than 2 m below the release site that month as well. Ophiogomphus colubrinus may naturally travel more as water temperatures begin to cool down (See Figure 4.8, Element 4). No mark-recapture studies were performed in September of any previous years to lend support to this view.

FIGURE 5.1A

**RECAPTURES: FEX + FCD, JULY 1989**

**% of Total Recaptured Per Two Meters**

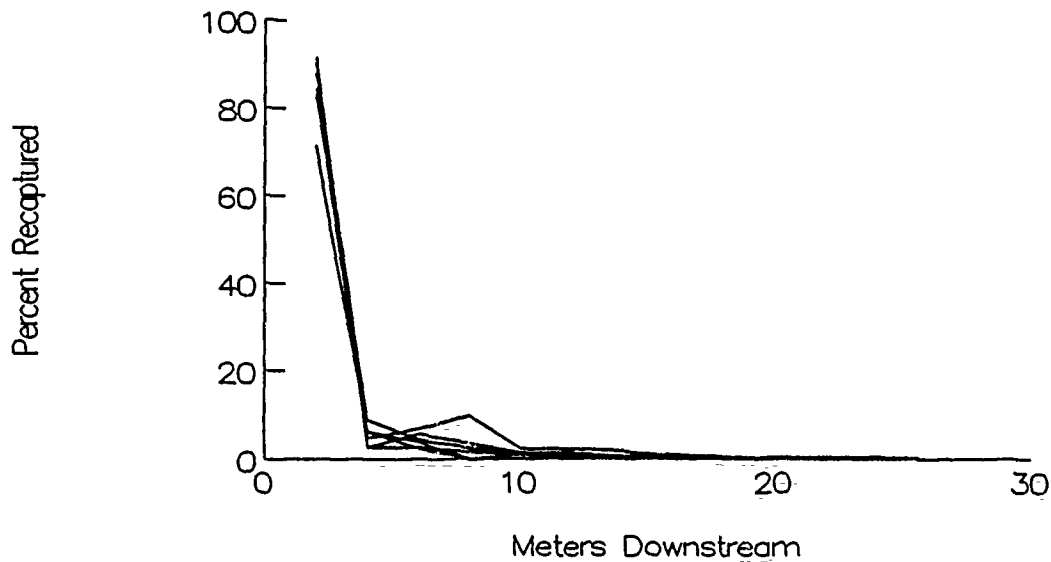


FIGURE 5.1B

**RECAPTURES: FEX + FCD, AUGUST 1989**

**% of Total Recaptured Per Two Meters**

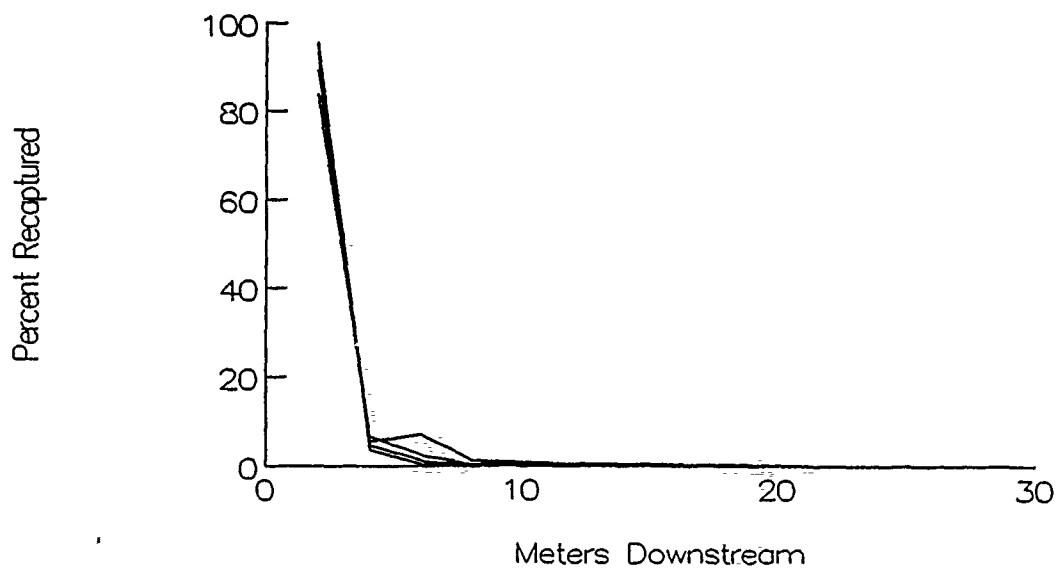


Figure 5.1. A: Percent marked animals recaptured every 2 M at FEX and FCD in July, 1989. B: August, 1989.



FIGURE 5.2

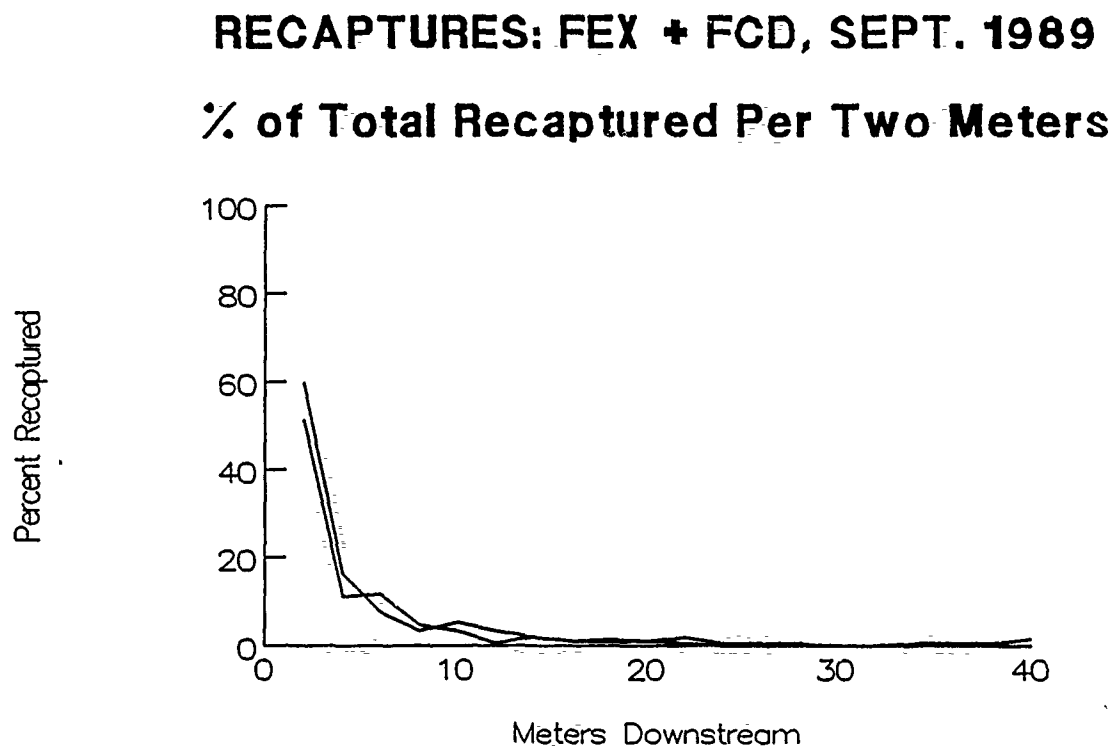


Figure 5.2. Percent marked animals recaptured every 2 M at FEX and FCD in September, 1989.

FIGURE 5.3A

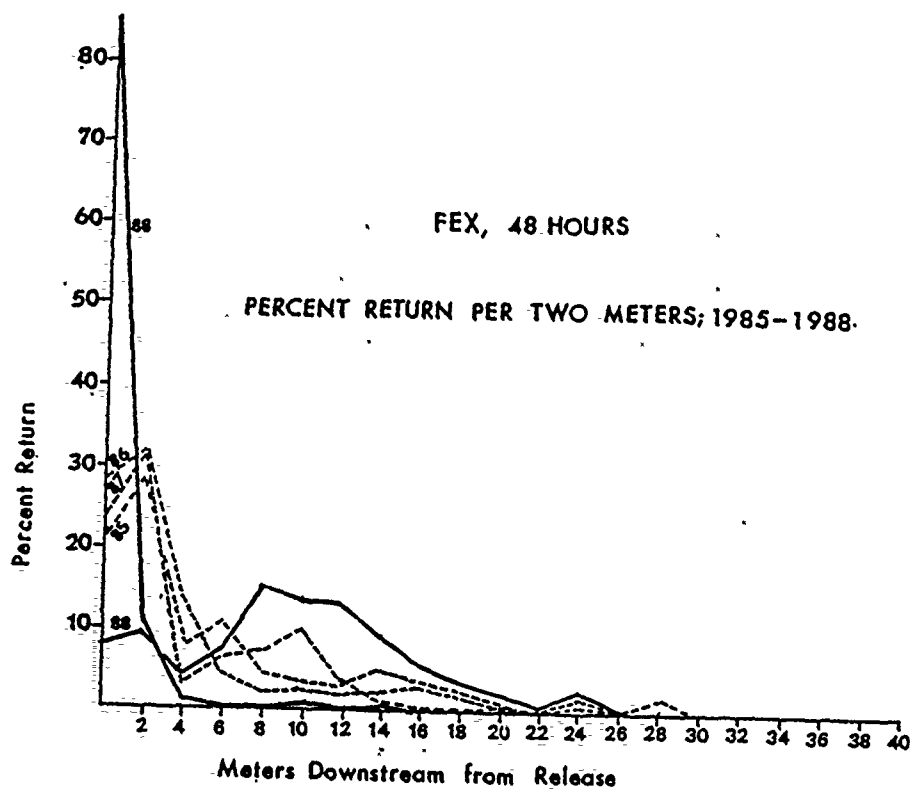


FIGURE 5.3B

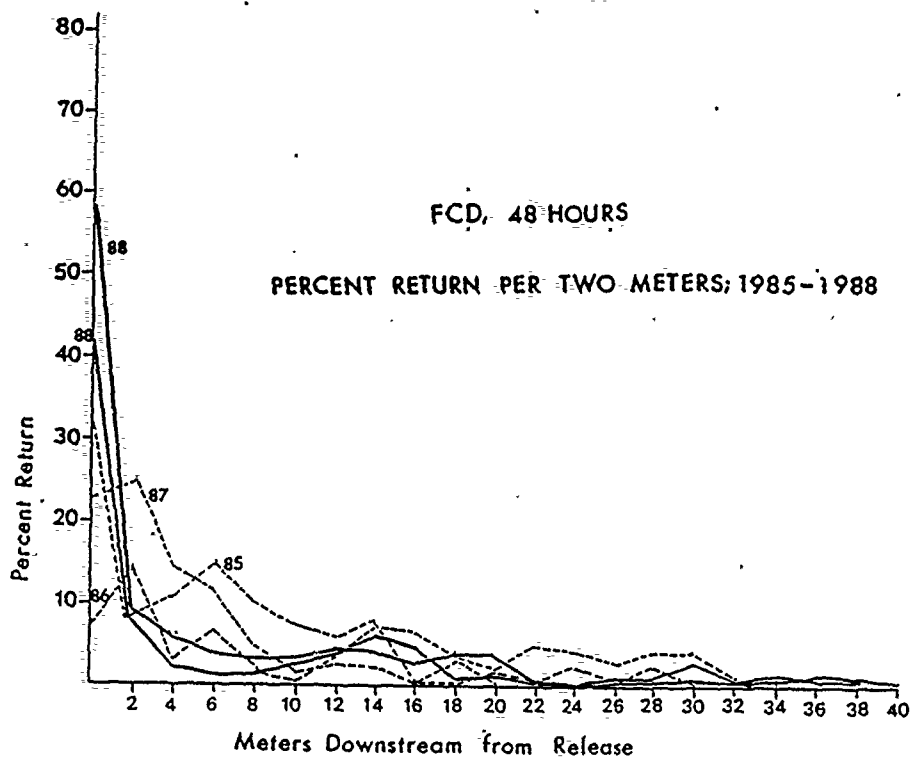


Figure 5.3A. Percent marked animals recaptured every 2 M at FEX from 1985 Through 1988.

Figure 5.3B. Percent marked animals recaptured every 2 M at FCD from 1985 Through 1988.

TABLE 5.3

Percent of Recaptured Animals Within 2 M of Release  
and Maximum Distances Travelled after 48 Hr  
July, August, September, 1989

| Date       | % Recaptured<br>within 2 M |      |         | Maximum Dist.<br>Travelled |     |       |
|------------|----------------------------|------|---------|----------------------------|-----|-------|
|            | FEX                        | FCD  | Diff.   | FEX                        | FCD | Diff. |
| July 19,20 | 91.4                       | 90.2 | +1.2    | 18                         | 6   | +12   |
| July 20,21 | 84.4                       | 87.8 | -3.4    | 20                         | 24  | - 4   |
| July 23,24 | 71.2                       | 82.6 | -11.4   | 24                         | 22  | + 2   |
| Aug. 18,19 | 89.4                       | 95.5 | -6.1    | 16                         | 8   | +8    |
| Aug. 20,21 | 83.9                       | 93.4 | -9.5    | 16                         | 16  | 0     |
| Sept. 7, 8 | 59.6                       | 51.3 | +8.3    | 22                         | 40  | -18   |
|            |                            |      | -----   |                            |     | ----- |
|            | SUM:                       |      | -20.90% |                            |     | 0     |

In 1989 when many mark-recapture studies were performed, marked animals were recaptured closer to the release site than in prior years (See Table 5.4, Figure 5.3). This difference is probably attributable to the utilization of baffle systems for the first 15 minutes after the release period to minimize current flow while the animals were being re-introduced to the stream. Even though one can see great differences among years with respect to observed minus expected values, there were distinct overall similarities within each year. In 1989 there were many more than expected recaptured at the release site as compared with prior years (Figures 4.3a, b). This large difference in 1989 affected the overall Chi Square matrix. For example, even in 1988 when a high percentage of marked animals were recaptured within 2 m of the release site as compared with prior years, fewer than expected were found that close when all the years were compared with one another. It is obvious that pairs of data sets within a given year will be a less confounded way to analyze the data to determine whether there may be ELF effects. A plan as to another method of analysis is detailed in the Future Plans section of this Element. When all the data for the 48 hr recapture studies are compared simultaneously, it is apparent (Table 5.4) that there were significant differences in distances moved between the sites over the years.

TABLE 5.4

Differences Between Observed and Expected Numbers of  
Recaptured Animals at Various Distances from Release  
at FEX and FCD after 24 Hours, 1985 - 1989

| Years | Site | Distance Downstream From Release (m) |        |         |         |
|-------|------|--------------------------------------|--------|---------|---------|
|       |      | 0 - 2                                | 3 - 10 | 11 - 20 | 21 - 40 |
| 1985  | FEX  | -22                                  | +52    | +22     | +10     |
|       | FCD  | -16                                  | +36    | +16     | - 0     |
| 1986  | FEX  | -39                                  | +75    | +18     | + 6     |
|       | FCD  | - 7                                  | +28    | +21     | +42     |
| 1987  | FEX  | -73                                  | +41    | +17     | +11     |
|       | FCD  | -54                                  | +73    | +13     | +14     |
| 1988  | FEX  | -149                                 | +51    | +39     | + 9     |
|       | FCD  | -171                                 | -40    | +62     | +30     |
| 1989  | FEX  | +1206                                | -238   | -40     | - 3     |
|       | FCD  | +1037                                | -104   | - 7     | - 8     |

Chi Square = 1534,  $p < < 0.0001$ , d.f. = 27

Orthogonal subsets of data were apriori selected for more detailed analysis; they appear in Table 5.5.

TABLE 5.5

Chi Square Tests for Mark-Recaptures of Ophiogomphus  
colubrinus after 48 hours, 1985 through 1989

| Test Description                                                                       | Chi Square | d.f. | Prob. Level |
|----------------------------------------------------------------------------------------|------------|------|-------------|
| <u>Yearly Differences for</u><br><u>Distances Travelled, Sites</u><br><u>Collapsed</u> |            |      |             |
| 1989 vs. 1985-1988                                                                     | 872        | 3    | <0.001      |
| 1985 vs. 1986-1988                                                                     | 50         | 3    | <0.001      |
| 1986 vs. 1987-1988                                                                     | 99         | 3    | <0.001      |
| 1987 vs. 1988                                                                          | 56         | 3    | <0.001      |

TABLE 5.5 continues

Distances Moved by Years  
(1985-1989), Sites Collapsed

|                  |     |   |        |
|------------------|-----|---|--------|
| Moved 3-10 M vs. |     |   |        |
| 11-40 M          | 152 | 4 | <0.001 |
| Moved 3-20 M vs. |     |   |        |
| 21-40 M          | 32  | 4 | <0.001 |

Site Differences, Moved vs.  
Not Moved

|             |       |   |        |
|-------------|-------|---|--------|
| 1985 - 1989 | 1.94  | 1 | >0.10  |
| 1985        | 0.29  | 1 | >0.50  |
| 1986        | 16.21 | 1 | <0.001 |
| 1987        | 8.05  | 1 | <0.005 |
| 1988        | 0.74  | 1 | >0.10  |
| 1989        | 37.47 | 1 | <0.001 |

All year combinations differed from one another with respect to distances moved. Although the pre-operational year (1985) as compared with post-operational years (excluding 1989, owing to baffles) had a lower Chi Square value than for other combinations, the differences were still very significant.

Even when distances moved were collapsed (3-10 m vs. 11-40 m and 3-20 vs. 21-40 m) for each year, there were significant differences. However, when distances were categorized into those moved versus those remaining stationary (remaining within 1 - 2 m of release), sites were shown to not differ in 1985 and in 1988. 1985 was a pre-operational year and 1988 was a post-operational year. In 1986 and 1987, fewer than expected moved at FEX; however, in 1989 more than expected moved at FEX. Thus, as in the 24 hr recapture study, these results do not indicate any consistency in the moved versus not moved changes as a function of E.L.F. activation.

Taking all years together for this test, no differences exist between sites. This results from the reversal of patterns in 1986 and 1987 as compared with patterns in 1989. We had concentrated our work in 1989 to the 48 hr recapture studies. In that year, more than expected moved at FEX. This same pattern occurred in 1985, the pre-operational year. In all other years, more than expected remained stationary at FEX as compared with the reference site, FCD. No consistent pattern emerges for our 48 hr mark-recapture studies. Variances among years, between sites, and distances

moved are high. Even in 1989, when we performed six separate 48 hr experiments at each site, the significant difference between sites for those moved versus those not moved were not similar to other post-operational years. The environmental variables coupled with the behavior of this animal may make it very difficult to detect any small differences in movement patterns owing to E.L.F. effects.

### Future Plans

Before the 1990 field season, we will analyze the data, year by year, using distances travelled after 48 hr by each individual for each pair of experiments (FEX, FCD). Unpaired t-tests for each data set will be studied to see whether a pattern, which was unapparent by our Chi Square analyses, emerges for movement rates of this predator and FEX and FCD.

A great deal of person-effort is expended during the summer months for this element. If it appears that there are no consistent differences in movement patterns for this animal, we will choose to delete this Element and direct our efforts on the two remaining elements. After discussions at the recent Annual Meeting, we may add another series of leaf processing experiments and place them farther downstream than the present sites for the studies in an attempt to be 'closer' to the guidelines for electromagnetic differences between test and control sites. Because we have many years of data for Element 6, no changes will be made with regard to location or experimental design. We may only add another experiment and will not delete anything from Element 6.

Two of the three reviewers for this Report support the idea of deleting Element 5. If further analyses show no trends, we will have addressed a major reservation of one of the reviewers prior to the deletion of this Element. Discussions with Dr. Jack Zapotosky will occur before a final decision is made.

### Summary

Movement patterns for naiads of Ophiogomphus colubrinus were studied by marking and releasing them, and recapturing them after they had been at FEX and FCD for 24 or 48 hrs. Chi Square analyses showed highly significant differences among and between years for distances moved at both sites. When sites were compared with one another for those moved versus those remaining stationary, many years showed no site differences for either the 24 or 48 hr experiments. When sites were significantly different, no particular pattern emerged, either before or after E.L.F. activation. In some years, more animals remained stationary at FEX; in other years, more moved at the FEX. As the data analyses chosen may have obfuscated a pattern, pairs of experiments where data were collected at FEX and FCD within a one to two-

day period will be analyzed separately. Each analysis will be then studied to see whether any overall pattern exists. The element will be deleted if the variability within each site is greater than the variability between sites.

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## ***Element 6 - Leaf Litter Processing***

Changes from the Work Plan - None.

### ***Objectives***

1) To quantify leaf processing rates for fresh and autumn abscised speckled (tag) alder leaves (*Alnus rugosa*) each year to see whether leaf processing rates differ as a function of E.L.F. fields; 2) to determine structural and functional community indices for insects colonizing tag alder leaves for subsequent analyses as to E.L.F. effects; 3) to measure changes in mean dry weight per individual values (MDW/IND) for two species of mayflies and one species of stonefly each year to see whether E.L.F. affects growth rates of those "target" species.

### ***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 not be detectable even though the variance around the means for many of the parameters presented in this Element are very low (see this report).



A number of anthropogenic factors can also affect leaf processing rates and colonization of insects on those leaves. Examples include chemical inputs (Fairchild et al. 1984, Stout and Cooper 1983, Cairns 1985), thermal stress associated with impoundments and commercial industries (Gersick and Brusven 1981), and forest alterations (Webster and Waide 1982). As E.L.F. fields appear to be an anthropogenic phenomenon for which there is no analog, the foundations for decisions as to which factors may most strongly affect any given organism -- intensity, duration, transient behavior -- are poorly understood (O.T.A. 1989). This problem is especially critical when studying potential effects under field conditions, where several non-anthropogenic and anthropogenic factors may interact. Considering these uncertainties, the continual monitoring of biological parameters that show low variation in time and space is the most pragmatic approach for detecting any E.L.F. effects under field conditions.

### *Materials and Methods:*

#### **A. Leaf Preparation and Processing**

Fresh tag alder leaves were collected from a grove adjacent to the Ford River near FCD each year. Leaves were removed from whole branches at the laboratory and weighed into individual leafpacks with an average fresh mass of 5 to 6 gm. Prior to 1988, fresh mass varied between 4.8 and 5.2 gm. After that time, fresh mass was increased to between 5.8 and 6.2 so that the fresh leafpacks and autumn abscised leafpacks would have similar numbers of leaves.

After leafpacks were weighed, they were taken to the field, lashed to bricks using rubber bands to which replicate identification numbers were attached, and placed in riffles at the FEX and FCD sites.

After 1985, autumn abscised tag alder leaves were collected in late September or early October from beneath a grove of tag alder near the Ford River. Those leaves were used for the following year's study so that fresh and autumn leaves could be placed in the river at the same time. (In 1984, leaves came from a different grove, which we abandoned in favor of the grove closer to the Ford River.) In 1985, insufficient numbers of leaves were available from the prior year. We therefore oven-dried some fresh leaves, but results from that treatment showed that oven-dried leaves were more similar to fresh leaves than to autumn-abscised leaves. Although the leafpack dry masses were similar for any year ( $\pm 0.20$  gm) the mean dry mass differed from 2.30 to 3.00 gm over the years.

Leafpacks for both treatments, fresh and autumn-abscised, were collected six times when possible. After 1986, it was determined that the critical

incubation period was between 21 and 28 days. At that point, the coefficient of variation values for insects colonizing leaves were very low for most of the structural and functional community parameters. We also found that variability was very high for all parameters after 80 days. As 50% of the dry mass of leaves is usually gone after 54 days, we changed our collection schedule in 1986 to more carefully bracket the critical period between three and four weeks and to delete leaf collection after 90 days. Thus, collection days changed from 3, 9, 24, 50, 90 and 120 days to 7, 14, 21, 28, 50 and 80 days, weather and travelling permitting. On collection days, each leafpack was removed carefully from its brick and placed in a plastic box. The portion of the brick touching the leafpack was carefully washed into that box. After returning to the laboratory, each leafpack was washed over a 60 micron mesh sieve, which retained the insects. Insects were preserved in 90% alcohol; leaves were placed in paper triangles and dried at less than 40°C for 48 hr, at which time they were weighed to the nearest 0.01 gm.

Leaf processing rates were computed as  $-k/\text{day}$  after Petersen and Cummins (1974) and as  $-k/\text{degree day}$ , using cumulative degree days above 2°C, beginning at the initiation of each year's leafpack experiment. Both sets of data were plotted against time (before and after activation of E.L.F.). As the resulting plots are not linear, Wilcoxon rank sum tests were run to see whether  $-k/\text{day}$  values over the years differed between the two sites. Fresh and autumn-abscised leaf data were treated separately, as fresh and autumn-abscised leaf losses differed within sites and displayed no within treatment differences between sites (see previous annual reports).

## B. Colonization of Insects on Leaves

The insect taxa from the leaves were determined to the lowest taxon possible except for chironomids. Time constraints disallowed their systematic identification below family level. Identified insects were then measured to the nearest mm for later computation of biomass values. Species diversity ( $H'$ ) and richness ( $S'$ ) were computed for each sample, along with numbers of individuals and total biomass. For certain taxa, percent numerical dominance, mean dry biomass per individual (MDW/IND), or both, were determined for each collection date. Coefficient of variation (C.V.) values for each estimated parameter from each set of samples were obtained. A power test was used to determine if there were sufficient replicates to be confident 95% of the time that the mean varied no more than  $\pm 40\%$  with an alpha of .05. (Seven replicates were sufficient if the parameter had a C.V. value of 20% or less.) If values for any parameter were not normally distributed, they were transformed prior to analysis (e.g., percent data). The lowest C.V. values for  $H'$ ,  $S'$ , numbers of individuals, and total insect biomass adjusted to leaf biomass occurred between 24 and 28 days.  $H'$ ,  $S'$ , numbers of individuals, and mean insect

biomass adjusted to leaf mass during that time period were analyzed, using 2-Way ANOVA tests, to determine whether there were site, year, or site x year differences.

Three species, Ephemerella subvaria, E. invaria, and Isoperla transmarina were analyzed for differences in growth rates (MDW/IND) between sites and among years. Physiological time (cumulative degree days) was shown to be a more accurate independent variable than was chronological time (actual dates) and was therefore used in the statistical analysis. Although the graphical representations show that these data hardly require analysis, Wilcoxon-Mann-Whitney test were performed on the data for each year to see whether there were site differences for growth rates. This non-parametric test was selected because, "This is one of the most powerful of the nonparametric tests, and it is a very useful alternative to the parametric t test's assumptions or when the measurement in the research is weaker than interval scaling". (Siegel and Castellani, p. 127, 1988).

## *Results and Discussion*

### **Leaf Processing Rates**

#### **1. Fresh Leaves**

Processing rates (-k/day) were very similar at FEX and FCD, with one exception. In 1985, leaves were processed much faster at FEX than other years, and much faster than fresh leaves at FCD for any year (Figure 6.1, Table 6.1). The yearly variation was also greater at FEX than at FCD. One omnivore, which is very common at FEX, is a crayfish (Orconectes virilis). It sometimes enters holes in the bricks and consumes the leaf above the hole. When that happens, large masses of leaves are lost in a short time period. The higher variation at FEX may be caused by this invertebrate predator, or by some other unknown variable. A plot of the difference between -k/day values at FEX versus FCD (FEX minus FCD) against years more vividly shows the high processing rate at FEX in 1985 (Figure 6.2). In 1986 and 1987, leaves were processed slightly faster at FCD than at FEX. A Wilcoxon rank sum test revealed no site differences across years [ $P(T_s = 6) > 0.05$ ], in spite of the usually higher processing rates some years at FEX.

Processing rates, which are the slopes for the linear regression lines that appear in Figure 6.1, and regression coefficients ( $r^2$ ) for fresh and autumn leaves at the two sites appear in Table 6.1. (All levels of significance for the regressions were  $< 0.05$ ).

FIGURE 6.1A

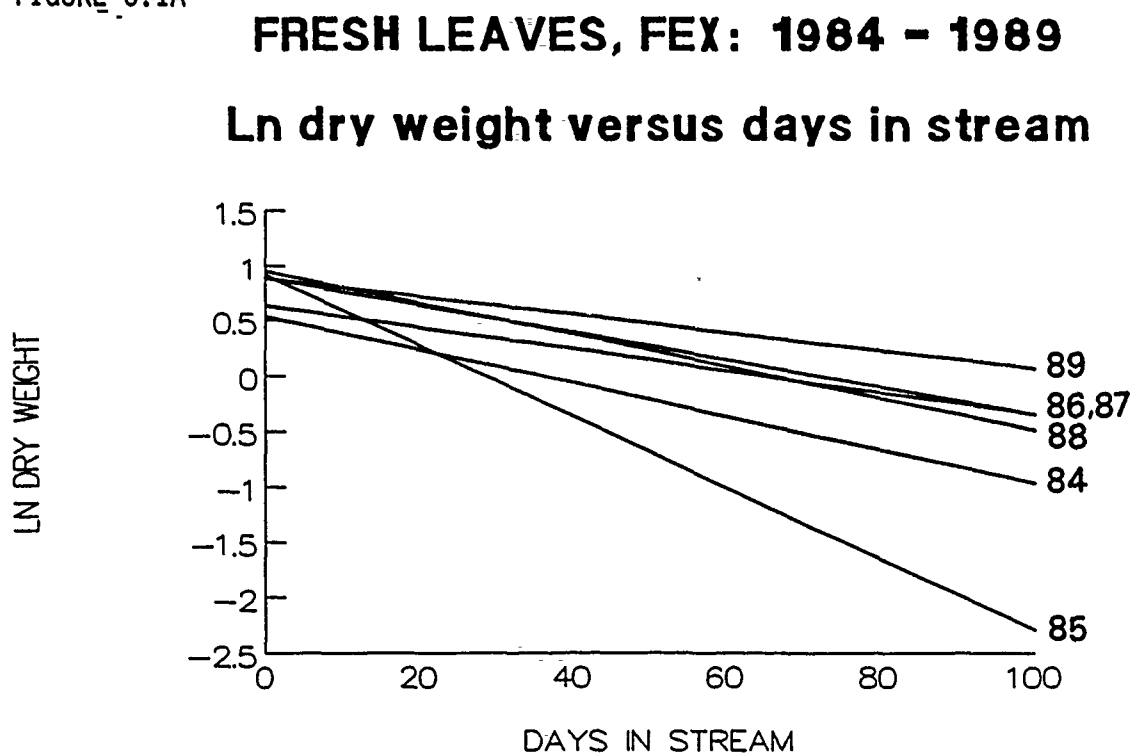


FIGURE 6.1B

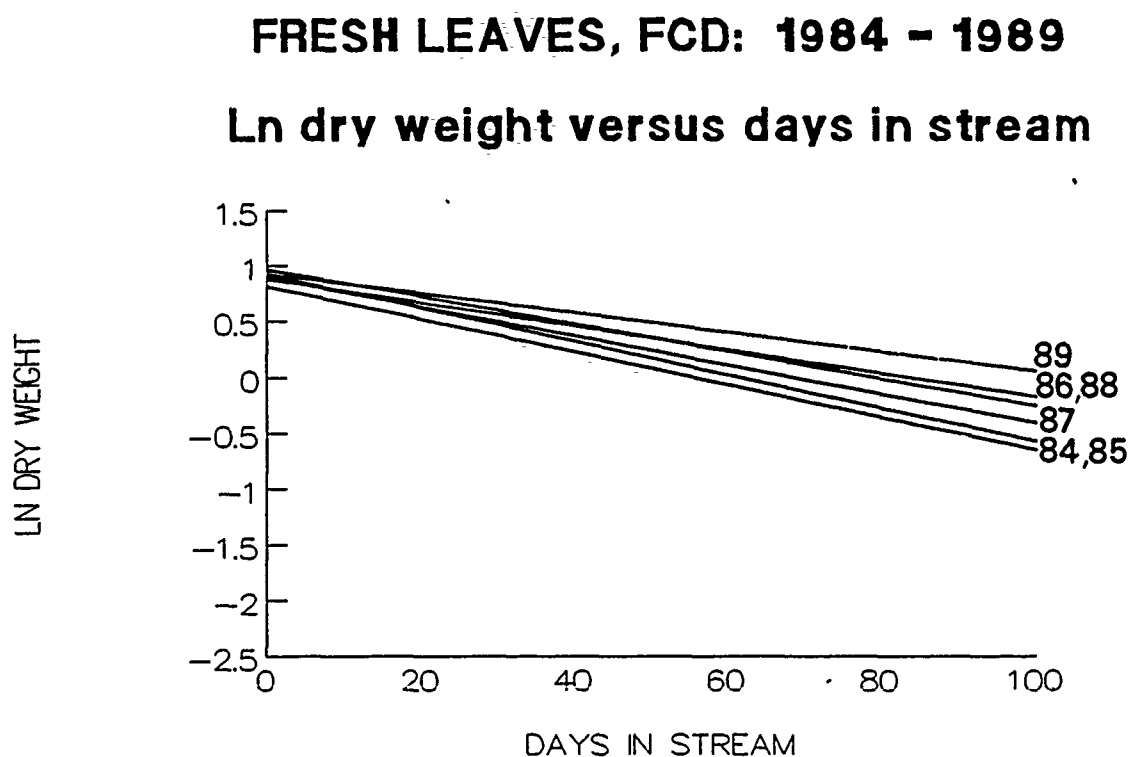


Figure 6.1 (A). Changes in dry mass values (Ln) over time for fresh leaves at FEX, 1984 - 1989. See Table 6.1 for slopes and p values.

(B). Changes in dry mass values (Ln) over time for fresh leaves at FCD, 1984 - 1989. See Table 6.1 for slopes and p values.

TABLE 6.1

Processing Coefficients (-k/day) and Regression  
Coefficients for Fresh and Autumn Leaves  
in the Ford River, 1984 - 1989

| Year | FEX                    |     |                         |     | FCD                    |     |                         |     |
|------|------------------------|-----|-------------------------|-----|------------------------|-----|-------------------------|-----|
|      | Fresh<br>-k/day, $r^2$ |     | Autumn<br>-k/day, $r^2$ |     | Fresh<br>-k/day, $r^2$ |     | Autumn<br>-k/day, $r^2$ |     |
| 1984 | .0151                  | .78 | .0081                   | .67 | .0149                  | .83 | .0060                   | .50 |
| 1985 | .0321                  | .62 | -                       |     | .0146                  | .47 | -                       |     |
| 1986 | .0099                  | .69 | .0035                   | .86 | .0105                  | .68 | .0029                   | .36 |
| 1987 | .0124                  | .80 | .0070                   | .52 | .0130                  | .74 | .0050                   | .27 |
| 1988 | .0145                  | .70 | .0072                   | .83 | .0122                  | .57 | .0049                   | .42 |
| 1989 | .0102                  | .84 | .0099                   | .77 | .0087                  | .74 | .0076                   | .60 |

## 2. Autumn-Abscised Leaves

Autumn-abscised leaves were consistently processed faster at FEX than at FCD (Figure 6.3, Table 6.1). Y-intercepts differ, as initial dry leafpack weights differed (See Materials and Methods section.). A Wilcoxon rank sum test showed significant site differences across years [ $P(T = 0) = 0.0156$ ]. Figure 6.2 shows that autumn leaves placed at FEX were always processed faster than those at FCD (the difference values always being above the zero line). Even though leaves were processed very slowly at FEX in 1986, the same was true for FCD. This is reflected by similar difference values between FEX and FCD across all years (Figure 6.2). (Note that no autumn leaves were used in 1985; a continuous line across years for autumn leaves in the figure was made for heuristic purposes.)

## 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

FIGURE 6.2

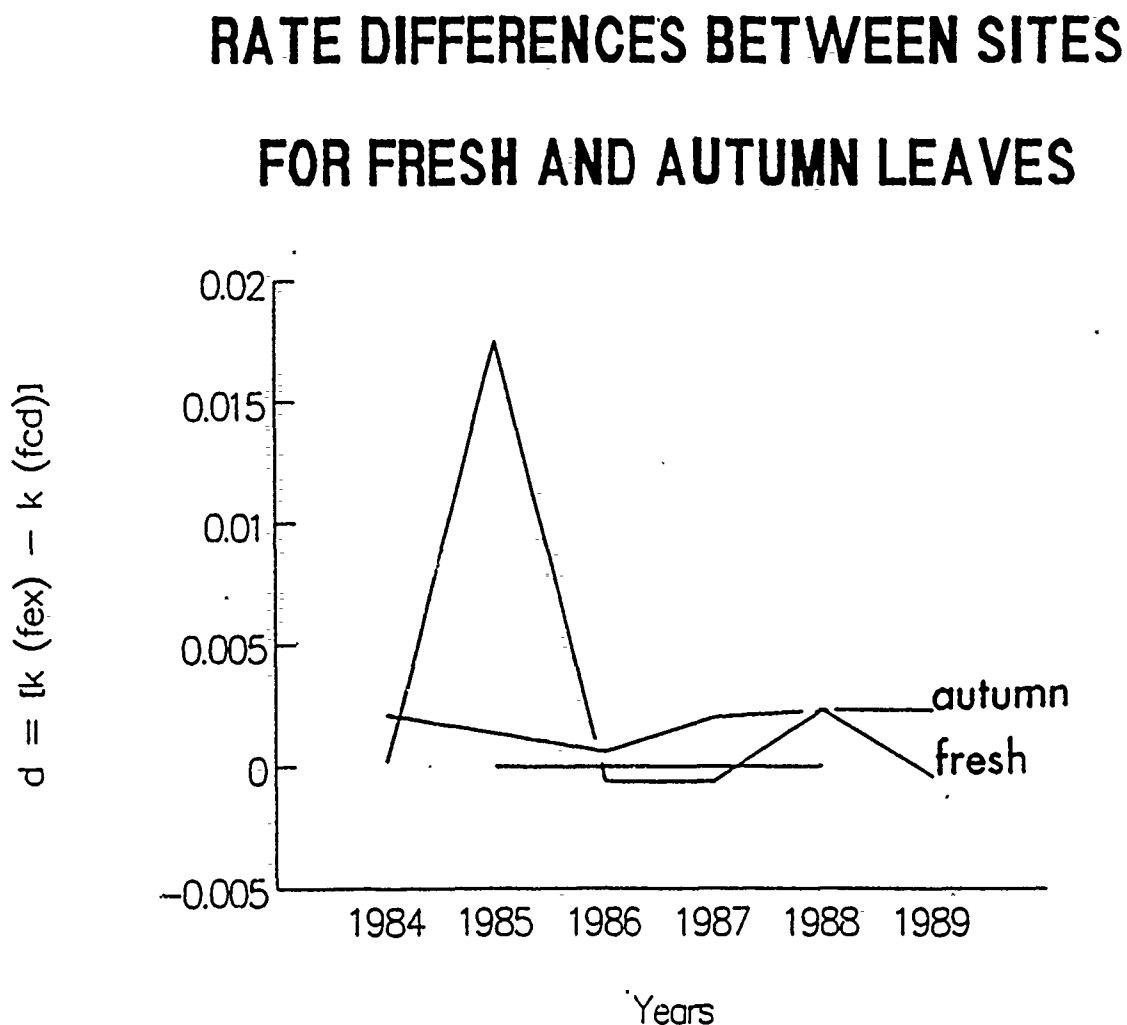


Figure 6.2. Leaf processing rate ( $-k/\text{day}$ ) differences between the two sites (FEX minus FCD) over time for Fresh and Autumn leaves. For heuristic purposes, line for autumn leaves is continuous, even though no experiments were performed in 1985. (Note that only fresh leaves go below the zero line.)

FIGURE 6.3A

# **AUTUMN LEAVES, FEX: 1984, 1986 - 1989**

## **Ln dry weight versus days in stream**

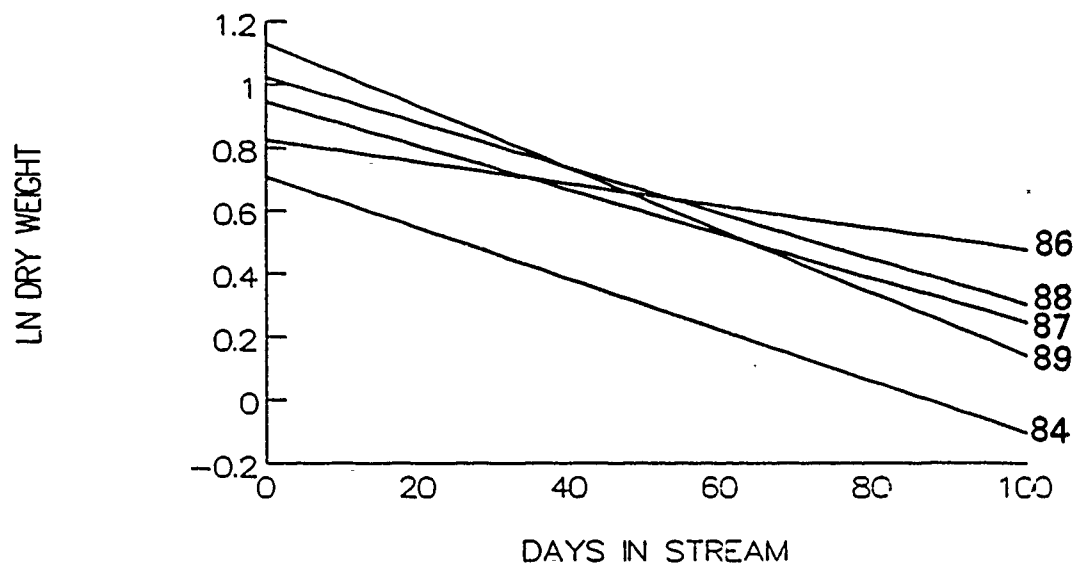


FIGURE 6.3B

# **AUTUMN LEAVES, FCD: 1984, 1986 - 1989**

## **Ln dry weight versus days in stream**

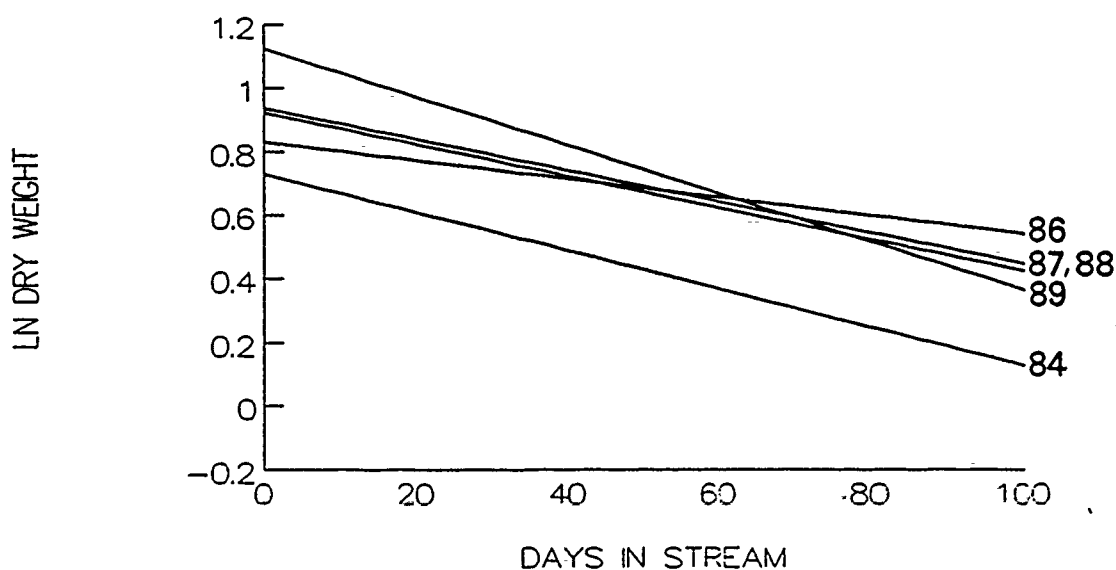


Figure 6.3 (A) Changes in dry mass values (Ln) for autumn leaves at FEX; 1984; 1986 - 1989. See Table 6.2 for slopes and p values.

(B) Changes in dry mass values (Ln) for autumn leaves at FCD; 1984; 1986 - 1989. See Table 6.2 for slopes and p values.

that time period to look for any differences between the two sites across years. We have also previously shown that the two treatments, fresh and autumn leaves, usually differed within any year with respect to substrate preferences for the aquatic insects. Those two treatments are handled separately in the statistical analyses. Both treatments are presented together in the figures for illustrative purposes.

Taxon diversity ( $H'$ ) was higher on autumn leaves than on fresh leaves, except for 1984 (Figure 6.4). In 1988,  $H'$  values for both treatments were lower than for previous years. When within treatment differences are considered, communities were more diverse at FEX than at FCD throughout the years. A Two Way ANOVA for fresh leaves, looking at possible differences for year, site and year x site showed that there were very significant differences among years, significant differences between sites, and year x sites (Table 6.2). In 1984, insects on fresh leaves were more diverse at FCD than at FEX. This was never the case in later years (Figure 6.4). The same phenomenon did not occur for autumn leaves; taxon diversity was higher or near the same at both sites. There were significant yearly differences for autumn leaves but no significant site or year x site differences Table 6.2).

TABLE 6.2  
Two-Way ANOVA Tests for  $H'$  of Insects on (A) Fresh and  
on (B) Autumn Abscised Leaves After 24 to 28 Days,  
1984 through 1988

| Source                   | d.f. | SS    | MSS   | F value   |
|--------------------------|------|-------|-------|-----------|
| <b>(A) Fresh Leaves</b>  |      |       |       |           |
| Years                    | 4    | 6.789 | 1.697 | 31.547*** |
| Site                     | 1    | 0.471 | 0.471 | 8.762**   |
| Interaction              | 4    | 0.626 | 0.157 | 2.911*    |
| Error                    | 60   | 3.226 | 0.054 |           |
| <b>(B) Autumn Leaves</b> |      |       |       |           |
| Years                    | 3    | 4.651 | 1.550 | 15.381*** |
| Site                     | 1    | 0.396 | 0.396 | 3.931     |
| Interaction              | 3    | 0.484 | 0.161 | 1.601     |
| Error                    | 48   | 4.837 | 0.101 |           |

Taxon Richness ( $S'$ ) was highest in 1986 (Figure 6.4). That year, the fall was very mild. It was on autumn leaves that  $S'$  was at its highest values. Richness on autumn leaves was similar at both sites over the years. Although



FIGURE 6.4A **STRUCTURAL COMMUNITY PARAMETERS**

**Diversity, Days 24 - 28**

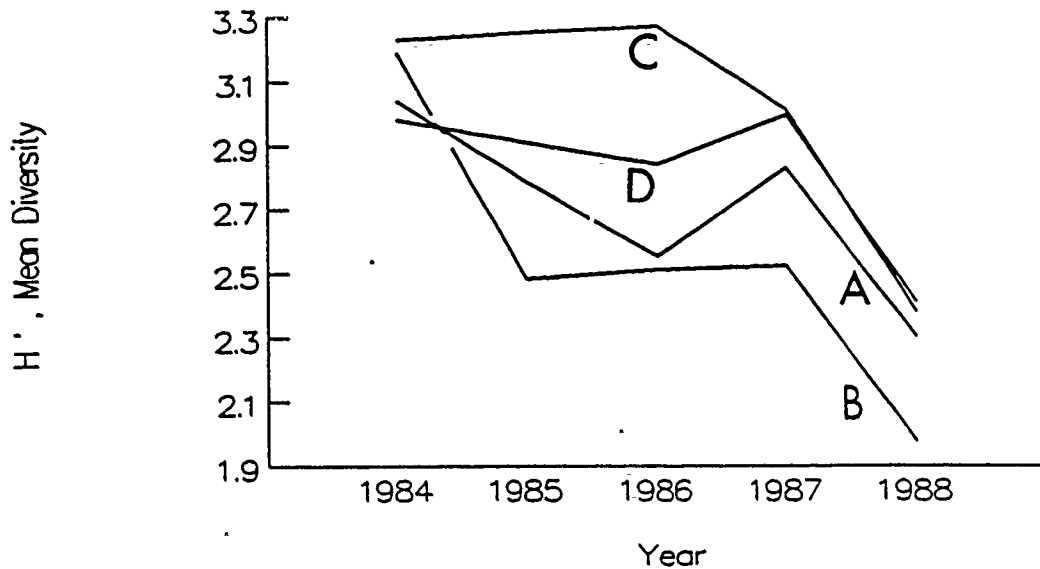


FIGURE 6.4B

**STRUCTURAL COMMUNITY PARAMETERS**

**Species Richness, Days 24 - 28**

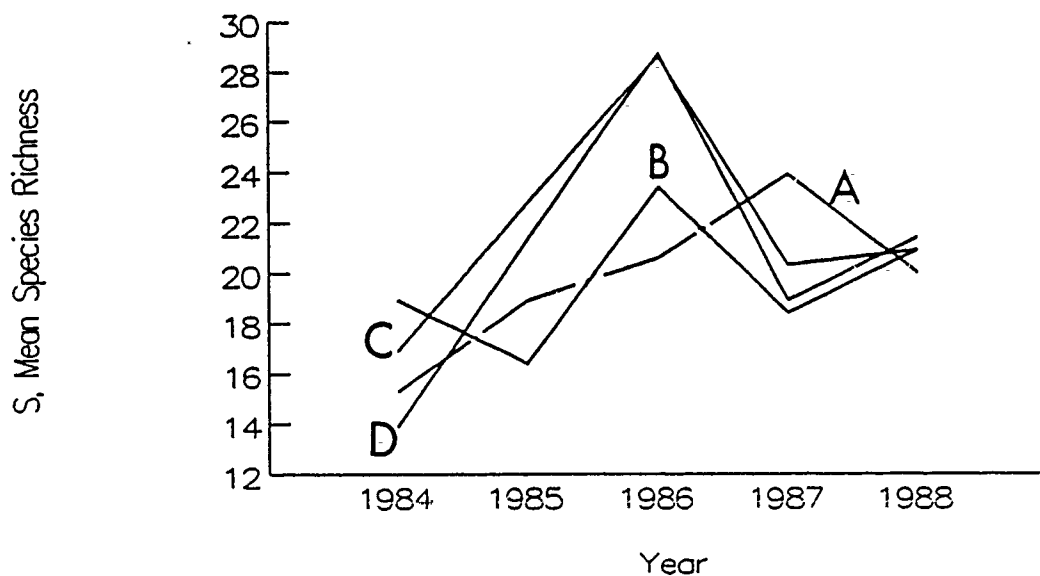


Figure 6.4A. Mean diversity ( $H'$ ) of insects on fresh and autumn leaves at FEX and FCD after 24 to 28 days immersion. Key: A = FEX Fresh, B = FCD Fresh, C = FEX Autumn, D = FCD Autumn.

Figure 6.4B. Mean taxon richness ( $S'$ ) for insects on fresh and autumn leaves at FEX and FCD after 24 to 28 days. Key: same as above.

S' values on fresh leaves were similar at both sites as well, values deviated somewhat in 1987. Further, peak values varied with respect to sites. Some years FEX showed the highest S' and other years FCD showed the highest S' values. A Two Way ANOVA shows that, for fresh leaves, there were significant year effects and year x site interaction effects, but no site differences, emphasizing the randomness of site peaks over the years (Table 6.3). On the other hand, only years were significantly different for insect community richness on autumn leaves (Table 6.3).

TABLE 6.3  
Two Way ANOVA Tests for Taxon Richness (S') of Insects on  
Fresh (A) and Autumn Abscised (B) Leaves  
after 24 to 28 Days,  
1984 through 1988

| Source            | d.f. | SS       | MSS     | F value   |
|-------------------|------|----------|---------|-----------|
| (A) Fresh Leaves  |      |          |         |           |
| Years             | 4    | 266.486  | 66.621  | 10.257*** |
| Site              | 1    | 0.229    | 0.229   | 0.035     |
| Interaction       | 4    | 199.343  | 49.836  | 7.673***  |
| Error             | 60   | 389.714  | 6.495   |           |
| (B) Autumn Leaves |      |          |         |           |
| Years             | 3    | 1290.643 | 430.214 | 46.124*** |
| Site              | 1    | 12.071   | 12.071  | 1.294     |
| Interaction       | 3    | 27.786   | 9.262   | 0.993     |
| Error             | 48   | 447.714  | 9.327   |           |

As for S', numbers of individuals were at their peak in 1986 (except for fresh leaves at FEX). The more mild fall and winter that year may also account for those peaks. Both fresh leaves and autumn leaves at the two sites showed similar patterns over the years (Figure 6.5). A Two Way ANOVA gave results similar to those for S' on fresh or autumn leaves (Table 6.4).

FIGURE 6.5A

## STRUCTURAL COMMUNITY PARAMETERS

### Numbers of Individuals, Days 24 - 28

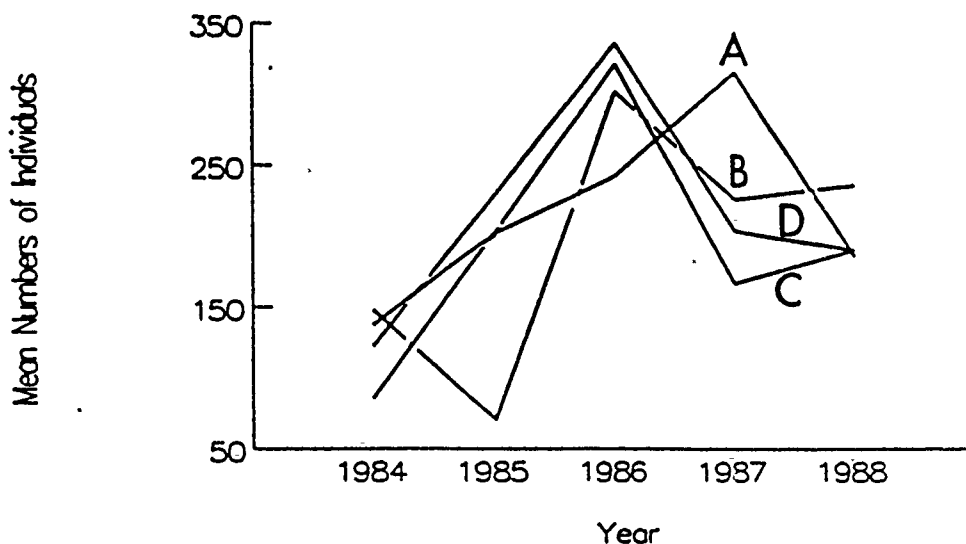


FIGURE 6.5B

### Insect/Leaf Biomass Ratio, Days 24 - 28

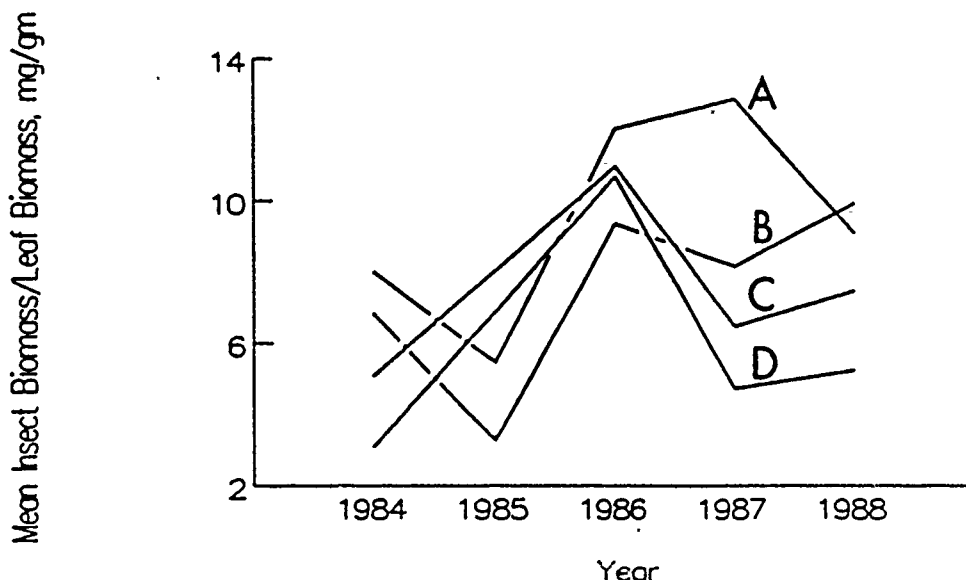


Figure 6.5A. Mean numbers of insects on fresh and autumn leaves at FEX and FCD after 24 to 28 days immersion. Key: A = FEX fresh, B = FCD fresh, C = FEX autumn, D = FCD autumn.

Figure 6.5B. Mean total insect biomass/leaf dry mass (mg/gm) on fresh and autumn leaves at FEX and FCD after 24 to 28 days. Key: same.

TABLE 6.4  
Two Way ANOVA Tests for Differences in  
Numbers of Individuals of Insects on  
Fresh (A) and Autumn Abscised (B) Leaves  
After 24 to 28 Days, 1984 through 1988

| Source                                    | d.f. | SS      | MSS     | F value   |
|-------------------------------------------|------|---------|---------|-----------|
| <hr/> (A) Fresh Leaves <hr/>              |      |         |         |           |
| Years                                     | 4    | 242,475 | 60,619  | 24.706*** |
| Site                                      | 1    | 7,161   | 7,161   | 2.919     |
| Interaction                               | 4    | 102,122 | 25,531  | 10.405*** |
| Error                                     | 60   | 147,217 | 2,454   |           |
| <hr/> ----- <hr/> (B) Autumn Leaves <hr/> |      |         |         |           |
| Years                                     | 3    | 360,277 | 120,092 | 29.057*** |
| Site                                      | 1    | 4,810   | 4,810   | 1.164     |
| Interaction                               | 3    | 2,485   | 828     | 0.200     |
| Error                                     | 48   | 198,384 | 4,133   |           |

#### Functional Community Parameters

##### 1. Total Insect Biomass

Total Insect Biomass, adjusted for leaf mass, was highest in 1986, except for fresh leaves at FEX. This was also true for S' and numbers of individuals, described above. In general, fresh leaves supported a higher insect biomass than did autumn leaves (Figure 6.5). This was especially true for insects on fresh leaves at FEX. Table 6.5 quantifies this pattern. Both year and site differences were significant. As for other indices for the autumn leaf treatment, there were significant year differences but no site differences (Table 6.5).

TABLE 6.5

Two Way ANOVA Tests for Mean Total Insect Biomass,  
Adjusted for Leaf Mass on  
Fresh (A) and Autumn Abscised (B) Leaves  
After 24 to 28 days, 1984 through 1988

| Source            | d.f. | SS      | MSS     | F value   |
|-------------------|------|---------|---------|-----------|
| (A) Fresh Leaves  |      |         |         |           |
| Years             | 4    | 391.786 | 97.946  | 13.056*** |
| Site              | 1    | 68.416  | 68.416  | 9.120***  |
| Interaction       | 4    | 57.273  | 14.318  | 1.909     |
| Error             | 60   | 450.125 | 7.502   |           |
| -----             |      |         |         |           |
| (B) Autumn Leaves |      |         |         |           |
| Years             | 3    | 352.163 | 117.388 | 10.238*** |
| Site              | 1    | 33.962  | 33.962  | 2.962     |
| Interaction       | 3    | 8.143   | 2.714   | 0.237     |
| Error             | 48   | 550.378 | 11.466  |           |

## 2. Mean Dry Weight per Individual (MDW/IND)

Individuals of species that are found in sufficient numbers on leafpacks and grow during the autumn and winter seasons can be followed for possible changes in growth rates from year to year at the experimental and reference sites. Three species fulfilled those two criteria: Ephemerella invaria, Ephemerella subvaria (mayfly collector-gatherers) and Isoperla transmarina (a predatory stonefly).

In the past, changes in MDW/IND values for each species were plotted against chronological time in order to look at growth patterns. It was found this year that physiological time showed those patterns much better. Yearly differences in growth rates for E. invaria were probably caused by differences in water temperatures (Figure 6.6). In 1984, 1985, and 1986, leaves were put in the Ford River in September. In 1987, 1988, and 1989, leaf processing experiments were begun in mid- to late-August. Because the average water temperatures were warmer during the last three years of the experiments, the slopes of the line for changes in MDW/IND are less steep. Thus, small changes in cumulative degree days over any 30 day period were associated with large increases in MDW/IND values for the first three years of the study. Insects during those times were in the stream when water temperatures had begun to be consistently cold (October through December). This species, as

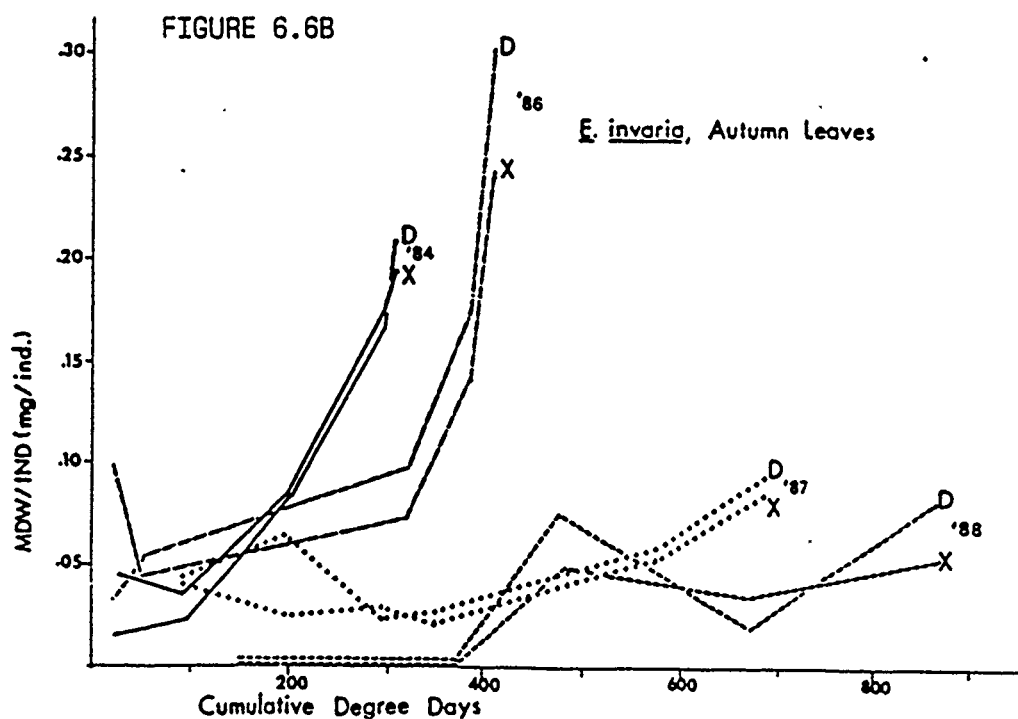
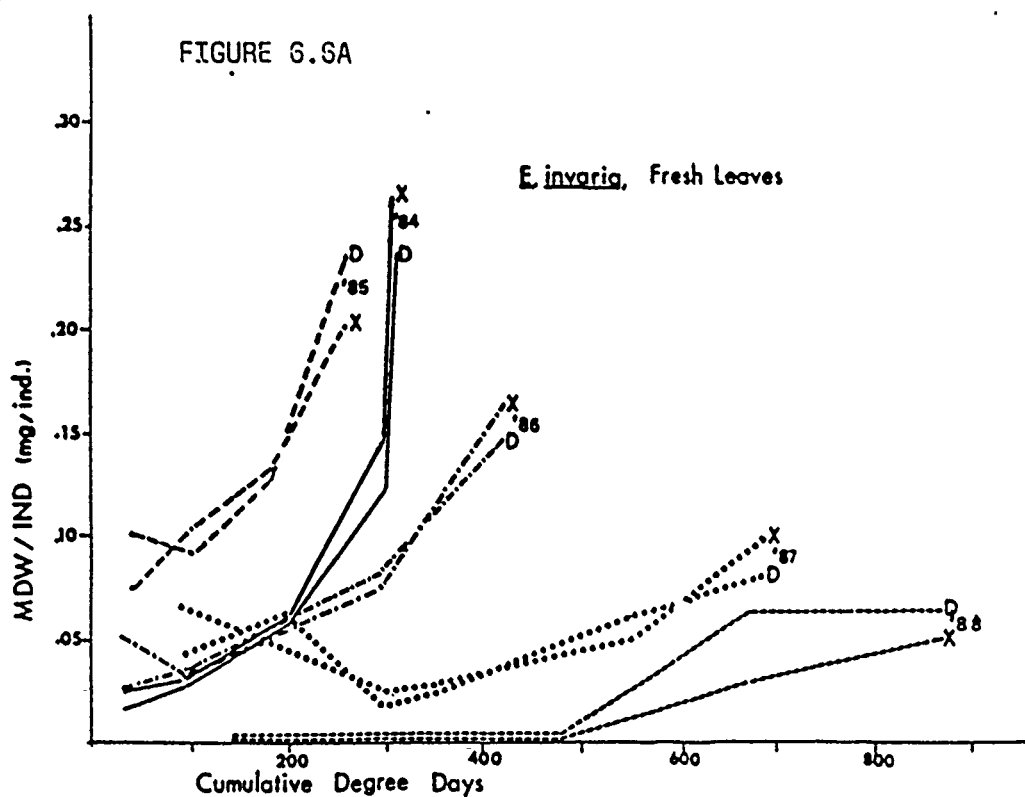


Figure 6.6A. Changes in MDW/IND values of *Ephemerella invaria* on fresh leaves from 1984 through 1988, using cumulative degree days (threshold = 2 oC) X = FEX site, D = FCD site.

Figure 6.6B. Changes in MDW/IND values of *Ephemerella invaria* on autumn leaves in 1984, 1986, 1987, 1988; cumulative degree-days.

well as the other species studied, are cold-adapted and undergo their major growth as soon as water temperatures cool substantially. The major growth phase for E. invaria was not detected in 1987 and 1988, as the last leafpack collection occurred in mid-November, rather than in mid-December. As far as possible effects of E.L.F. are concerned, there were no differences between the two sites. With few exceptions, there were no significant differences between leaf treatments for this parameter (Table 6.6.).

TABLE 6.6

Wilcoxon-Mann-Whitney Tests for Differences in MDW/IND Values for Ephemerella invaria. FEX versus FCD, Fresh and Autumn Leaves Pooled. 1984 through 1988

| Year  | FEX Rank Sum | FCD Rank Sum | Prob. Level | m, n   |
|-------|--------------|--------------|-------------|--------|
| 1984  | 111          | 99           | .342        | 10, 10 |
| 1985* | 23           | 31           | .210        | 5, 5   |
| 1986  | 107          | 103          | .456        | 10, 10 |
| 1987  | 113          | 97           | .289        | 10, 10 |
| 1988  | 20           | 35           | .075        | 5, 5   |

\* Fresh Leaves only (no autumn leaf study done in 1985). (Note that in 1988 leaves were put in the stream in mid-August. A number of leafpacks did not harbor this species and so m (N for FEX) and n (N for FCD) were < 10).

The second species for this genus, E. subvaria, is a much larger mayfly prior to emergence. Yet, its growth pattern was very similar to that of E. invaria over the years (Figure 6.7; compare with Figure 6.6). There were no differences between FEX and FCD except in 1985. That year, no individuals were found on fresh leaves at FCD in October when the leaves had been in the stream for 54 days. As this species grows in the fall, and some animals were found on fresh leaves at FEX, differences in growth rates over time were shown to be significantly different for fresh leaves that year. 1985 was prior to operation of ELF; therefore, growth rates for this species as well as E. invaria showed no effect as a function of ELF operation.

FIGURE 6.7A

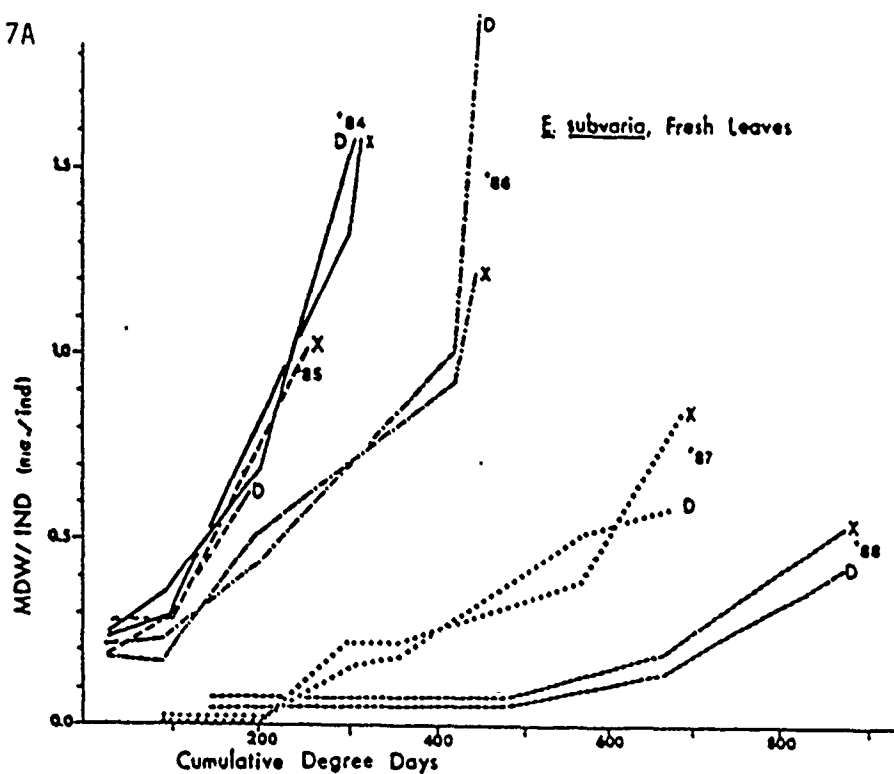


FIGURE 6.7B

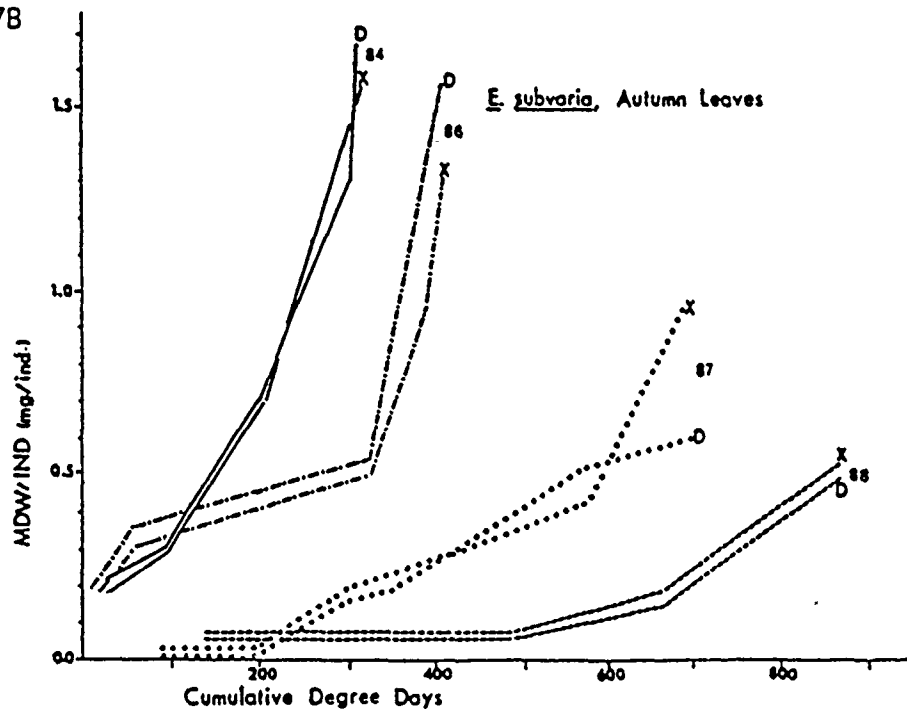


Figure 6.7A. Changes in MDW/IND values of *Ephemerella subvaria* on fresh leaves from 1984 through 1988, using cumulative deg.days (threshold = 2 oC). X = FEX, D = FCD.

Figure 6.7B. Changes in MDW/IND values of *Ephemerella subvaria* on autumn leaves in 1984 and 1986 through 1988. X = FEX, D = FCD.



TABLE 6.7

Wilcoxon-Mann-Whitney Tests for Differences in MDW/IND Values  
for Ephemerella subvaria. FEX versus FCD, Fresh and Autumn  
Leaves Pooled, 1984 through 1988

| Year | FEX Rank Sum | FCD Rank Sum | Prob. Level | m, n   |
|------|--------------|--------------|-------------|--------|
| 1984 | 81           | 91           | .365        | 9, 9   |
| 1985 | 18           | 10           | .018*       | 5, 3   |
| 1986 | 99           | 111          | .342        | 10, 10 |
| 1987 | 75           | 61           | .78         | 8, 8   |
| 1988 | 74           | 62           | .747        | 8, 8   |

Both species in the genus emerge in late spring (See Element 4, this report). Because few individuals are found in substrate samples, their growth patterns in winters and early springs could not be accurately documented.

The last species, Isoperla transmarina showed growth patterns similar to the other two taxa described (Figure 6.8). It certainly appears from comparing all three figures (6.6 through 6.8) that peak growth rates in 1987 and 1988 were not "captured" because our leafpack studies began earlier in the season. It also appears that the growth rates for these species are very similar. We plan on modeling our cumulative degree program for cold adapted species (some factor/degree days). That work will be submitted to a peer reviewed journal next year (1990). As there were no differences in MDW/IND values for I. transmarina on fresh or autumn leaves, the data were pooled (Table 6.8).

TABLE 6.8

Wilcoxon-Mann-Whitney Tests for Differences in MDW/IND Values  
for Isoperla transmarina. FEX versus FCD.  
Fresh and Autumn Leaves Pooled.  
1984 through 1988

| Year | FEX Rank Sum | FCD Rank Sum | Prob. Level | m, n   |
|------|--------------|--------------|-------------|--------|
| 1984 | 72           | 99           | .129        | 9, 9   |
| 1985 | 12           | 15           | .200        | 3, 4   |
| 1986 | 107          | 103          | .456        | 10, 10 |
| 1987 | 110          | 100          | .379        | 10, 10 |
| 1988 | 67           | 69           | .660        | 7, 9   |

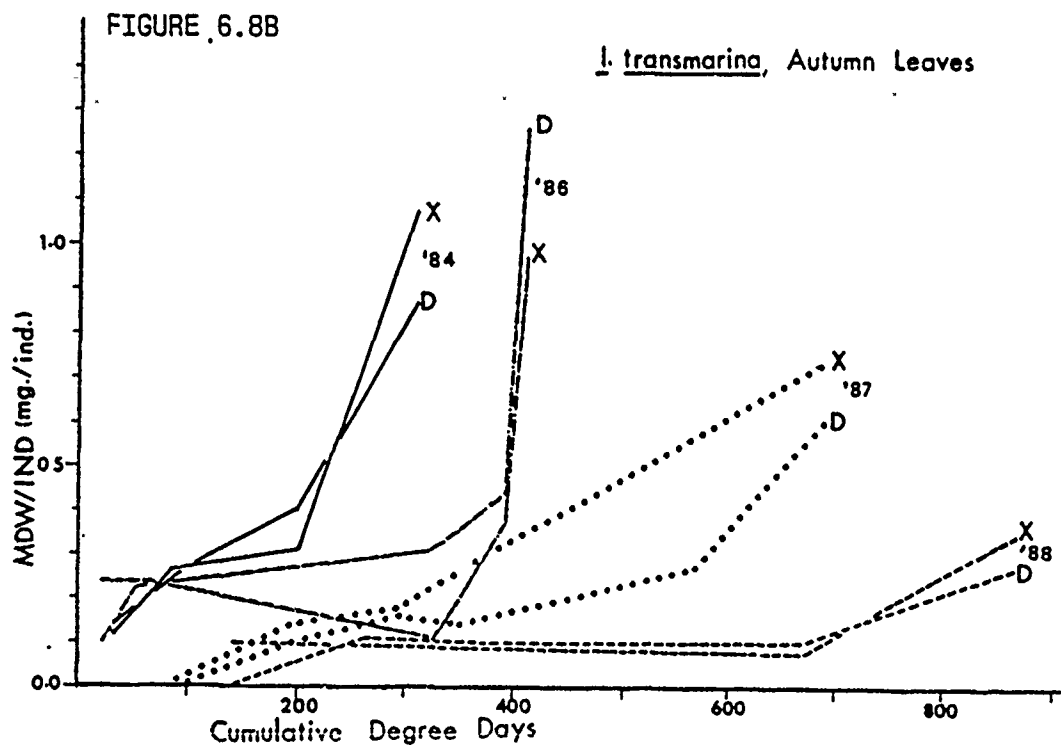
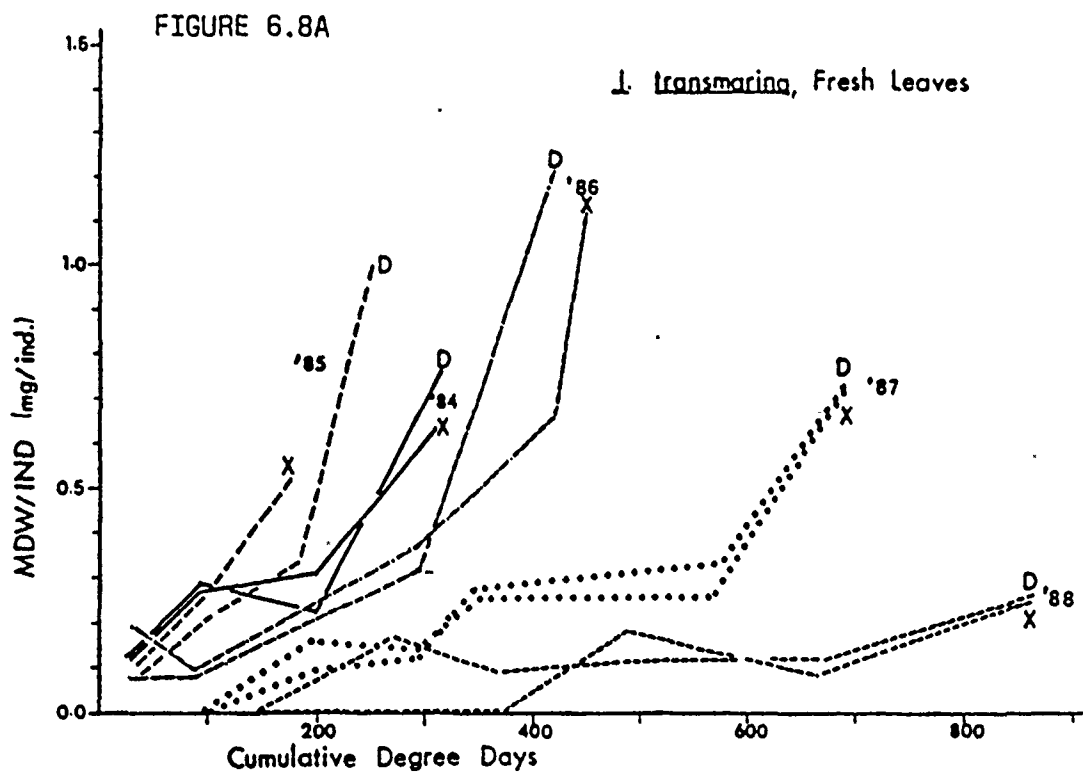


Figure 6.8A. Changes in MDW/IND for *Isoperla transmarina* on fresh leaves, 1984 through 1988 using cumulative deg.day (threshold: 20C). X = FEX, D = FCD.

Figure 6.8B. Changes in MDW/IND for *Isoperla transmarina* on autumn leaves, 1984, and 1986 - 1988, using cumulative deg.days. X = FEX, D = FCD.

### Future Plans for This Element

Fresh and autumn abscised leaf experiments will begin each year in late August so that the last retrieval date will be in mid-November. In the past, December retrievals were often difficult. When gauss-days are collated, they will serve as an independent variable for leaf processing rates, taxon diversity, and numbers of individuals. Very little is known regarding the potential effects of extremely low frequency electromagnetic fields on biological systems. Accordingly, any insights germane to the transient behavior of the fields during changes in activity, or any other factors associated with the fields will be used in the analyses of the least varying biological variables for this element.

A paper on the use of a variant of cumulative degree days for determining fall and winter growing aquatic insects' growth patterns will be written. Nineteen-eighty-nine data for insects colonizing the leaves will be incorporated into the Element for the revision in the spring of 1990. After the 1990 leaf processing data are completed, a paper will be written and submitted to a peer reviewed journal.

### Summary

Each year, fresh leaves were processed faster than autumn leaves at each site. Although processing rates varied from year to year, FEX and FCD were not significantly different with respect to fresh leaves. There were site differences for autumn leaves over the years. Autumn leaves were always processed faster, before and after E.L.F. activation at FEX. The site differences for autumn leaves may be caused by the usually higher biomass and numbers of aquatic insects at that site, determined both from substrate and leafpack samples. Taxon diversity, richness, numbers of individuals, and mean total biomass (adjusted for leaf mass) on autumn leaves after the leaves had been incubated approximately four weeks showed significant yearly variation but no site variation. On the other hand, although those variables for insects on fresh leaves showed yearly differences as well, for some variables, there were site differences ( $H'$ , mean total biomass) and year x site differences ( $H'$ ,  $S'$ , number of individuals). These results illustrate, once again, that fresh and autumn leaves are "seen" differently by the aquatic insects who consume them, directly or indirectly. None of the differences are related to the time period after activation of ELF in 1986. Growth rates and patterns of three species of aquatic insects were shown not to differ with respect to leaf treatment or site. Physiological time (cumulative degree days) revealed these similarities in growth rates much better than did chronological time.

Appendix II presents results of a theoretical paper on the effects of condensed tannins on leaf processing rates in tropical and temperate biomes (Can.Jour.Fish. & Aquat.Sci., 46:1097) and results of a cooperative study on testing the hypothesis in the paper. It was found that leaves high in condensed tannins were processed more slowly than leaves low in condensed tannins at each of three sites (Alaska, Michigan, Costa Rica). Further, if cumulative degree-days (physiological time) rather than days (chronological time) was used in computing processing rates, leaves lacking or low in condensed tannins were processed much faster; whereas, no strong differences in processing rates occurred for leaves high in condensed tannins when they were in warm water. The difference between physiological and chronological time for those latter species of leaves was minimal.

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## APPENDIX II

### *Condensed Tannins and Leaf Decomposition Rates*

In addition to the monitoring of leaf decomposition rates and monitoring of insect colonization patterns on those leaves, a theoretical paper on effects of condensed tannins on leaf processing in mid-latitude and tropical streams was published (a copy of the paper is included herein), and a cooperative study on testing the hypothesis was done in 1988 - 1989. A report on those latter results was given at the American Institute of Biological Sciences (A.I.B.S.) meeting in Toronto, Canada in August, 1989. A paper is currently being written on those results. For now, a report on those results follows.

#### *Results of an International Leaf Swap*

The body of literature on the role that plant defensive compounds plays in the 'arms race' between potential herbivores and their plant hosts has been increasing at a rapid rate in the last 10 to 15 years. Much of the literature has come from tropical, warm environments -- areas where the arms race appears to be intense, given the year-round herbivore pressure on plants that are often growing on nutrient-poor soils. It is there that many species of plants produce 'expensive' leaves; i.e., the physiological cost to the plant in the production of the leaves is high. Many of those leaves are rich in defensive compounds. One such defensive compound is condensed tannins. Because condensed tannins are not sequestered back from leaves into other parts of the plant prior to leaf drop and because condensed tannins are not easily leached in water, they have been theorized to inhibit leaf degradation by aquatic hyphomycetes and bacteria after the leaves fall into streams (Stout 1989).

A test of this hypothesis was done by a number of aquatic ecologists at six sites: Alaska (Mark Oswood and Jack Irons), New York (William McDowell), the Ford River in Michigan (Jean Stout), North Carolina (Seth Reice), Puerto Rico (Clyde Asbury), and Costa Rica (Cathy Pringle). Leaves from two species of trees, one high and one low in condensed tannins, were collected at each site, dried at less than 40°C, and sent to each collaborator. Leaves were placed in a stream at each site in the fall of 1988 and collections were made after 7, 14, 21, 28, 54, and 112 days. Leaves were dried at <40°C for two days and weighed. Data accumulated during the study included leaf processing rates per day (-k/day), leaf processing rates per degree day (-k/degree day), concentration of condensed tannins, carbon/nitrogen ratios in leaves, and insects found on leaves over time.

Leaves that were high in condensed tannins were processed slower, irrespective of place of origin, than were leaves low in condensed tannins (Figure 1A, 1B, 1C). For leaves high in condensed tannins, the difference between -k/day and -k/degree day at each site was minimal. For leaves lacking or low in

condensed tannins, the difference between  $-k/\text{day}$  and  $-k/\text{degree day}$  at each site was large (Table 1). In other words, physiological time was an important factor in determining leaf processing rates for leaves unprotected by condensed tannins. The data support the hypothesis that aquatic decomposers have much more effect on the breakdown of leaves without condensed tannins than on the breakdown of leaves with condensed tannins. A plot of the difference between  $-k/\text{degree day}$  and  $-k/\text{day}$  against percent (dry mass) condensed tannin content for the three sites where the data are complete (Alaska, Michigan, and Costa Rica) shows that when leaves lacked or were low in condensed tannins, water temperature at each site ( $-k/\text{degree day}$ ) played a large role in decomposition rates. As condensed tannin loads increased, it did not matter whether daily water temperatures (physiological time) or days (chronological time) was used to compute processing rates. Thus, it appears that when water temperatures were higher and, therefore, probably the activity of fungi and bacteria was also high, processing rates of unprotected leaves was also increased; for those leaves that were protected by condensed tannins, the increased water temperatures did not appreciably increase processing rates of those leaves.

TABLE 1

Differences Between  $-k/\text{Degree Day}$  and  $-k/\text{Day}$  at 3 Sites and Percent Condensed Tannins for 10 Species of Leaves

| SPECIES (native location)     | DIFFERENCES AT THREE SITES |          |            | % C.T. |
|-------------------------------|----------------------------|----------|------------|--------|
|                               | ALASKA                     | MICHIGAN | COSTA RICA |        |
| <u>Trema micrantha</u> (CR)   | +0.0035                    | -.0783   | -.5024     | 0.00   |
| <u>Salix alaxensis</u> (AL)   | +0.1055                    | -.0158   | -.0737     | 1.30   |
| <u>Alnus crispa</u> (AL)      | +0.2082                    | -.012    | -.3903     | 1.21   |
| <u>Cornus florida</u> (NC)    | +0.0737                    | -.0193   | -.4781     | 1.34   |
| <u>Alnus rugosa</u> (MI)      | +0.1960                    | -.0120   | -.3748     | 2.48   |
| <u>Acer saccharum</u> (NY)    | +0.2082                    | +0.0165  | -.1446     | 2.85   |
| <u>Quercus rubra</u> (MI)     | +0.0144                    | -.0110   | -.1119     | 4.88   |
| <u>Fagus grandifolia</u> (NY) | +0.0143                    | -.0060   | -.0786     | 5.86   |
| <u>Quercus falcata</u> (NC)   | +0.0057                    | -.0053   | -.0698     | 9.46   |
| <u>P. longifolium</u> (CR)    | +0.0035                    | -.0003   | -.0168     | 10.16  |

AL: Alaska NY: New York MI: Michigan NC: N. Carolina  
CR: Costa Rica

This research generated many more questions, some of which include: (1) Are aquatic microbial communities similar across altitudinal and/or latitudinal gradients, or (2) Are communities systematically different, with differing evolutionary lines that give rise to geographical differences among action and activity peaks for microbial decomposers? (3) Are there some microbial species, macroinvertebrates, and/or vertebrates that specialize on condensed tannins as carbon sources, (4) Are some species capable of neutralizing the action of condensed tannins on biological systems?

Some of the research along these lines may have applied potentials, such as in production of paper and in processing of by-products from lumber mills, the sizes of buffer strips along river courses, the species of plants best grown along river courses during reconstruction of damaged systems, the medicinal use of condensed tannins for inhibition of pathogenic micro-organisms.



# Effects of Condensed Tannins on Leaf Processing in Mid-Latitude and Tropical Streams: A Theoretical Approach

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Stout, R. J. 1989. Effects of condensed tannins on leaf processing in mid-latitude and tropical streams: a theoretical approach. *Can. J. Fish. Aquat. Sci.* 46: 1097-1106.

Differences in the dynamics of allochthonous leaf processing in tropical streams are compared with those at mid-latitudes. Phytochemical differences are linked with transferral of energy in stream ecosystems. Condensed tannins, defensive secondary compounds that remain in leaves after cellular death, are suggested as inhibiting and altering leaf processing microorganisms. Comparisons between condensed tannin concentrations and leaf processing rates in mid-latitude and tropical streams support this view. Although many data are available for leaf processing rates per day in mid-latitude streams, there are few quantitative data on plant secondary compounds. The reverse is true for research in tropical regions. Leaf transfer experiments between Costa Rica and Michigan showed the interpretations based on processing rates per day may mask phytochemical differences in cross-biome studies. Processing rates normalized for temperature as degree days for such studies are preferred, as temperature differences then can be distinguished from biotic differences.

Les différences dans la dynamique de transformation des feuilles allochtones dans les cours d'eau tropicaux sont comparées à celles relevées aux latitudes moyennes. Les différences phytochimiques sont liées au transfert d'énergie dans les écosystèmes des cours d'eau. On croit que les tanins condensés, composés secondaires de défense qui demeurent dans les feuilles après la mort cellulaire, inhibent et altèrent les microorganismes de décomposition. Cette hypothèse est confirmée par la comparaison des concentrations de tanins condensés et des taux de décomposition des feuilles dans les rivières tropicales et aux latitudes moyennes. Bien que l'on possède une information détaillée sur les taux quotidiens de transformation des feuilles dans les rivières aux latitudes moyennes, on manque de données quantitatives sur les composés végétaux secondaires. L'inverse est vrai pour la recherche dans les régions tropicales. Les travaux comportant l'échange de feuilles entre Costa Rica et l'État du Michigan ont montré que les interprétations qui s'appuyaient sur les taux quotidiens de décomposition masquaient peut-être les différences phytochimiques relevées dans les études qui recourent des biomes distincts. Pour ces études, on préfère normaliser les taux de transformation en fonction de la température sous la forme de degrés-jour, étant donné que les écarts de température peuvent alors être distingués des différences biotiques.

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In terrestrial communities, condensed tannins (proanthocyanidins) have been suggested as protecting leaves, bark, seeds, and root tissue from microbial invasion (Zucker 1983), as antibiotic agents (Porter 1986), and as defensive chemicals against herbivores (Swain 1978; Barbosa and Krischik 1987).

Condensed tannins in leaves that fall into streams also could affect aquatic bacterial and fungal activity, as they are not sequestered back into living plant tissue prior to leaf abscission. In this review I examine the hypothesis that leaves rich in condensed tannins falling into heterotrophic streams inhibit aquatic fungal and bacterial utilization of those leaves. By so doing, tannins alter biotic interchanges and energy transfers among the micro- and macroorganisms directly or indirectly dependent on the leaves. Leaves are a very important organic source for streams; any alterations to the utilization of leaves will affect the stream's energy budget.

Leaves that fall into streams draining watersheds low in available nutrients contain, on average, more condensed tannins than leaves produced on nutrient-rich soils (Janzen 1974). Higher levels of condensed tannins can be expected in leaves from trop-

ical areas, dry forests, and boreal areas than in those from mid-latitude deciduous forests. The latter have been the sites for most of the research on the dynamics of leaf processing. Yet, the effect of condensed tannins on leaf processing is expected to be most profound in aquatic environments, where there has been little research on allochthonous inputs.

Data used to support the hypothesis come from a literature search of condensed tannin concentrations in leaves, from papers on processing rates of leaves in streams, and from transfer experiments on processing rates of leaves in Costa Rican and Michigan streams.

## Background and Theory

Ecologists have been concerned with the utilization of leaf inputs in streams for nearly two decades, as those inputs are major organic resources for heterotrophic stream processes (Hynes and Kaushik 1969; Mathews and Kowalszewski 1969; Kaushik and Hynes 1971; Iverson 1973; Petersen and Cummins 1974; Triska et al. 1975; Suberkropp et al. 1976; Anderson et al. 1978). Phytochemical ecology of plant-animal interactions so richly studied of late in terrestrial systems (Feeny 1970; Har-

borne 1972; 1982; van Emden 1973; Gilbert and Raven 1974; Rhoades and Cates 1976; Swain 1977, 1978; Rosenthal and Janzen 1979; Macauley and Fox 1980; Fox 1981; Futuyma and Slatkin 1983) have not been explored for aquatic systems. Efforts at relating leaf litter utilization in streams to secondary plant compounds may further our understanding of cause-and-effect relationships between defensive plant compounds and trophic dynamics among aquatic organisms.

As condensed tannins are also found in bark (Stafford 1985), there is commercial value in studying the effects of condensed tannins on aquatic fungi and bacteria. Damage from logging may be diminished if the stripped bark of species known to be rich in tannins is not discarded in streams and rivers. Furthermore, streams draining areas with vegetation high in condensed tannins (as in certain tropical areas) may contain microorganisms adapted to condensed tannins as a carbon source. Microorganisms from those areas could be tested for their usefulness in wood processing.

Leaves of different plant species are processed in streams at different rates (Kaushik and Hynes 1971; Sedell et al. 1975; Short et al. 1980). These rates were modeled by Petersen and Cummins (1974) as the decay coefficient,  $-k$ ,  $\log (\%R/100)/t$ , where  $\%R$  is the percent of initial dry mass remaining, and  $t$  is the number of days in the stream. Decay coefficients ( $-k/d$ ) were categorized by Petersen and Cummins (1974) as being (1) fast,  $>0.010$ , (2) intermediate,  $0.0101 < -k < 0.005$ , and (3) slow,  $0.005$  or less.

The observation that some leaves are more resistant than others led researchers to look at dynamics of leaf conditioning by aquatic microorganisms as a prelude to aquatic insect processing (Kaushik and Hynes 1968; Triska 1970; Bärlocher 1980). The invasion of the leaf by aquatic hyphomycetes conditions leaf surfaces for later bacterial colonization (Suberkropp and Klug 1976, 1981), which in turn facilitates and increases insect consumption rates (Triska 1970; MacKay and Kalff 1973; Petersen and Cummins 1974).

Physicochemical data have been related to leaf processing rates: carbon-nitrogen ratios (Witcamp 1966); percent lignin (Minderman 1968; Van Cleve 1974; Fogal and Cromack 1977); polyphenols and leaf hardness (King and Heath 1967); and actual evapotranspiration (Meentemeyer 1978). Many of the data have not been linked directly with rheophilic microbial and macrofaunal communities and most of the relational data from mid-latitude regions.

Condensed tannins have been implicated as antibiotic and antifungal agents (Harrison 1971; Grant 1976; Zucker 1983; Porter 1986), but aquatic hyphomycetes and bacteria enhance

leaf quality for aquatic invertebrate and vertebrate consumers. Thus, if condensed tannins decrease leaf processing rates in streams, they should influence the ecology of the biotic community by decreasing consumption rates and by altering spatial and temporal food linkages among the primary and secondary consumers.

#### Mid-Latitude and Tropical Comparisons

Mid-latitude deciduous forest streams and tropical wet lowland forest streams differ in a number of ways (see Table 1). Stream water temperatures vary little seasonally in lowland tropical forests (Bishop 1973; Sioli 1975; Stout 1982; Day and Davies 1986) when compared with mid-latitude forested streams (Ward 1985). Differences in water temperatures can affect leaf processing rates (Witcamp 1966; Suberkropp 1984), especially for leaves that contain easily leached defensive compounds (such as water-soluble latex). These differences have to be considered when making latitudinal comparisons.

Rainfall in tropical wet lowland forests is less seasonal and usually higher, on an annual basis, than in mid-latitude deciduous forests (Minshall et al. 1983). Microbial activity should be less seasonal as well (Suberkropp 1984) and more constant, on an annual basis, in tropical streams, given the more constant and warmer air and water temperatures. Deterrents to microbial invasion by water-insoluble secondary compounds should be even more pronounced in those leaves.

In wet tropical forests, some mono- and dicotyledenous leaves remain on trees for several years while undergoing continual microbial, invertebrate, and vertebrate herbivory (Bentley 1979; Vandermeer et al. 1979). Plants rich in secondary compounds and/or physical barriers that are adapted to withstand continual herbivore pressure are likely to produce "expensive" (Janzen 1974), long-lived leaves. Any plant defensive compound that is not sequestered back into the plant prior to leaf drop and is not leached quickly after leaf drop could play a vital role in leaf processing in streams.

There is no leaf-fall period in tropical wet lowland forests comparable with the autumnal season of mid-latitude deciduous forests. Leaves fall throughout the year into the tropical streams and are always available to the aquatic biota. Some microorganisms, arthropods, and fish may specialize on those continual inputs in tropical areas. Leaves that lack chemical or physical deterrents and are processed rapidly are expected to be utilized by mobile consumers; slowly processed leaves are expected to be more important as physical substrata for stream biota that derive nutrition from season and/or slowly released products of decomposition.

TABLE 1. Comparisons between mid-latitude deciduous forest streams and tropical wet lowland forest streams.

| Characteristic                    | Mid-latitude        | Tropical              |
|-----------------------------------|---------------------|-----------------------|
| Temperature fluctuations          | strongly seasonal   | weakly diurnal        |
| Rainfall                          | seasonal, lower     | less seasonal, higher |
| Microbial effect                  | seasonal            | aseasonal*            |
| Leaf longevity                    | spring-fall         | up to 4 yr            |
| Leaf inputs                       | seasonal            | year-round            |
| Leaf chemistry (percent dry mass) |                     |                       |
| resins                            | lower               | higher                |
| alkaloids                         | lower               | higher                |
| condensed tannins                 | lower               | higher                |
| Array of leaf processing rates    | normal distribution | bimodal distribution* |

\*Indicates hypothesized differences.

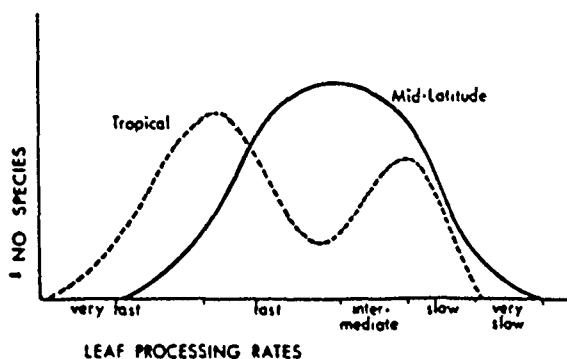


FIG. 1. Hypothesized comparisons between leaf processing rates in mid-latitude streams and in tropical streams. Solid line represents mid-latitude species. Dashed line represents tropical species.

It is in tropical environments that the highest diversity and richest concentrations of defensive plant compounds exist, and these include condensed and hydrolyzable tannins, alkaloids, resins, and gums (Janzen 1974; Gibbs 1974; Levin 1976; McKey et al. 1978; Rosenthal and Jansen 1979; Oates et al. 1980; Waterman et al. 1980; Arrhenius and Langenheim 1983; Coley 1983).

#### Condensed Tannins

Condensed tannins, a major class of defensive compounds, do not appear on most stream ecologists' "lists" of chemical compounds to be analyzed in allochthonous leaf studies except for Irons et al. (1988). Condensed tannins are suggested as protecting plant photosynthetic, seed, and root tissues by complexing themselves with plant pectins and celluloses. Those complexed products in the plants form barriers against pectinases and cellulases produced by many microorganisms as they try to penetrate plant tissue. Zucker (1983) suggests that condensed tannins have protective capabilities against microbial invasion but not against phytophagous invertebrates, but Swain (1978) believes that both microorganisms and invertebrates are deterred by condensed tannins in plants. Unlike hydrolyzable tannins, which Zucker (1983) thinks are the protective agents against invertebrates and vertebrates, condensed tannins are not sequestered back into the plant during leaf senescence. After leaf drop, intact condensed tannins would delay microbial processing. In tropical wet forests, delayed microbial decomposition could enhance recycling efficiency of leaf micro- and macronutrients by reducing their losses via leaching during heavy rains (Stark and Jordan 1978).

Condensed tannins are considered to have evolved prior to hydrolyzable tannins (Swain 1978). They are found in the horsetail (*Equisetum*), some ferns, gymnosperms, monocotyledons, and dicotyledons (Lawton 1976; Swain 1978), and they are the most widely distributed group of tannins in vascular plants (Crankshaw and Langenheim 1981). Hydrolyzable tannins are found only in dicotyledons. Concentrations of condensed tannins usually are higher in the more primitive plant families (Sporne 1973; Gibbs 1974). Primitive angiosperm families contain higher percentages of species with condensed tannins than do the more advanced families (Bate-Smith and Metcalfe 1957).

The evolution of flowering plants is thought to have occurred primarily in humid tropical areas, and it is there that the more primitive angiosperm families are found rather than in mid-

latitude regions (Coe 1949; Harborne 1977; Raven and Axelrod 1981). Angiosperm leaves that fall into tropical streams are expected to contain, on average, more condensed tannins than such leaves falling into mid-latitude deciduous forest streams. Waterman (1983) states that more than 70% of rainforest tree species contain significant quantities of condensed tannins, hydrolyzable tannins, or both. Some tropical leaves contain more than 40% dry mass condensed tannins (Janzen and Waterman 1984). Plants rich in condensed tannins (that is, more than 5% dry mass) are more resistant to both terrestrial and aquatic microbial processing than are leaves containing no or low concentrations of condensed tannins. Tannins impart strong defenses against fast microbial processing and are an important addition to the list of physicochemical factors that presently are linked with slow decomposition rates such as lignin content and leaf toughness.

A hypothetical model (see Fig. 1) predicts that leaves lacking or low in condensed tannins are processed at fast to intermediate rates in mid-latitude streams; similar leaves would be processed very fast ( $-k/d > 0.25$ ) to fast ( $0.01 < -k/d < 0.05$ ) in tropical streams. It is predicted that leaves rich in condensed tannins are processed slowly to very slowly in mid-latitude streams and slowly in tropical streams. If leaves of those tropical species were transferred to mid-latitude forested streams, the rates would be even slower, especially because most leaf processing, and studies of the phenomenon, occur in fall and winter. Most leaf processing coefficients are expressed relative to days in stream,  $-k/d$ ; whereas, leaf loss data used for latitudinal comparisons should be related to degree days to normalize water temperature differences.

#### Leaf Tannin Concentrations and Processing Rates in Mid-Latitude Streams

Mid-latitude leaves lacking or low in condensed tannins have fast ( $-k/d > 0.01$ ) processing rates (see Fig. 2A and Table 2); leaves with intermediate levels of condensed tannins are processed at an intermediate rate ( $0.005 < -k/d < 0.01$ ) with one exception, *Liquidambar styraciflua*. It is placed in the intermediate level for condensed tannins, although there is disagreement as to whether it is low (Bate-Smith 1962) or intermediate (Bate-Smith and Lerner 1954; Jay 1968). Leaves with slow processing rates ( $-k/d < 0.005$ ) are generally high in condensed tannins. Box elder (*Acer negundo*) is listed as having high levels of condensed tannins (Bate-Smith 1977), yet its leaves are processed quickly. A beech, *Nothofagus solandri* var. *cliffortioides*, has a very slow processing coefficient ( $-k/d = 0.0010$  to  $0.0025$ ) (Rounick and Winterbourn 1983), but no quantitative condensed tannin data are available for its leaves. Davis and Winterbourn (1977) worked with this species and found very few aquatic hyphomycetes on leaves. They also noted a lack of hyphal penetration even after 4 mo incubation in a New Zealand stream. Based on their findings and the fact that the genus is a member of a primitive angiosperm family, that species is predicted to have high concentrations of condensed tannins. Cambie et al. (1961) listed only presence or absence for members of this genus; the species contained condensed tannins. Upchurch et al. (1975) show that both heartwood and sapwood of this beech contained abundant amounts of condensed tannins, but they did no leaf tissue analysis.

Of the 39 mid-latitude species for which condensed tannin data are available, 19 either lack or have very low condensed tannin concentrations (Fig. 2A). As a group, they are processed

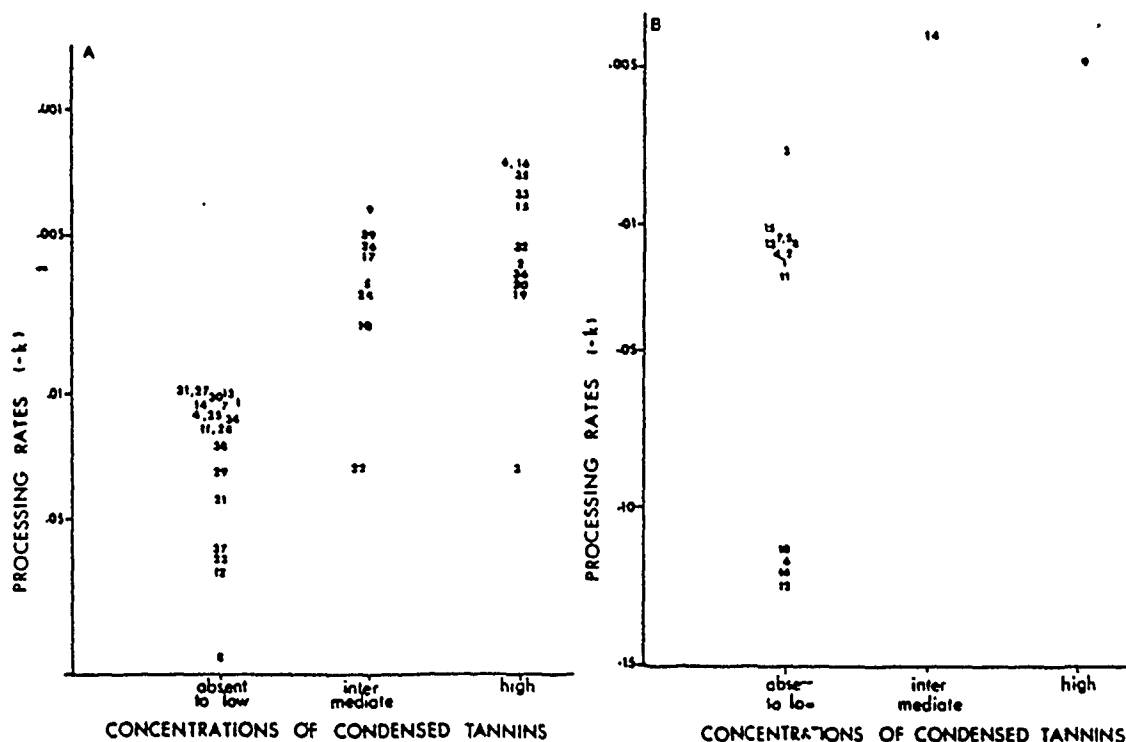


FIG. 2. (A) Mid-latitude leaf processing rates as a function of condensed tannin concentrations. (Processing rates from Webster and Benfield 1986.) (B) Tropical leaf processing rates as a function of condensed tannin concentrations.

fast (mean  $-k/d = 0.0312$ ,  $SD = 0.0245$ ). Eight species have intermediate condensed tannin levels, with an intermediate processing rate of  $0.0094$  ( $SD = 0.0096$ ). If the species for which condensed tannin concentrations are open to question are excluded, the mean  $-k/d$  rate would be  $0.0060$  ( $SD = 0.0013$ ). Twelve species have high condensed tannin levels. Without *Acer negundo*, which was included in Fig. 2A, the mean processing rate is slow (mean  $-k/d = 0.0045$ ,  $SD = 0.0017$ ).

The processing coefficient for a coniferous gymnosperm, the Douglas fir (*Pseudotsuga menziesii*), was  $0.0055$ . It has the highest condensed tannin concentration by dry leaf mass for any mid-latitude species (20% according to Stafford (1985)), although it is lower than for many tropical angiosperms (see Table 4). Anderson and Grafius (1975) have shown that needles from *P. menziesii* require a long conditioning period. Although the toughness and waxiness of the needles are probably very influential, the high condensed tannin concentrations also should extend the conditioning period.

Three plant families, Aceraceae, Betulaceae, and Salicaceae, include many species; as a group these species are highly variable with respect to condensed tannin concentrations (Bate-Smith and Lerner 1954; Binns et al. 1968; Jaggi and Haslam 1969; Bate-Smith 1975, 1977). Species in the Fagaceae are usually rich in condensed tannins, whereas those in the Oleaceae seldom contain tannins. Among species in these five families there is a gradation from no tannins to rich concentrations of condensed tannins. These families are well represented throughout the world, and many of their species have been used in leaf processing studies. All five families would be prime choices for research on the relationship between leaf processing dynamics and condensed tannin concentrations in similar sized streams at similar altitudes along latitudinal gradients.

#### Leaf Tannin Concentrations and Processing Rates in Tropical Streams

Published data for leaf processing rates in tropical streams are meager (see Fig. 2B and Table 3), although data for condensed tannin concentrations are more abundant for the tropics than for the mid-latitudes (see Table 4). There are processing coefficients for tropical leaves deposited on forest floors (for example, Ewel 1976; Tanner 1981; Proctor 1984; Spain and LeFeuvre 1987), but these coefficients cannot be confidently converted to rates in flowing waters.

Figure 2B and Table 3 include only the tropical species for which processing coefficients were determined for leaves in streams. Condensed tannin data for tropical species for which associated leaf processing data are lacking are presented in Table 4. Additional data may be found in Bate-Smith (1962), Bate-Smith and Metcalfe (1957), Bate-Smith and Lerner (1954), Gibbs (1974) and Hegner (1961–1964, 1966, 1969, 1973, and 1986). Condensed tannin concentrations for the species listed in Table 4 and in the above references were presented to identify tropical species with high concentrations, which thus are potential subjects for testing the hypothesis in this paper.

Of the 14 species low or lacking in condensed tannins, processing rates for four were very fast ( $-k/d$  mean  $= 0.1182$ ,  $SD = 0.0050$ ), for nine were fast (mean  $= 0.0178$ ,  $SD = 0.0045$ ), and for one, *Cordia alliodora*, was intermediate ( $-k/d = 0.0077$ ). The mean processing rate for these 13 "fast" species was  $0.0487$  ( $SD = 0.0484$ ). The category with intermediate levels condensed tannins contains only one tropical species for which there are leaf processing data in an aquatic environment. That taxon, *Ardisia* sp., was processed slowly in a Costa Rican

TABLE 2. Mid-latitude plant species used in Fig. 2A, with  $-k/d$  values, condensed tanning levels, and references for condensed tannins (CT).

| Species                                                  | Family           | $-k/d$            | C.T.         | References         |
|----------------------------------------------------------|------------------|-------------------|--------------|--------------------|
| 1. <i>Acer circinatum</i>                                | Aceraceae        | .013 <sup>a</sup> | Low          | <sup>a</sup>       |
| 2. <i>A. macrophyllum</i>                                |                  | .005 <sup>a</sup> | High         | <sup>a</sup>       |
| 3. <i>A. negundo</i>                                     |                  | .034 <sup>a</sup> | High         | <sup>a</sup>       |
| 4. <i>A. platanoides</i>                                 |                  | .020 <sup>a</sup> | Low          | <sup>a</sup>       |
| 5. <i>A. rubrum</i>                                      |                  | .006 <sup>a</sup> | Intermediate | <sup>a</sup>       |
| 6. <i>A. saccharum</i>                                   |                  | .002 <sup>a</sup> | High         | <sup>a</sup>       |
| 7. <i>A. saccharinum</i>                                 |                  | .015 <sup>a</sup> | Low          | <sup>a</sup>       |
| 8. <i>Oplopanax horridum</i> *                           | Araliaceae       | .096 <sup>a</sup> | Low          | <sup>a</sup>       |
| 9. <i>Alnus glutinosa</i>                                | Betulaceae       | .004 <sup>a</sup> | Intermediate | <sup>a</sup>       |
| 10. <i>Betula papyrifera</i>                             |                  | .008 <sup>a</sup> | Intermediate | <sup>a</sup>       |
| 11. <i>Baccharis glutinosa</i> *                         | Compositae       | .022 <sup>a</sup> | Low          | <sup>a</sup>       |
| 12. <i>Tussilago farfara</i> *                           |                  | .068 <sup>a</sup> | Low          | <sup>a</sup>       |
| 13. <i>Cornus amomum</i>                                 | Comaceae         | .011 <sup>a</sup> | Low          | <sup>a, c</sup>    |
| 14. <i>C. florida</i>                                    |                  | .018 <sup>a</sup> | Low          | <sup>a</sup>       |
| 15. <i>Rhododendron maximum</i> *                        | Ericaceae        | .004 <sup>a</sup> | High         | <sup>a, d, f</sup> |
| 16. <i>Quercus macrocarpa</i>                            | Fagaceae         | .002 <sup>a</sup> | High         | <sup>a, d</sup>    |
| 17. <i>Fagus sylvatica</i>                               |                  | .005 <sup>a</sup> | Intermediate | <sup>a, d</sup>    |
| 18. <i>Nothofagus solandri</i> var <i>cliffortioides</i> |                  | .001 <sup>a</sup> | High?        | <sup>a, d</sup>    |
| 19. <i>N. cunninghami</i> *                              |                  | .006 <sup>a</sup> | High?        | <sup>a</sup>       |
| 20. <i>N. fusca</i>                                      |                  | .006 <sup>a</sup> | High?        | <sup>a</sup>       |
| 21. <i>Nymphoides peltata</i> *                          | Gentianaceae     | .045 <sup>a</sup> | Low          | <sup>a</sup>       |
| 22. <i>Liquidambar styraciflua</i>                       | Hamamelidaceae   | .033 <sup>a</sup> | Intermediate | <sup>a, d, f</sup> |
| 23. <i>Elodea canadensis</i>                             | Hydrocharitaceae | .064 <sup>a</sup> | Low          | <sup>a</sup>       |
| 24. <i>Juglans nigra</i> *                               | Juglandaceae     | .007 <sup>a</sup> | Intermediate | <sup>a, d, f</sup> |
| 25. <i>Umbellularia californica</i>                      | Lauraceae        | .020 <sup>a</sup> | Low          | <sup>a, d</sup>    |
| 26. <i>Robinia pseudoacacia</i>                          | Leguminosae      | .005 <sup>a</sup> | Intermediate | <sup>a</sup>       |
| 27. <i>Decodon verticillatus</i>                         | Lythraceae       | .010 <sup>a</sup> | Low          | <sup>a</sup>       |
| 28. <i>Liriodendron tulipifera</i>                       | Magnoliaceae     | .023 <sup>a</sup> | Low          | <sup>a, f</sup>    |
| 29. <i>Potamogeton nodosus</i>                           | Najadaceae       | .036 <sup>a</sup> | Low          | <sup>a</sup>       |
| 30. <i>Fraxinus americana</i>                            | Oleaceae         | .013 <sup>a</sup> | Low          | <sup>a, d, f</sup> |
| 31. <i>F. niger</i>                                      |                  | .009 <sup>a</sup> | Low          | <sup>a</sup>       |
| 32. <i>Pseudotsuga menziesii</i>                         | Pinaceae         | .005 <sup>a</sup> | High         | <sup>a</sup>       |
| 33. <i>Platanus occidentalis</i>                         | Platanaceae      | .003 <sup>a</sup> | High         | <sup>a</sup>       |
| 34. <i>Ranunculus calcareus</i> *                        | Ranunculaceae    | .021 <sup>a</sup> | Low          | <sup>a, f</sup>    |
| 35. <i>Salix viminalis</i>                               | Salicaceae       | .003 <sup>a</sup> | High         | <sup>a, d</sup>    |
| 36. <i>S. alexensis</i>                                  |                  | .006 <sup>a</sup> | High         | <sup>a</sup>       |
| 37. <i>Ribes bracteosum</i> *                            | Saxifragaceae    | .063 <sup>a</sup> | Low          | <sup>a</sup>       |
| 38. <i>Tilia americana</i>                               | Tiliaceae        | .022 <sup>a</sup> | Low          | <sup>a, d</sup>    |
| 39. <i>Ulmus americana</i> *                             | Ulmaceae         | .005 <sup>a</sup> | Intermediate | <sup>a, f</sup>    |

\*A related species analyzed for condensed tannins. Low indicates low or nonexistent.

<sup>a</sup>Gibbs (1974).

<sup>b</sup>Bate-Smith (1977).

<sup>c</sup>Bate-Smith and Lemer (1954).

<sup>d</sup>Irons et al. (1988).

<sup>e</sup>Bate-Smith and Metcalfe (1957).

<sup>f</sup>Cambie et al. (1961).

<sup>g</sup>Martin and Martin (1982).

<sup>h</sup>Uprichard et al. (1975).

<sup>i</sup>Bate-Smith (1962).

<sup>j</sup>Jay (1968).

<sup>k</sup>McClure (1970).

<sup>l</sup>Santamour (1966).

<sup>m</sup>Berenbaum (1983).

<sup>n</sup>Stafford (1985).

<sup>o</sup>Binns et al. (1968).

<sup>p</sup>Jaggi and Haslam (1969).

stream ( $-k/d = 0.0040$ ). The paucity of data for processing coefficients for leaves with intermediate and high levels of condensed tannins once again must be stressed. The last species for which there is both  $-k$  values in streams and probably concentrations of condensed tannins is *Pithecellobium longifolium*. Other species in this genus contain very high levels of condensed tannins (Janzen and Waterman 1984). Fresh, undried

leaves of *P. longifolium* were processed slowly ( $-k/d = 0.0048$ ) (Stout 1980).

#### Cross-Latitude Leaf Transfer Experiments

In the fall of 1986, I collected autumn-abscised leaves of white oak, *Quercus alba* (Fagaceae), from Livingston County,

TABLE 3. Tropical plant species used in Fig. 2A, with -k/d values, condensed tannin levels, and references for condensed tannins (CT).

| Species                                           | Family         | -k/d  | CT           | References |
|---------------------------------------------------|----------------|-------|--------------|------------|
| 1. <i>Anaxagorea costaricensis</i>                | Annonaceae     | .0217 | Low          | a          |
| 2. <i>Araucaria cunninghamii</i>                  | Araucariaceae  | .0198 | Low          | b          |
| 3. <i>Cordia borinquensis</i> <sup>a</sup>        | Boraginaceae   | .0077 | Low          | c          |
| 4. <i>Casuarina cunninghamiana</i>                | Casurinaceae   | .0198 | Low          | d, e       |
| 5. <i>Buchenavia capitata</i>                     | Combretaceae   | .0136 | Low          | f          |
| 6. <i>Nasturtium officinale</i> <sup>a</sup>      | Cruciferae     | .1150 | Low          | g          |
| 7. <i>Sloanea berteriana</i> <sup>a</sup>         | Elacocarpaceae | .0139 | Low          | h          |
| 8. <i>Aleurites montana</i> <sup>a</sup>          | Euphorbiaceae  | .0173 | Low          | i, j       |
| 9. <i>Pithecellobium longifolium</i> <sup>a</sup> | Fabaceae       | .0048 | High         | k          |
| 10. <i>Myriophyllum propinquum</i>                | Haloragaceae   | .1133 | Low          | l          |
| 11. <i>Liquidambar formosana</i>                  | Hamamelidaceae | .0258 | Low          | d, b       |
| 12. <i>Ficus glabrata</i> <sup>a</sup>            | Moraceae       | .1244 | Low          | d, f       |
| 13. <i>Eucalyptus blakelyi</i>                    | Myrtaceae      | .0172 | Low          | l, i       |
| 14. <i>Ardisia</i> sp. <sup>a</sup>               | Myrsinaceae    | .0040 | Intermediate | j          |
| 15. <i>Manilkara bidentata</i>                    | Sapotaceae     | .0111 | Low          | k          |
| 16. <i>Trema micrantha</i>                        | Ulmaceae       | .1200 | Low          | c          |

<sup>a</sup>Related species analyzed for condensed tannins.

<sup>a</sup>Janzen and Waterman (1984).

<sup>a</sup>Bate-Smith (1954).

<sup>a</sup>Coley (1983).

<sup>a</sup>Bate-Smith and Metcalfe (1957).

<sup>a</sup>Salch and El-Lakany (1979).

<sup>a</sup>Bate-Smith (1962).

<sup>a</sup>Cambie et al. (1961).

<sup>a</sup>Matano et al. (1986).

<sup>a</sup>Macaulay and Fox (1980).

<sup>a</sup>Hergert (1962).

TABLE 4. Tropical species rich in condensed tannins (CT).

| Species                            | Family          | CT (dry wt.) | Place      | References |
|------------------------------------|-----------------|--------------|------------|------------|
| <i>Cassia grandis</i>              | Caesalpiniaceae | 43.82        | Costa Rica | a          |
| <i>Hymenaea courbaril</i>          |                 | 23.11        |            | b          |
| <i>Bursera simaruba</i>            | Burseraceae     | 13.63        |            | c          |
| <i>B. tomentosa</i>                |                 | 19.63        |            | d          |
| <i>Curatella americana</i>         | Dilleniaceae    | 13.94        |            | e          |
| <i>Zuelania guidonia</i>           | Flacourtiaceae  | 16.07        |            | f          |
| <i>Byrsonima crassifolia</i>       | Malpighiaceae   | 13.58        |            | g          |
| <i>Pithecellobium oblongum</i>     | Mimosaceae      | 10.28        |            | h          |
| <i>P. saman</i>                    |                 | 16.05        |            | i          |
| <i>Calycophyllum candidissimum</i> | Rubiaceae       | 13.96        |            | j          |
| <i>Luehea speciosa</i>             | Tiliaceae       | 17.06        |            | k          |
| <i>Anthonotha macrophylla</i>      | Caesalpiniaceae | 16.19        | Cameroon   | l          |
| <i>Berlinia bracteosa</i>          |                 | 11.40        |            | m          |
| <i>Protomegabaria stapfiana</i>    | Euphorbiaceae   | 25.88        |            | n          |
| <i>Garcinia ovalifolia</i>         | Guttiferaceae   | 14.44        |            | o          |
| <i>Mammea africana</i>             |                 | 26.40        |            | p          |
| <i>Hippocratea</i> sp.             | Hippocrateaceae | 33.14        |            | q          |
| <i>Barteria fistulosa</i>          | Passifloraceae  | 10.28        |            | r          |
| <i>Cassipouira rewezensiensis</i>  | Rhizophoraceae  | 16.24        | Uganda     | s          |
| <i>Mimusops bagshawei</i>          | Sapotaceae      | 16.15        |            | t          |

<sup>a</sup>Janzen and Waterman (1984).

<sup>a</sup>Garlan et al. (1980).

Michigan, and tag alder, *Alnus rugosa* (Betulaceae) from Dickinson County, Michigan; leaves of oak are rated high in tannins and of alders as intermediate (see Table 2). Chamier and Dixon (1982) found that colonization rates of aquatic hyphomycetes and pectolytic bacteria were lower on oak (*Quercus robur*) and on alder (*Alnus glutinosa*), which is compatible with research showing that condensed tannins inhibit fungal colonization (Harrison 1971). In January 1987, the weighed leaf packs were

taken from Michigan & Costa Rica, placed in mesh bags with 2-cm openings, and tied onto submerged wood snags in a wet tropical forest stream, the El Sura (site description in Stout 1980). At the same time, two tropical species were placed in that stream. Leaves from *Pithecellobium longifolium* (rich in condensed tannins) and *Trema micrantha* (low in condensed tannins) were oven-dried at 40°C for 48 h before weighing to approximate the physiological state of the autumn-abscised

TABLE 5. Processing rates for leaves in native and exotic streams, leaf transfer experiment.

| Species,<br>Processing coefficient | Costa Rica | Michigan       | References<br>for Michigan |
|------------------------------------|------------|----------------|----------------------------|
| <i>Quercus alba</i>                |            |                |                            |
| — $k/d$                            | .0539      | .0036          | *                          |
| — $k/\text{degree day}$            | .0039      | .0014          | *                          |
| <i>Alnus rugosa</i>                |            |                |                            |
| — $k/d$                            | .1239      | .0053          | *                          |
| — $k/\text{degree day}$            | .0053      | .00048 — .0086 | *                          |
| <i>Pithecellobium longifolium</i>  |            |                |                            |
| — $k/d$                            | .0085      | .0002          |                            |
| — $k/\text{degree day}$            | .00036     | .000038        |                            |
| <i>Trema micrantha</i>             |            |                |                            |
| — $k/d$                            | .1352      | .0306          |                            |
| — $k/\text{degree day}$            | .0057      | .0036          |                            |

\*Daily maximum—minimum temperatures from Dan Lawson, Michigan State University, East Lansing, USA.

\*Suberkropp et al. (1976).

\*Peterson and Cummins (1974).

\*Stout et al. (1985).

mid-latitude leaves. Five replicates for each species were collected after 7, 16, 21, and 54 d; dry mass values and the percentage mass loss were determined. On August 26, 1987, oven-dried leaves of the tropical species were placed in the Ford River, Dickinson County, Michigan, along with autumn-abscised leaves of the native *Alnus rugosa*. All leaves were tied onto bricks and five replicates for each species were collected after 7, 14, 21, 28, 52, 78, and 107 d. (Leaf processing data for the second mid-latitude species, *Quercus alba*, in its native habitat come from Augusta Creek, Michigan (after Suberkropp et al. 1976 and Petersen and Cummins 1974)).

Leaves of all except one species (*Alnus rugosa*) were processed faster in the Costa Rican stream than in the Michigan streams as determined by either  $-k/D$  or  $-k/\text{degree day}$  values (see Table 5). Based on  $-k/d$  values, three findings were made. First, leaves of *Quercus alba* were processed one hundred times faster in the Costa Rican stream than in Augusta Creek, Michigan. In fact, the processing rate in Costa Rica approached the leaching rate of this species. (This rate equals dry mass loss during the first 24 to 48 h, usually a 20 to 40% loss of original mass (Cummins et al. 1989)). Second, leaves of the mid-latitude species lower in tannins, *Alnus rugosa*, were processed in the El Sura at one of the fastest rates recorded for deciduous leaves (see Webster and Benfield 1986). Third, dried leaves of both tropical species were processed much more slowly in the Ford River than in the Sura. *Trema micrantha* (tropical) and *Alnus rugosa* (mid-latitude), which have the highest processing coefficients, are low and intermediate, respectively, in tannin concentrations (see Table 3).

As mean stream temperatures of the Sura differ widely from the Ford River and Augusta Creek,  $-k/\text{degree day}$  values were computed to normalize temperature differences (see Table 5). Rate categories defined by Petersen and Cummins (1974) are for  $-k/d$  and not for  $-k/\text{degree day}$  values. For heuristic purposes, those categories are used below for replacement of processing rates determined by  $-k/\text{degree day}$ .

According to degree days, *Quercus alba* was processed "slowly" in Costa Rica and Michigan. *Pithecellobium longifolium* was processed "very slowly" at both sites. Both species

are high in tannins. *Alnus rugosa* was processed at "intermediate" rates in Michigan and Costa Rica. *Trema micrantha* was processed "slowly" in Michigan and at an "intermediate" rate in Costa Rica.

After differences in water temperature were normalized by using degree days, only leaves of *P. longifolium* were processed substantially slower in Michigan than in Costa Rica. Although only two species of the genus have been analyzed for condensed tannins, they range from containing more than 10% to more than 16% by dry mass of condensed tannins. It appears probable that *P. longifolium* also is very rich in condensed tannins. The second species used in the present study that is tannin-rich is *Q. alba*. Its reported tannin content is relative to other species in the genus; even so, its tannin content is much lower than 10% (Martin and Martin 1982). Its degree day processing rates, although slower in Michigan than in Costa Rica, were not an order of magnitude different between the two sites.

It is intriguing to speculate that the defensive compound accounts for the slower processing rates in Michigan. Very high concentrations in leaves of some tropical species may significantly slow processing rates, especially in exotic areas such as Michigan where the biota have not experienced the quantity or array of tropical defensive compounds. In future studies, described below, the exchange among tropical, mid-latitude and boreal regions of leaves rich and poor in condensed tannins may address these speculative statements.

At a workshop entitled Factors Controlling Community Structure and Function in Tropical versus Temperate Streams (Flathead Lake, Montana, April 1987), six scientists decided to exchange leaves of two plant species from each of their research sites; one species theorized as being high and the other known to be low in condensed tannins. The experimental design is specifically intended to compare processing rates of these leaves in native and "exotic" streams. Six sites located in Costa Rica, Puerto Rico, North Carolina, New York, Michigan, and Alaska, will be used. Data from these experiments will be the first direct tests of the hypothesis.

Terrestrial decomposition studies show that, overall, mid-latitude leaf processing rates are slower than tropical rates, although there is "considerable" overlap between litter decomposition rates for the slowest tropical species and the fastest temperate species" (Anderson and Swift 1983). Would the results be the same if variances in soil temperature were normalized? Variances not attributable to temperature may include the effects of phytochemical and physical protective mechanisms in terms of herbivory and microbial decay. Calculation of processing rates using  $-k/\text{degree days}$  may reveal those effects. Such investigations will require collection of maximum—minimum daily (or possibly weekly) temperatures.

## Conclusions

Studies showing that condensed tannins affect decomposition and microbial activity (Benoit et al. 1968; Harrison 1971; Grant 1976) are sufficiently compelling to promote stream ecologists to look at these concentrations in plant tissues. Understanding action of condensed tannins in aquatic ecosystems, especially at the microorganismic level, could provide a fresh perspective on plant-animal interactions in aquatic food chains. If cross-latitudinal comparisons are done, daily monitoring, if possible, of maximum—minimum water temperature will be necessary in order to normalize latitudinal differences. Weekly monitoring would provide useful but less precise information.

The underlying functional effect of condensed tannins on aquatic fungal and bacterial populations probably will not be understood without condensed tannin bioassays different from those being developed to study the effects of tannins on vertebrates and insects (Martin and Martin 1982, 1983; Mole and Waterman 1987a, 1987b).

Methods for determining condensed tannin concentrations are varied; for example, Binns et al. (1968); Bate-Smith (1977); and Stafford (1985). Laboratories using the same methods of analysis may differ in technique, making utilization of data from various sources difficult. Until methods are standardized, the best approach would be to have analyses done in a single laboratory.

Studies on the dynamics of leaf inputs in mid-latitude streams lack specific data on secondary compounds. Although tropical ecologists working on terrestrial sites have such data for many plant species, little information on processing rates of leaves in tropical streams is available. Baseline data on the phytochemistry of riparian vegetation and on leaf processing in tropical streams should be obtained before tropical watersheds are severely disturbed by herding, timbering, and agricultural practices (Lugo and Brown 1982; Myers 1980; Buschbacher 1986; Janzen 1986; Tangle 1986a, 1986b). Accumulation of these sorts of data may add robustness and precision to the River Continuum Theory (Vannote et al. 1980), as the chemistry of allochthonous inputs may control or influence aquatic communities dependent on them more than does stream order designation. This could be especially relevant for the biomes of watersheds where soils are low in available nutrients. Research on plant-animal interactions in rheophilic systems also could be enhanced by studying phytochemical ecology in streams.

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## Element 7 - Fish Community Composition and Abundance

### Objectives

The overall goal of this element is to determine the effects of the Navy's ELF project on the fish community structure and movement characteristics in the Ford River. Our specific objectives are to determine: 1) The fish community species composition and relative abundance at FEX and FCD; 2) The age, length/weight characteristics, growth, and condition of the species most represented in the gear (burbot, common shiners, creek chubs and white suckers) excluding brook trout (see Element 8); 3) The relative mobility of the fish community excluding brook trout (see Element 8) in the Ford River.

### Materials and Methods

#### A. Community Composition and Abundance

Fish were caught using fyke nets fished in tandem, one facing upstream and one facing downstream, at FEX and FCD. In addition, two 1/2 inch wire mesh weir sites (FCU and TM), in a configuration similar to Hall's (1972), were fished in an effort to determine the movement patterns and rates of fish marked at FEX and FCD. In 1989, nets were fished continuously from May 23 to August 1 with the exception of 12 days in late May and early June when discharge levels were above gear and personnel capabilities to fish. When catch rates were low (< 1 fish/day) from August 1 through October 31, the gear was fished 4 days/week (deployed on Monday and removed on Friday). All gear was checked every 24 hours. The number of sampling days for each year is reported in Figure 7.1.

All fish were enumerated, measured for total length, weighed and marked by a fin clip distinctive for each study site. The fish were then returned to the water upstream or downstream from the station in their original direction of travel.

#### B. Age, Growth and Condition

Age and growth was calculated in the laboratory using scales and the body-scale backcalculation technique outlined by Smale and Taylor (1987). Backcalculation of length was done using the linear technique in Bagenal and Tesch (1978). Scales were projected onto a Summagraphics digitizing pad using a Ken-A-Vision Microprojector scope. The focus, subsequent annuli and outside edge of each scale were digitized and recorded on a linked Tandy 102 portable and then downloaded to an IBM pc for determination of

SITE

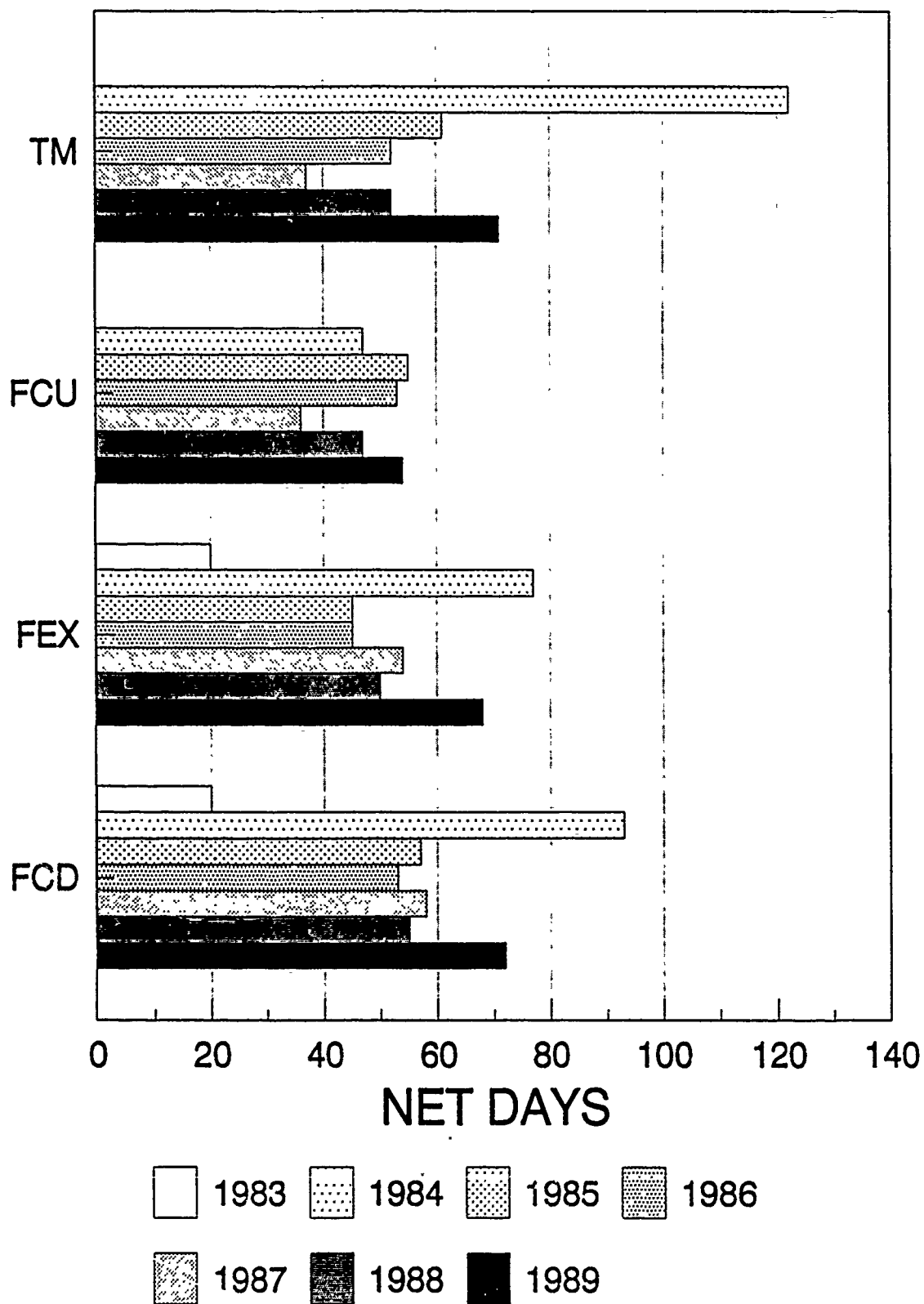


Figure 7.1. Net days at all ELF sites from 1983 - 1989.

backcalculated length at age.

### C. Fish Community Mobility

Movement patterns for the dominant species in the Ford River were monitored by observing the frequency of recapture of fin clipped fish in our gear. Fish recaptured at a site other than the original marking site were measured for total length and given an additional fin clip specific to the recapture site.

## Results and Discussion

### A. Species composition

Fourteen species from five orders and ten families were collected at FEX in 1989 (Table 7.1). No new species were observed in 1989 at FEX. Differences in the overall FEX species composition between years can be attributed to changes in the catch of rare species.

The catch at FCD in 1989 consisted of nineteen species from eleven families and six orders (Table 7.2). One new species, horneyhead chub (Nocomis biguttatus), was added to the species list at FCD in 1989. Again, as in the FEX samples, the only changes in the species composition occurred in the rare species which occur infrequently.

As in the past, the species composition was slightly higher at FCD than at FEX which is a result of species infrequently captured. Overall the two sites continued to be similar in species composition and consistent within a site over the duration of the study.

### B. Species abundance

The percent catch by number at FEX was dominated by five species with the majority of the individuals caught from the cyprinid family (Figure 7.2). Common shiner percent catch by number (62.4 %) dominated the catch at FEX in 1989 and was above their mean for all years combined (14.5 %). Creek chubs made up 20.4 % of the catch which is slightly lower than the mean over all years combined (25.8 %). Brook trout percent catch by number (4.1 %) in 1989 was below the mean for all years combined (10.4 %). Burbot percent catch by number also declined to 2.4 % in 1989 which is well below 13.6 %, the mean for all years combined. White sucker percent catch by number (7.5 %) fluctuated slightly below the mean for all years combined (11.8 %) in 1989 at FEX.

The relative numeric abundance of the catch at FCD was dominated by the same species (common shiners) as at FEX (Figure 7.2). Common shiners made up 65.6 % of the total

Table 7.1. Fish species collected at FEX from May 1983 through October 1989 using 1/2" mesh fyke nets. Scientific names are from Robins et al. 1980.

| Scientific Name                                   | Common Name            | FEX  |      |      |      |      |      |
|---------------------------------------------------|------------------------|------|------|------|------|------|------|
|                                                   |                        | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 |
| <b>Cypriniformes</b>                              |                        |      |      |      |      |      |      |
| <b>Catastomidae</b>                               |                        |      |      |      |      |      |      |
| <i>Catastomus commersoni</i> (Lacepede)           | White sucker           | x    | x    | x    | x    | x    | x    |
| <i>Hypentellum nigricans</i> (Lesueur)            | Northern hog sucker    |      |      | x    |      |      |      |
| <b>Cyprinidae</b>                                 |                        |      |      |      |      |      |      |
| <i>Notropis cornutus</i> (Mitchill)               | Common shiner          | x    | x    | x    | x    | x    | x    |
| <i>Rhinichthys atratulus</i> (Hermann)            | Blacknose dace         | x    | x    | x    | x    | x    | x    |
| <i>Rhinichthys cataractae</i> (Valenciennes)      | Longnose dace          | x    | x    | x    | x    | x    | x    |
| <i>Semotilus atromaculatus</i> (Mitchill)         | Creek chub             | x    | x    | x    | x    | x    | x    |
| <i>Semotilus margarita</i> (Cope)                 | Pearl dace             | x    | x    |      | x    | x    | x    |
| <b>Gadiformes</b>                                 |                        |      |      |      |      |      |      |
| <b>Gadidae</b>                                    |                        |      |      |      |      |      |      |
| <i>Lota lota</i> (Linnaeus)                       | Burbot                 | x    | x    | x    | x    | x    | x    |
| <b>Perciformes</b>                                |                        |      |      |      |      |      |      |
| <b>Centrarchidae</b>                              |                        |      |      |      |      |      |      |
| <i>Ambloplites rupestris</i> (Rafinesque)         | Rock bass              |      | x    | x    | x    | x    | x    |
| <i>Micropterus dolomieu</i> (Lacepede)            | Smallmouth bass        |      | x    |      |      | x    | x    |
| <i>Micropterus salmoides</i> (Lacepede)           | Largemouth bass        |      | x    |      | x    | x    | x    |
| <i>Lepomis gibbosus</i> (Linnaeus)                | Pumpkinseed            |      |      |      |      | x    |      |
| <b>Cottidae</b>                                   |                        |      |      |      |      |      |      |
| <i>Cottus bairdi</i> (Girard)                     | Mottled sculpin        | x    | x    | x    | x    | x    | x    |
| <b>Percidae</b>                                   |                        |      |      |      |      |      |      |
| <i>Percina maculata</i> (Girard)                  | Blackside darter       | x    | x    | x    | x    |      | x    |
| <b>Petromyzontiformes</b>                         |                        |      |      |      |      |      |      |
| <b>Petromyzontidae</b>                            |                        |      |      |      |      |      |      |
| <i>Ichthyomyzon fossor</i> (Reighard and Cummins) | Northern brook lamprey |      |      | x    |      |      |      |
| <i>Petromyzon marinus</i> (Linnaeus)              | Sea Lamprey            |      | x    | x    | x    |      | x    |

Table 7.1 continued

| Scientific Name                         | Common Name       | FEX  |      |      |      |      |      |
|-----------------------------------------|-------------------|------|------|------|------|------|------|
|                                         |                   | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 |
| Salmoniformes                           |                   |      |      |      |      |      |      |
| Esocidae                                |                   |      |      |      |      |      |      |
| <i>Esox lucius</i> (Linnaeus)           | Northern pike     | x    | x    | x    | x    | x    | x    |
| Salmonidae                              |                   |      |      |      |      |      |      |
| <i>Oncorhynchus kisutch</i> (Walbaum)   | Coho salmon       |      |      |      |      | x    | x    |
| <i>Oncorhynchus mykiss</i>              | Rainbow trout     |      | x    | x    | x    | x    | x    |
| <i>Salvelinus fontinalis</i> (Mitchill) | Brook trout       | x    | x    | x    | x    | x    | x    |
| Umbridae                                |                   |      |      |      |      |      |      |
| <i>Umbra limi</i> (Kirtland)            | Central mudminnow | x    | x    | x    | x    | x    | x    |
| Siluriformes                            |                   |      |      |      |      |      |      |
| Ictaluridae                             |                   |      |      |      |      |      |      |
| <i>Ictalurus nebulosus</i> (Lesueur)    | Brown bullhead    |      |      |      |      |      | x    |

Table 7.2. Fish species collected at FCD from May 1983 through October 1989 using 1/2" mesh fyke nets. Scientific names are from Robins et al. 1980.

| Scientific Name                              | FCD  |      |      |      |      |      |      |
|----------------------------------------------|------|------|------|------|------|------|------|
| Common Name                                  | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 |
| <b>Clupeiformes</b>                          |      |      |      |      |      |      |      |
| Clupeidae                                    |      |      |      |      |      |      |      |
| <u>Alosa pseudoharengus</u> (Wilson)         | x    |      |      |      |      |      |      |
| <b>Cypriniformes</b>                         |      |      |      |      |      |      |      |
| Catostomidae                                 |      |      |      |      |      |      |      |
| <u>Catostomus commersoni</u> (Lacepede)      | x    | x    | x    | x    | x    | x    | x    |
| <u>Hypentellum nigricans</u> (Lesueur)       |      |      | x    |      |      |      | x    |
| <b>Cyprinidae</b>                            |      |      |      |      |      |      |      |
| <u>Nocomis biguttatus</u> (Kirtland)         |      |      |      |      |      |      | x    |
| <u>Notemigonus crysoleucas</u> (Mitchill)    |      |      |      |      |      | x    |      |
| <u>Notropis cornutus</u> (Mitchill)          | x    | x    | x    | x    | x    | x    | x    |
| <u>Pimephales promelas</u> (Rafinesque)      |      |      |      | x    |      |      |      |
| <u>Phoxinus eos</u> (Cope)                   |      |      |      |      |      |      |      |
| <u>Rhinichthys atratulus</u> (Hermann)       | x    |      |      |      |      |      |      |
| <u>Rhinichthys cataractae</u> (Valenciennes) |      | x    | x    | x    | x    | x    | x    |
| <u>Semotilus atromaculatus</u> (Mitchill)    | x    | x    | x    | x    | x    | x    | x    |
| <u>Semotilus margarita</u> (Cope)            | x    | x    | x    | x    | x    | x    | x    |
| <b>Gadiformes</b>                            |      |      |      |      |      |      |      |
| Gadidae                                      |      |      |      |      |      |      |      |
| <u>Loa loa</u> (Linnaeus)                    | x    | x    | x    | x    | x    | x    | x    |
| <b>Perciformes</b>                           |      |      |      |      |      |      |      |
| Centrarchidae                                |      |      |      |      |      |      |      |
| <u>Ambloplites rupestris</u> (Rafinesque)    | x    | x    | x    | x    | x    | x    | x    |
| <u>Lepomis gibbosus</u> (Linnaeus)           |      | x    | x    |      |      | x    | x    |
| <u>Lepomis macrochirus</u> (Rafinesque)      |      |      |      |      | x    | x    |      |
| <u>Micropterus dolomieu</u> (Lacepede)       |      | x    |      |      |      |      |      |
| <u>Micropterus salmoides</u> (Lacepede)      |      | x    |      | x    | x    | x    | x    |
| Cottidae                                     |      |      |      |      |      |      |      |
| <u>Cottus bairdi</u> (Girard)                | x    | x    | x    | x    | x    | x    | x    |
| Percidae                                     |      |      |      |      |      |      |      |
| <u>Percina maculata</u> (Girard)             | x    | x    | x    | x    |      | x    |      |



Table 7.2 continued.

| Scientific Name                         | Common Name       | FCD  |      |      |      |      |      |
|-----------------------------------------|-------------------|------|------|------|------|------|------|
|                                         |                   | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 |
| Petromyzontiformes                      |                   |      |      |      |      |      |      |
| Petromyzontidae                         |                   |      |      |      |      |      |      |
| <u>Petromyzon marinus</u> (Linnaeus)    | Sea lamprey       | x    | x    | x    | x    | x    | x    |
| Salmoniformes                           |                   |      |      |      |      |      |      |
| Esocidae                                |                   |      |      |      |      |      |      |
| <u>Esox lucius</u> (Linnaeus)           | Northern pike     | x    | x    | x    | x    | x    | x    |
| Salmonidae                              |                   |      |      |      |      |      |      |
| <u>Oncorhynchus kisutch</u> (Walbaum)   | Coho salmon       |      |      |      |      | x    | x    |
| <u>Oncorhynchus mykiss</u>              | Rainbow trout     |      |      |      |      | x    | x    |
| <u>Salvelinus fontinalis</u> (Mitchill) | Brook trout       | x    | x    | x    | x    | x    | x    |
| Umbridae                                |                   |      |      |      |      |      |      |
| <u>Umbra limi</u> (Kirtland)            | Central mudminnow |      | x    | x    | x    | x    | x    |
| Siluriformes                            |                   |      |      |      |      |      |      |
| Ictaluridae                             |                   |      |      |      |      |      |      |
| <u>Ictalurus punctatus</u> (Lesueur)    | Brown bullhead    |      |      | x    |      |      | x    |

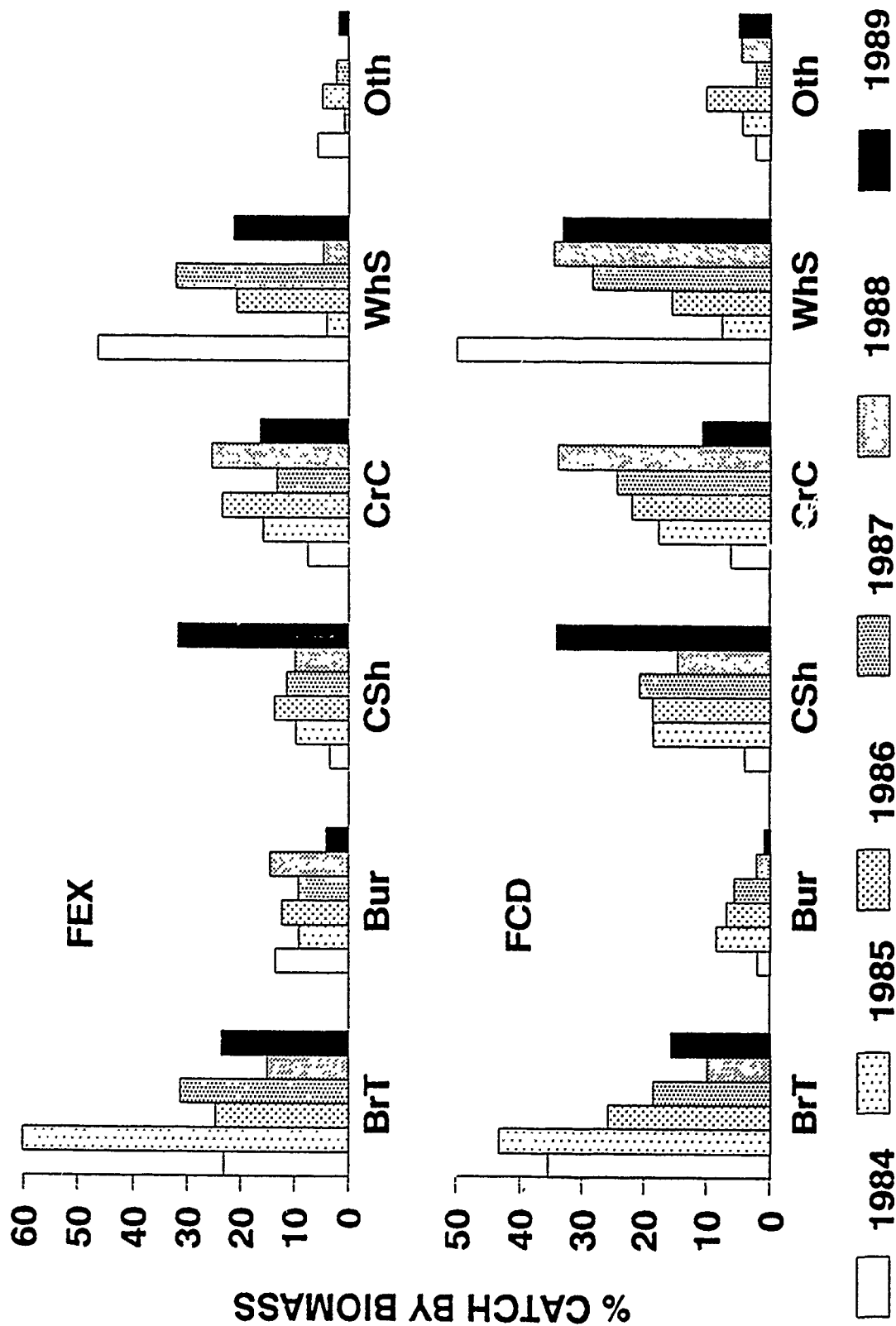


Figure 7.2. Percent catch by number at FEX and FCD from 1984 through 1989.

catch at FCD which was well above 34.4 %, the average for all years combined. The percent of creek chubs in the catch was 14.9 % which was down from the mean for all years combined (29.9 %). The white sucker component in 1989 consisted of 11.7 % of the total number of fish and was very near the mean for all years combined (12.1 %). Brook trout (2.9 %) and burbot (0.6 %) catch in 1989 decreased when compared to their combined means over all years (8.3 % and 7.8 % respectively).

Overall, there were no significant between site differences at FEX and FCD in percent catch by number (Spearman's Rank Correlation,  $p < 0.05$ ) over all years of the study despite species showing variable abundance from year to year (Table 7.3). Thus, effects from ELF should be detectible through changes in percent catch by number between the two sites.

Percent catch by biomass showed different trends in community structure than percent catch by number at both sites (Figure 7.3). Common shiners displayed the highest percent catch by biomass at FEX encompassing 31.9 % of the catch. This was well above 12.9 % which was the mean for all years combined at this site. Brook trout percent catch by biomass was second highest at FEX in 1989 at 23.7 % which was below the mean for all years combined (30.2 %). Percent catch by biomass for white suckers was about average for all years (21.4 %, mean = 21.1 %) as was creek chub biomass (16.6 %, mean = 17.0 %). Burbot percent catch by biomass (4.3 %) at FEX in 1989 was well below the mean for all years combined (11.4 %).

The catch biomass at FCD showed similar trends as FEX with the same five species dominating the catch (Figure 7.3). Common shiners and white suckers were the dominant species making up 34.2 % and 33.2 % of the biomass respectively, and were above the means over all years combined (18.3 % and 25.3 %). Brook trout percent catch by biomass (15.7 %) was below the mean for all years combined (25.4 %). Burbot made up only 1 % of the catch biomass in 1989 at FCD and is below the mean of 5.6 %.

The cyprinid biomass at FCD continued to be higher than at FEX. Overall, there were no significant differences in the relative abundances by biomass between years at FEX and FCD (Spearman's Rank Correlation,  $p < 0.05$ ) (Table 7.4) and there was little in species dominance over all years (Freidman's Test With Multiple Comparisons,  $p > 0.05$ ).

Shannon-Weiner diversity values showed a decrease at both sites in 1989 (Table 7.5). This trend was significant at both FEX and FCD (Kruskal-Wallis Test,  $p > 0.05$ ). No significant differences were found between sites in index values in any year (Kruskal-Wallis Test,  $p > 0.05$ ). In addition, the pattern of change in diversity in different years was similar (Spearman's Rank Correlation  $p = 0.05$ ).

Table 7.3 Spearman Rank Correlation Coefficients for percent catch by number over all years between FEX and FCD.

| YEAR | CORRELATION<br>COEFFICIENT | SIGNIFICANCE |
|------|----------------------------|--------------|
| 1983 | 0.943                      | $p < 0.05$ * |
| 1984 | 0.200                      | $p > 0.05$   |
| 1985 | 0.886                      | $p < 0.05$ * |
| 1986 | 0.829                      | $P < 0.05$ * |
| 1987 | 0.900                      | $p < 0.05$ * |
| 1988 | 0.829                      | $p < 0.05$ * |
| 1989 | 0.943                      | $p < 0.05$ * |

\* INDICATES SIGNIFICANT CORRELATION EXISTS

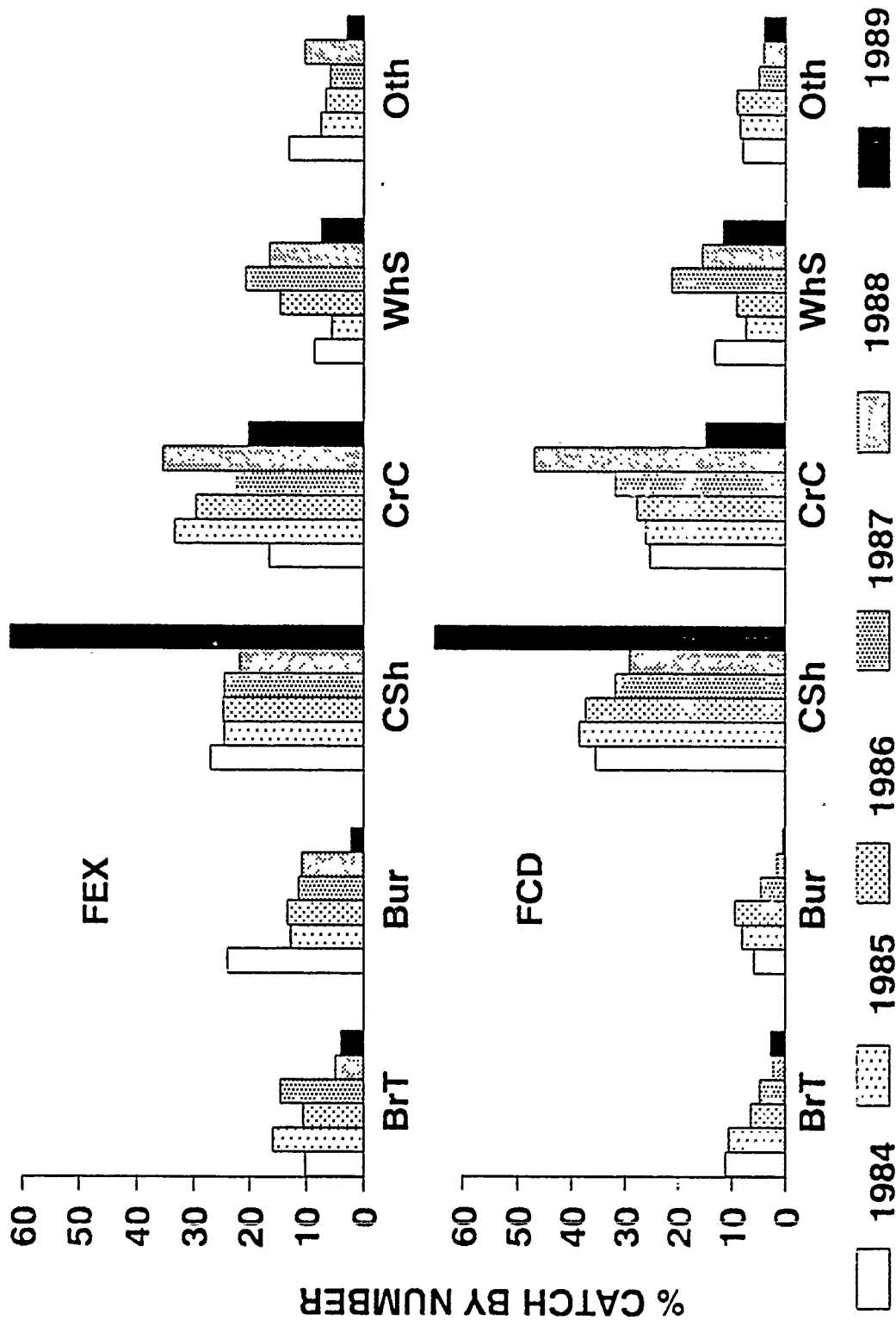


Figure 7.3. Percent catch by biomass at FEX and FCD from 1984 through 1989.

Table 7.4 Spearman Rank Correlation Coefficients for percent catch by biomass over all years between FEX and FCD.

| YEAR | CORRELATION<br>COEFFICIENT | SIGNIFICANCE |
|------|----------------------------|--------------|
| 1983 | 0.371                      | $p > 0.05$   |
| 1984 | 0.600                      | $p < 0.10$ * |
| 1985 | 0.943                      | $p < 0.05$ * |
| 1986 | 0.886                      | $P < 0.05$ * |
| 1987 | 0.829                      | $p < 0.05$ * |
| 1988 | 0.086                      | $p > 0.05$   |
| 1989 | 0.886                      | $p < 0.05$ * |

\* INDICATES SIGNIFICANT CORRELATION EXISTS

Table 7.5. Mean daily Shannon-Wiener diversity index values for FEX and FCD from 1983-1988.

| Year | FEX             | FCD             |
|------|-----------------|-----------------|
| 1983 | 2.16 $\pm$ 0.26 | 1.94 $\pm$ 0.36 |
| 1984 | 2.20 $\pm$ 0.56 | 2.03 $\pm$ 0.33 |
| 1985 | 1.97 $\pm$ 0.39 | 2.15 $\pm$ 0.33 |
| 1986 | 1.62 $\pm$ 0.48 | 1.87 $\pm$ 0.31 |
| 1987 | 2.13 $\pm$ 0.18 | 2.11 $\pm$ 0.45 |
| 1988 | 1.62 $\pm$ 0.34 | 1.54 $\pm$ 0.27 |
| 1989 | 1.41 $\pm$ 0.36 | 1.47 $\pm$ 0.43 |

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 a large amount of variance for all species as one would expect from catches having a negative binomial distribution (Figure 7.4). White suckers, common shiners and creek chubs all have high spring-early summer catch rates because of spawning movements. Brook trout catch rates are also high in the late spring - early summer but this is attributed to water temperatures increasing above optimal (see Element 8, Brook Trout Movement Characteristics).

Mean daily catch data exhibit a high amount of variability between years at FEX and FCD (Freidman's Test with Multiple Comparisons,  $p < 0.05$ ). However, mean daily catch patterns between sites showed no significance over all years except 1984 (Spearman's Rank Correlation,  $p < 0.05$ ) (Table 7.6). In general, changes in catch rates of species in different years are expressed mutually at FEX and FCD and this should be a powerful test for pre- and post-operational differences.

Mean lengths of the dominant species at FEX have remained fairly constant through all years (Figure 7.5). Brook trout showed a slight decrease in mean length from 1984-1988 (mean = 190.6 mm), but mean length in 1989 increased to the highest (231.5 mm) ever. Burbot mean length in 1989 was 212.4 mm which was larger than the mean for all years combined (172 mm). Common shiner (109.7 mm), creek chub (131.4 mm), and white sucker (173.7 mm) mean length was about average for all years combined (111.5 mm, 130.5 mm, and 170.8 mm respectively). Overall changes in mean length have been slight which indicates that the size structure is consistent from year to year within the mobile fish community at FEX.

FCD showed a pattern similar to FEX in that brook trout (243 mm) and burbot (211 mm) mean lengths were well above the means for all years combined (214.7 mm and 174 mm respectively) (Figure 7.5). Common shiners (114 mm), creek chubs (126 mm), and white suckers (175 mm) had mean lengths similar to the means for all years combined (116.3 mm, 135.8 mm and 179.7 mm respectively).

Brook trout and common shiners were generally significantly larger in mean length at FCD than FEX while burbot, creek chubs and white suckers showed no significant difference in mean length between sites (T-Test  $P < 0.05$ ). Overall, the two sites continued to be similar in mean length and in trends in mean length. Therefore, ELF effects



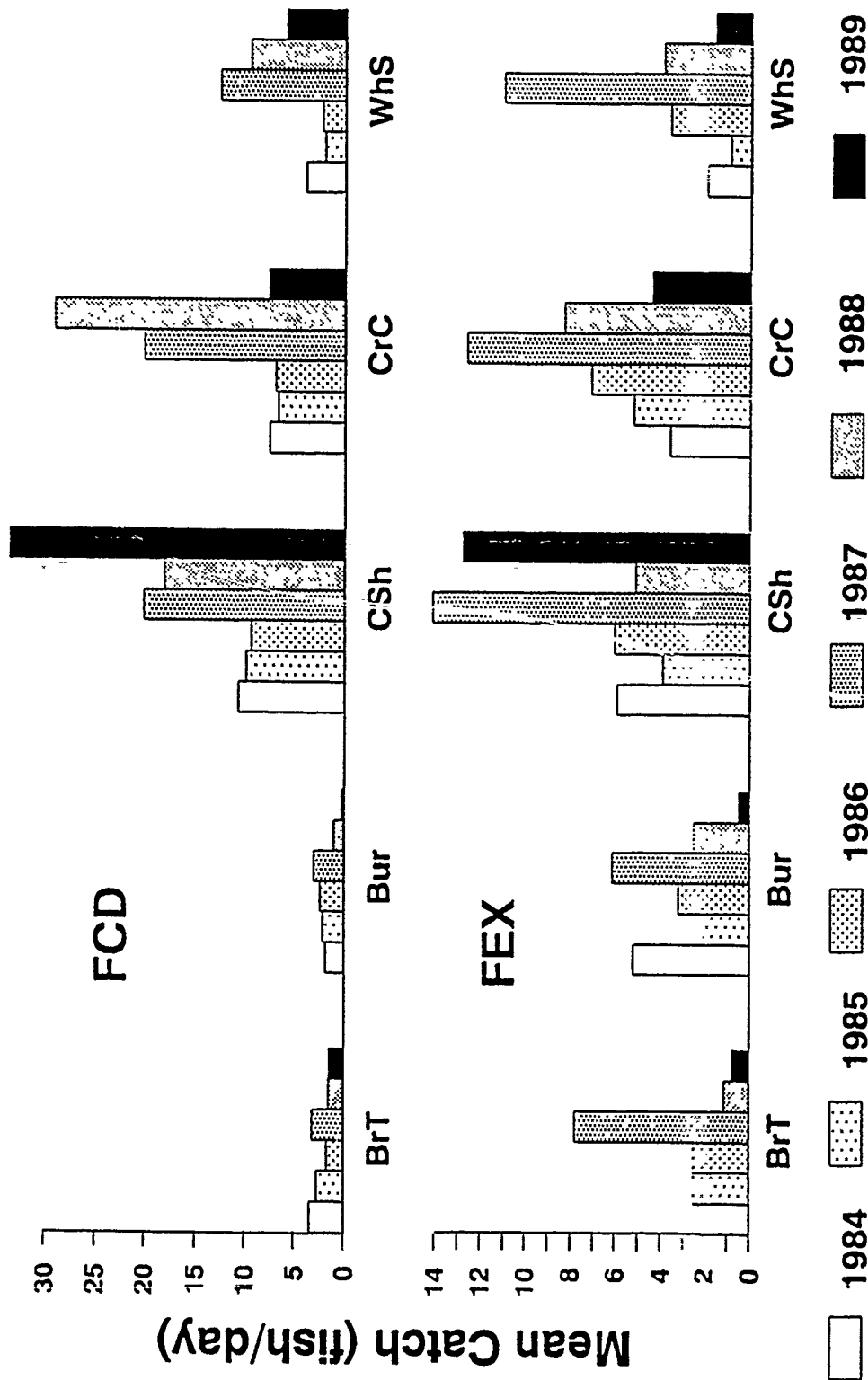


Figure 7.4. Mean daily catch for the fish species dominating the fyke net catch at FEX and FCD for 1984 through 1989.

Table 7.6 Spearman Rank Correlation Coefficients for mean daily catch over all years between FEX and FCD.

| YEAR | CORRELATION<br>COEFFICIENT | SIGNIFICANCE |
|------|----------------------------|--------------|
| 1983 | 1.00                       | p < 0.05 *   |
| 1984 | 0.60                       | p < 0.10 *   |
| 1985 | 0.94                       | p < 0.05 *   |
| 1986 | 0.89                       | P < 0.05 *   |
| 1987 | 0.98                       | p < 0.05 *   |
| 1988 | 0.94                       | p < 0.05 *   |
| 1989 | 1.00                       | p < 0.05 *   |

\* INDICATES SIGNIFICANCE

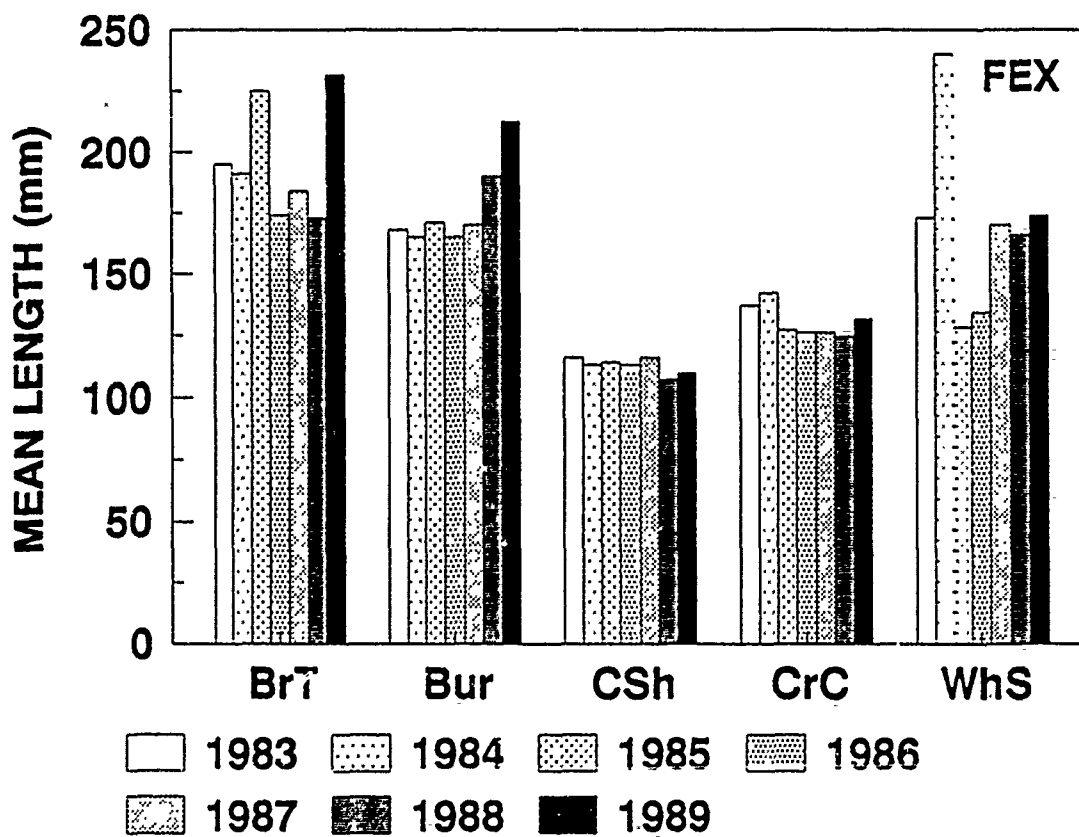
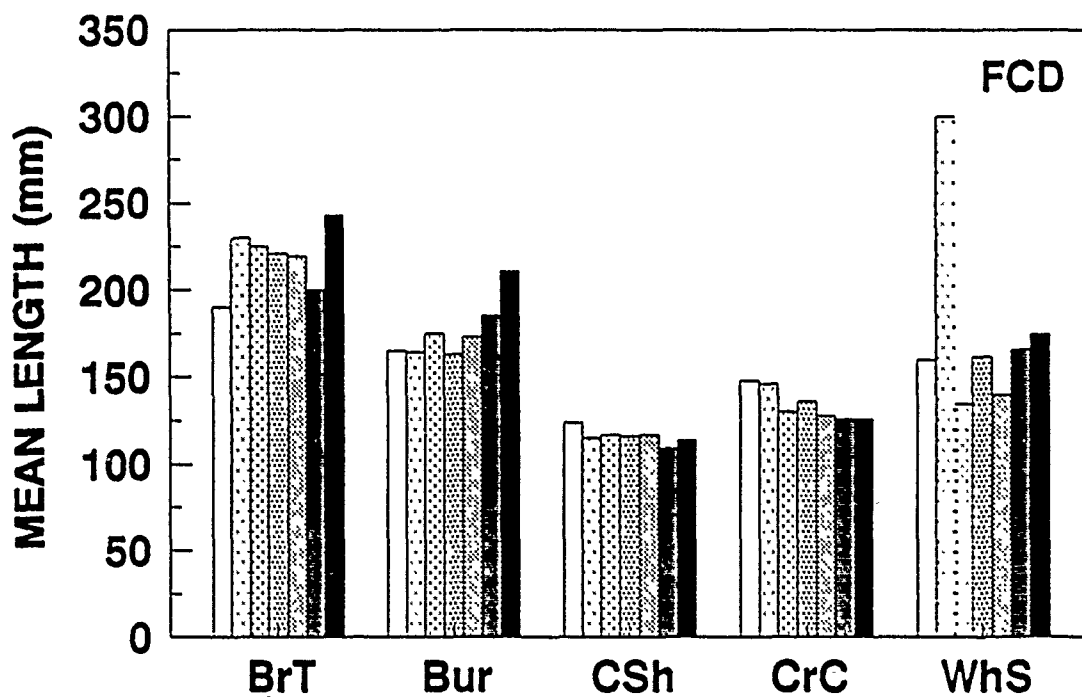


Figure 7.5. Mean length of fish dominating the fyke net catch at FCD and FEX for all years.

should be detectible through changes in species size structure.

#### D. Fish Community Mobility

Common shiners, creek chubs, longnose dace and white suckers demonstrated site to site movement as shown by the approximately 20.2 % recapture rate at sites other than the marking site (Table 7.7a and b). The total number of nonsalmonids marked at FEX and FCD in 1989 were: burbot 57, common shiners 3348, creek chubs 856, longnose dace 31 and white suckers 542. Overall recapture percentages were similar in 1989 to previous years (Table 7.7a and b). Site to site movement was not observed in 1989 for burbot, however, 20.2 % of common shiners marked moved from one site to another while 7.1 % of marked creek chubs displayed site to site movement. White suckers also exhibited site to site movement with 19 % of those marked at one site in 1989 being recaptured at another site. Recapture rates were higher in 1989 than in past years.

#### 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 is reported on in element 8.

Age and growth analyses on common shiners, creek chubs, northern pike and white suckers are reported in Table 7.8 (a-c). Common shiners exhibited better than average growth in the Ford River when compared to literature data in their third and fourth year (Carlander 1969) but similar growth during their first and second year. Lee's phenomenon (Ricker 1975) is seen in all years which may reflect the selectivity of our sampling gear or differential mortality of different sizes of common shiners.

Creek chub growth in the Ford River was above the average growth rate in the literature for all ages (Carlander 1969). No Lee's phenomenon was observed in any year class.

White suckers showed below average growth rates in the Ford River through all age classes reported when compared to literature values (Carlander 1969). Reverse Lee's phenomenon was seen with the age 4 fish having the best growth rates of the four years examined.

Age and growth analysis is complete on the 1984-1986 fish, and statistical comparisons to literature data and between years will be completed and reported in a future

Table 7.7a. Recapture data summary for all dominant species except brook trout from FEX and FCD for 1984 - 1986.

| % Recapture by Location |              |                   |              |              |          |        |         |
|-------------------------|--------------|-------------------|--------------|--------------|----------|--------|---------|
| Species                 | Total Marked | Number Recaptured | % Recaptured | Marking Site | Upstream |        | Up      |
|                         |              |                   |              |              | 1 Site   | 1 Site | 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    |         |
| Longnose dace           | 110          | 22                | 20.0         | 72.8         | 13.6     | 13.6   |         |
| Northern pike           | 13           | 5                 | 38.5         | 20.0         | 40.0     | 40.0   |         |
| 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    |         |
| Creek chub              | 520          | 28                | 5.4          | 82.1         | 14.3     |        | 3.2     |
| Longnose dace           | 20           | 1                 | 5.0          | 100.0        |          |        |         |
| Northern pike           | 5            | 0                 | 0.0          |              |          |        |         |
| 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      |        |         |
| Longnose dace           | 44           | 2                 | 4.5          | 50.0         | 50.0     |        |         |
| Northern pike           | 11           | 1                 | 9.1          | 100.0        |          |        |         |
| Rock bass               | 56           | 7                 | 12.5         | 71.4         | 14.3     | 14.3   |         |
| White sucker            | 259          | 12                | 4.6          | 75.0         | 16.7     | 8.3    |         |

Table 7.7b. Recapture data summary for all dominant species except brook trout from FEX and FCD for 1987 and 1989.

| Species         | % Recapture by Location |                   |              |              |                 |                        |
|-----------------|-------------------------|-------------------|--------------|--------------|-----------------|------------------------|
|                 | Total Marked            | Number Recaptured | % Recaptured | Marking Site | Upstream 1 site | Down 1 site 2 sites Up |
| 1987            |                         |                   |              |              |                 |                        |
| Burbot          | 540                     | 45                | 8.3          | 95.6         | 2.2             | 2.2                    |
| Common shiner   | 1693                    | 172               | 10.2         | 88.4         | 10.5            | 1.2                    |
| Creek chub      | 1816                    | 87                | 4.8          | 93.1         | 3.4             | 3.4                    |
| Longnose dace   | 192                     | 3                 | 1.6          | 100.0        |                 |                        |
| Rock bass       | 43                      | 2                 | 4.7          | 100.0        |                 |                        |
| Smallmouth bass | 51                      | 4                 | 7.8          | 100.0        |                 |                        |
| White sucker    | 1530                    | 42                | 2.7          | 78.6         | 9.5             | 9.5                    |
| 1988            |                         |                   |              |              |                 |                        |
| Burbot          | 340                     | 11                | 3.2          | 81.8         | 18.2            |                        |
| Common shiner   | 1402                    | 75                | 5.3          | 88.0         | 6.7             | 5.3                    |
| Creek chub      | 2649                    | 96                | 3.6          | 90.6         | 4.2             | 5.2                    |
| Longnose dace   | 164                     | 3                 | 1.8          | 66.7         | 33.3            |                        |
| Rock bass       | 30                      | 2                 | 6.7          | 100.0        |                 |                        |
| Smallmouth bass | 19                      | 1                 | 5.3          | 100.0        |                 |                        |
| 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                   |
| Creek chub      | 856                     | 28                | 3.2          | 92.9         | 7.1             | 1.6                    |
| Longnose dace   | 31                      | 2                 | 6.5          | 50.0         |                 |                        |
| White sucker    | 542                     | 21                | 3.9          | 81.0         | 50.0            | 19.0                   |

Table 7.8a. Mean backcalculated lengths for common shiners at all sites from 1983 through 1986.

| Age Class    | N  | Backcalculated Length at Annulus |                         |                         |                         |
|--------------|----|----------------------------------|-------------------------|-------------------------|-------------------------|
|              |    | 1                                | 2                       | 3                       | 4                       |
|              |    | $\bar{x} \pm \text{sd}$          | $\bar{x} \pm \text{sd}$ | $\bar{x} \pm \text{sd}$ | $\bar{x} \pm \text{sd}$ |
| 1            | 7  | 42 $\pm$ 17.9                    |                         |                         |                         |
| 2            | 41 | 39 $\pm$ 16.5                    | 81 $\pm$ 14.4           |                         |                         |
| 3            | 34 | 32 $\pm$ 11.6                    | 73 $\pm$ 17.2           | 116 $\pm$ 21.8          |                         |
| 4            | 5  | 31 $\pm$ 8.9                     | 71 $\pm$ 9.5            | 112 $\pm$ 14.8          | 160 $\pm$ 13.0          |
| Overall Mean |    | 36 $\pm$ 14.8<br>N=87            | 77 $\pm$ 15.9<br>N=80   | 115 $\pm$ 20.9<br>N=39  | 160 $\pm$ 13.0<br>N=5   |

Table 7.8b. Mean backcalculated lengths for Creek chubs at all sites from 1983 through 1986.

|              |     | Backcalculated Length at Annulus |            |            |            |
|--------------|-----|----------------------------------|------------|------------|------------|
|              |     | 1                                | 2          | 3          | 4          |
| Age Class    | N   | x ± sd                           | x ± sd     | x ± sd     | x ± sd     |
| 1            | 42  | 66 ± 15.8                        |            |            |            |
| 2            | 179 | 63 ± 15.7                        | 105 ± 24.0 |            |            |
| 3            | 91  | 63 ± 15.0                        | 105 ± 23.0 | 148 ± 29.9 |            |
| 4            | 12  | 69 ± 22.8                        | 113 ± 24.6 | 158 ± 27.5 | 199 ± 30.7 |
| Overall Mean |     | 64 ± 15.8                        | 106 ± 23.7 | 150 ± 29.7 | 199 ± 30.7 |
|              |     | N=324                            | N=282      | N=103      | N=12       |



Table 7.8c. Mean backcalculated lengths for white suckers at all sites from 1983 through 1986.

| Age Class | N  | Backcalculated Length at Annulus |                     |                    |                    |                    |                    |
|-----------|----|----------------------------------|---------------------|--------------------|--------------------|--------------------|--------------------|
|           |    | 1                                | 2                   | 3                  | 4                  | 5                  | 6                  |
|           |    | x ± sd                           | x ± sd              | x ± sd             | x ± sd             | x ± sd             | x ± sd             |
| 1         | 33 | 73 ± 6.0                         |                     |                    |                    |                    |                    |
| 2         | 35 | 73 ± 7.0                         | 112 ± 13.6          |                    |                    |                    |                    |
| 3         | 30 | 73 ± 6.4                         | 114 ± 17.4          | 175 ± 29.9         |                    |                    |                    |
| 4         | 30 | 76 ± 10.3                        | 126 ± 26.1          | 206 ± 54.0         | 285 ± 66.4         |                    |                    |
| 5         | 22 | 77 ± 7.6                         | 124 ± 24.4          | 202 ± 43.5         | 296 ± 53.1         | 369 ± 56.0         |                    |
| 6         | 13 | 75 ± 7.9                         | 113 ± 14.3          | 191 ± 34.7         | 283 ± 45.6         | 360 ± 53.8         | 416 ± 55.5         |
| Overall   |    |                                  |                     |                    |                    |                    |                    |
| Mean      |    | 74 ± 7.6<br>N=164                | 118 ± 20.6<br>N=131 | 193 ± 43.8<br>N=96 | 287 ± 58.1<br>N=66 | 363 ± 55.6<br>N=36 | 411 ± 56.5<br>N=14 |

report. Additional investigations will include analysis of yearly growth increments for the above species. These analyses will allow us to separate the environmental and density-dependent factors from the ELF effects in the examination of growth.

Fish condition factors for common shiners, creek chubs and white suckers were performed using relative weight (Wr) condition factors as described in Wege and Anderson (1978). Standard weight formulas were calculated from 3 literature populations for common shiners, 5 literature populations for creek chubs and 13 literature populations for white suckers using the 50% percentile method outlined in Wege and Anderson (1978). Individual weights were then compared to the standard weights and given a Wr value based on the formula:  $Wr = \text{Fish weight} / W_s * 100$ . 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  $W_s$  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 for creek chubs and white suckers were below the species means from populations reported in the literature possibly reflecting the highly variable abiotic conditions in the Ford River (Figure 7.6). Common shiner Wr values were above the species mean from populations reported in the literature in all years. Creek chubs declined in condition from above the species mean in 1984 and 1985 to approximately 10 % below the species mean in 1987 through 1989. White sucker condition was 10% below the species mean in 1989. Common shiner condition increased in 1989 to 11.4 % above the species mean. Additional analysis examining the effect of population size using CPUE and abiotic factors on Wr are in progress along with a statistical analysis of year to year variation and will be detailed in the next annual report.

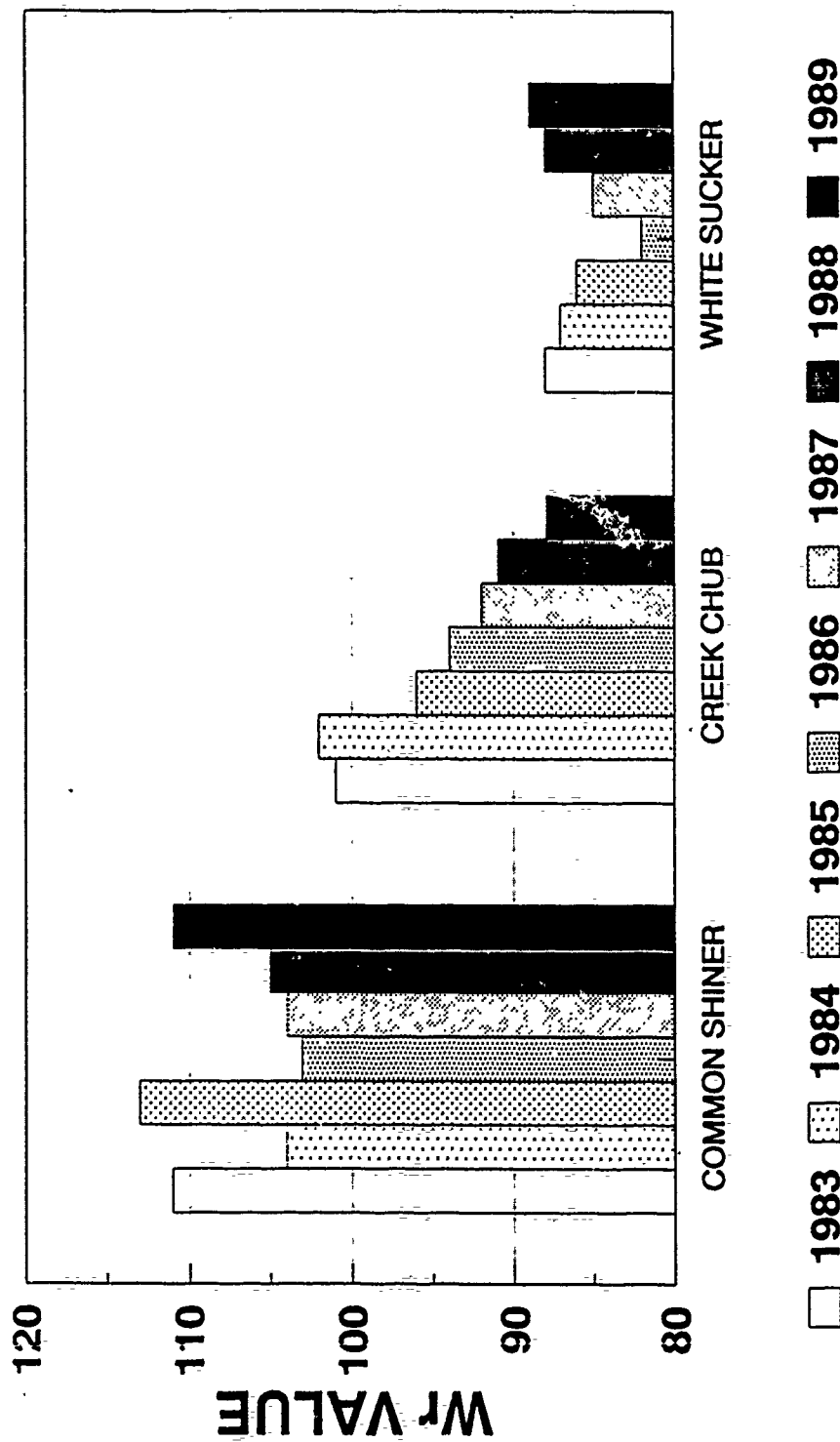


Figure 7.6. Yearly unweighted relative weight values for common shiners, creek chubs and white suckers in the Ford River. Dotted line at 100 indicates a condition equal to the average calculated from several populations in the literature.

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## Element 8 - Brook Trout Population Characteristics and Movement

### Objectives

The overall goal of this element is to examine the effects of the Navy's ELF project on brook trout (Salvelinus fontinalis) populations; an important sportfish to local residents. Earlier we showed that brook trout in the Ford River were highly mobile and are excluded from portions of the mainstream when water temperatures exceed 16 C. Any impediments to this migration pattern could affect growth and survival as trout are less efficient bioenergetically in water above 16 C (Graham, 1949). The specific objectives of this element are to determine: 1) The seasonal pattern and magnitude of brook trout movement through the ELF corridor; 2) The proximate cause(s) for these movements; 3) The rate of brook trout movement through the ELF corridor; 4) the relationship between length frequency distributions from fyke net catches and DeLury and Peterson population estimates; and 5) Population characteristics (age, growth and condition) of Ford River brook trout. By accomplishing these objectives, we will be able to evaluate if the ELF system has an impact on the population characteristics and movement of Ford River brook trout.

### Materials and Methods

The sites and gear used in this element were previously described in Element 7. All brook trout were removed on a daily basis from the fyke nets or weir traps and anesthetized with MS-222 at a 500 mg/l dosage as recommended by Meister and Ritzi (1958), and Schoettger and Julin (1967) to reduce handling stress. All brook trout were then enumerated, measured for total length and weighed. Scale samples were taken from each fish for age and backcalculated growth determination in the laboratory. All fish were given a site specific fin clip. In 1983-1985, fish longer than 135 mm were tagged using streamer or disk tags applied posterior to the dorsal fin. Due to a high incidence of infection in these years, strap tags were applied to the adipose fin and the operculum in 1986 and 1987 respectively. Tagged fish recaptured at the site of initial tagging and angler reports during these two years suggested poor tag retention. In 1988 brook trout were fin clipped with a site specific mark only. In 1989, 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 Elements 1). Physical data (discharge and temperature) at FCU and TM were collected by the fisheries staff from 1984-89. Discharge was calculated from a calibrated staff gauge at both FCU and TM on a daily basis. Temperature data was collected continuously using a calibrated max-min thermometer at TM and FCU. In addition, Ryan thermographs were deployed in 1988 and 1989 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.

Brook trout age and growth determination was done using the body-scale relationship technique described in Smale and Taylor (1987). Backcalculations were made using the linear technique described in Bagnenal and Tesch (1978). Techniques used for this analysis is the same as that used for scales from common shiners, creek chubs and white suckers in Element 7.

## Results and Discussion

### A. Marking Statistics

Numbers of fish tagged at FEX and FCD declined from a high of 314 in 1984 to 126 in 1985 and 82 in 1986 reflecting a decline in the brook trout population. Numbers of fish tagged increased to 170 fish in 1987 and dropped slightly to 142 fish in 1988. Brook trout tagged in 1989 totalled 134 fish at FEX and FCD which was about average (mean = 132) for all years combined. The between site recapture rate was 18.2% and 12.7% in 1984 and 1985 respectively, 0% in 1986 and less than 1% in 1987 and 1988. The recapture percentage for 1989 increased to 6.7% at FEX and FCD (Table 8.1). Observed handling and tagging mortality averaged 6.2% from 1984 to 1987. No tagging mortality was observed in 1988 and only 2.2% was seen in 1989 (Table 8.1). The percentage of angler returns declined throughout the study from 12.1% in 1984 to 3% in 1985 and 0% in 1986-1989 (Table 8.1). This may reflect a decrease in the total number of fish harvested in the Ford during this time period, however, we have no quantitative data on angling pressure.

### B. Brook Trout Catch Patterns

Brook trout catches peak in late May to early July depending on weather patterns during the year. Summer catches then drop to < 1 fish/day and this condition persists through late August to early September. At this time, daily catch again increases due to spawning activity. Since movement patterns were similar at all sites, data will be presented from FCD to depict between year differences (Figures 8.1 a-c). 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

Table 8.1. Brook trout marking and recapture summary for FEX and FCD for 1984 - 1989.

| Year  | Tag Summary                  | Site  |     |
|-------|------------------------------|-------|-----|
|       |                              | FEX   | FCD |
| 1984  | Number Tagged                | 71    | 243 |
|       | Number Fin Clipped           | 48    | 37  |
|       | Percent Tag Recapture        | 18.2% |     |
|       | Estimated Tagging Mortality  | 5.7%  |     |
|       | Percent Angler Recapture     | 12.1% |     |
| 1985  | Number Tagged                | 45    | 81  |
|       | Number Fin Clipped           | 38    | 53  |
|       | Percent Tag Recapture        | 12.7% |     |
|       | Estimated Tagging Mortality  | 8.7%  |     |
|       | Percent Angler Recapture     | 3.0%  |     |
| 1986  | Number Tagged                | 15    | 40  |
|       | Number Branded               | 19    | 8   |
|       | Number Clipped               | 58    | 32  |
|       | Percent Tag Recapture        | 0.0%  |     |
|       | Estimated Tagging Mortality  | 3.4%  |     |
| 1987  | Number Tagged                | 97    | 73  |
|       | Number Clipped               | 127   | 41  |
|       | Percent Tag Recapture        | 0.1%  |     |
|       | Estimated Handling Mortality | 7.1%  |     |
|       | Percent Angler Recapture     | 0.6%  |     |
| 1988* | Number Clipped               | 57    | 85  |
|       | Estimated Handling Mortality | 0.0%  |     |
| 1989  | Number Tagged                | 49    | 86  |
|       | Number Clipped               | 12    | 11  |
|       | Percent Tag Recapture        | 6.7%  |     |
|       | Estimated Handling Mortality | 2.2%  |     |
|       | Percent Angler Recapture     | 0.0%  |     |

\* No tagging done in 1988.



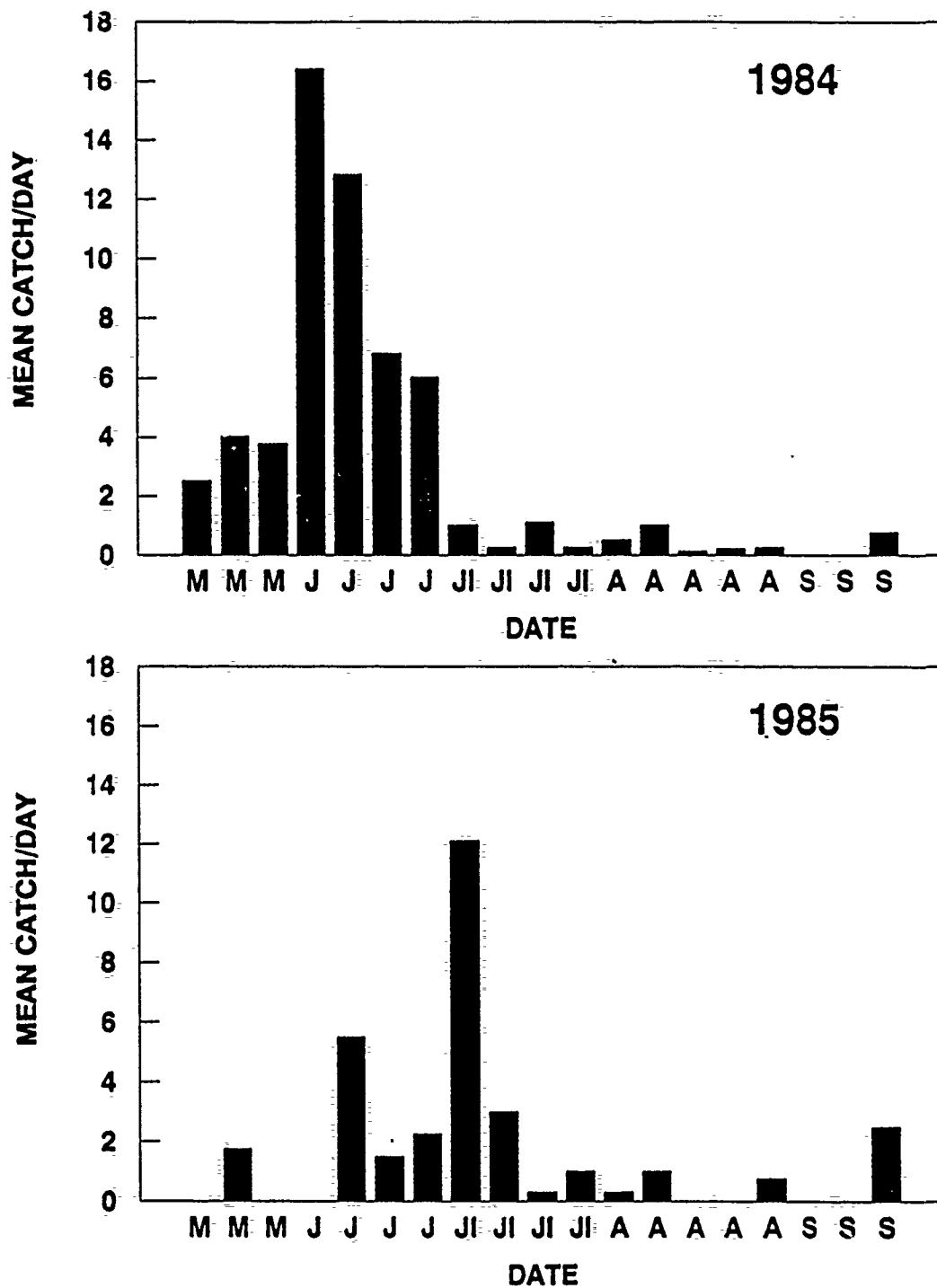


Figure 8.1a. Mean daily catch of brook trout plotted on a weekly basis at FCD from 1984 and 1985.

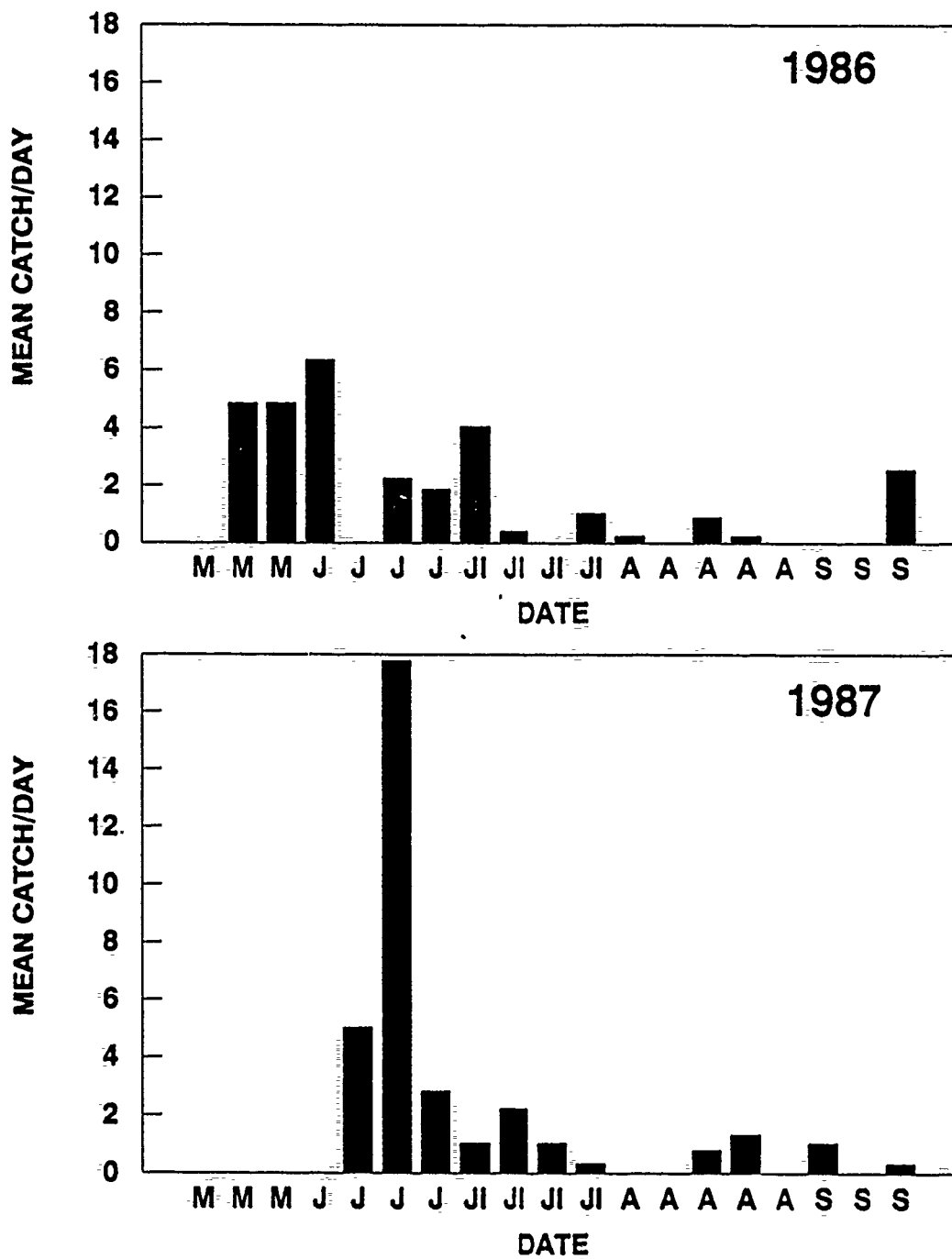


Figure 8.1b. Mean daily catch of brook trout plotted on a weekly basis at FCD from 1986 and 1987.

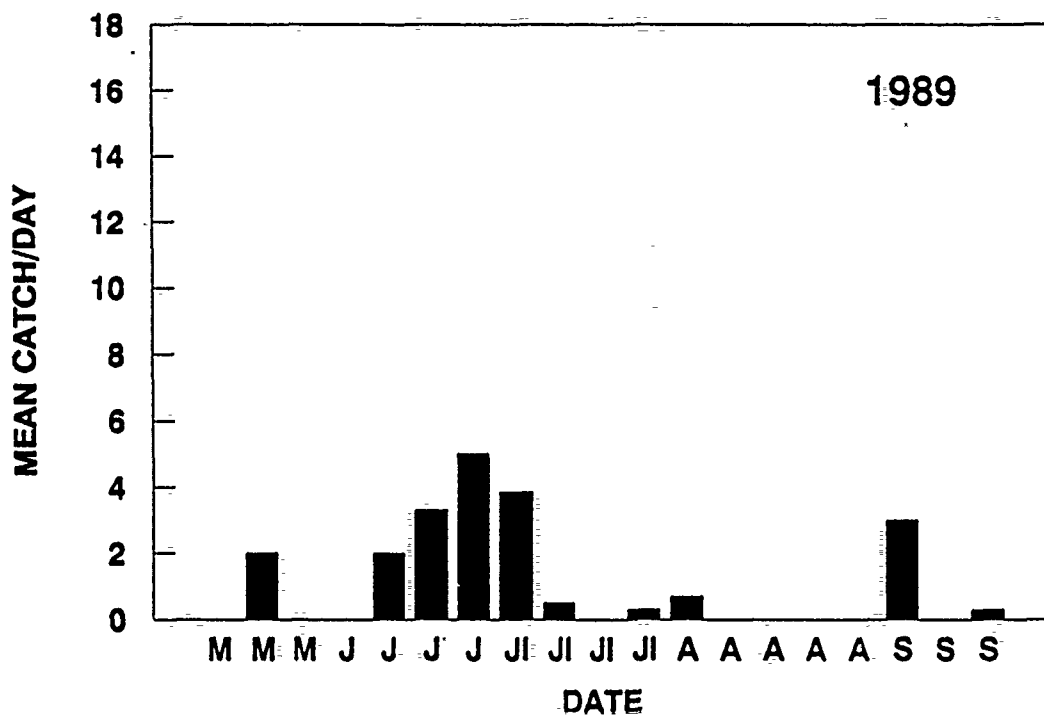
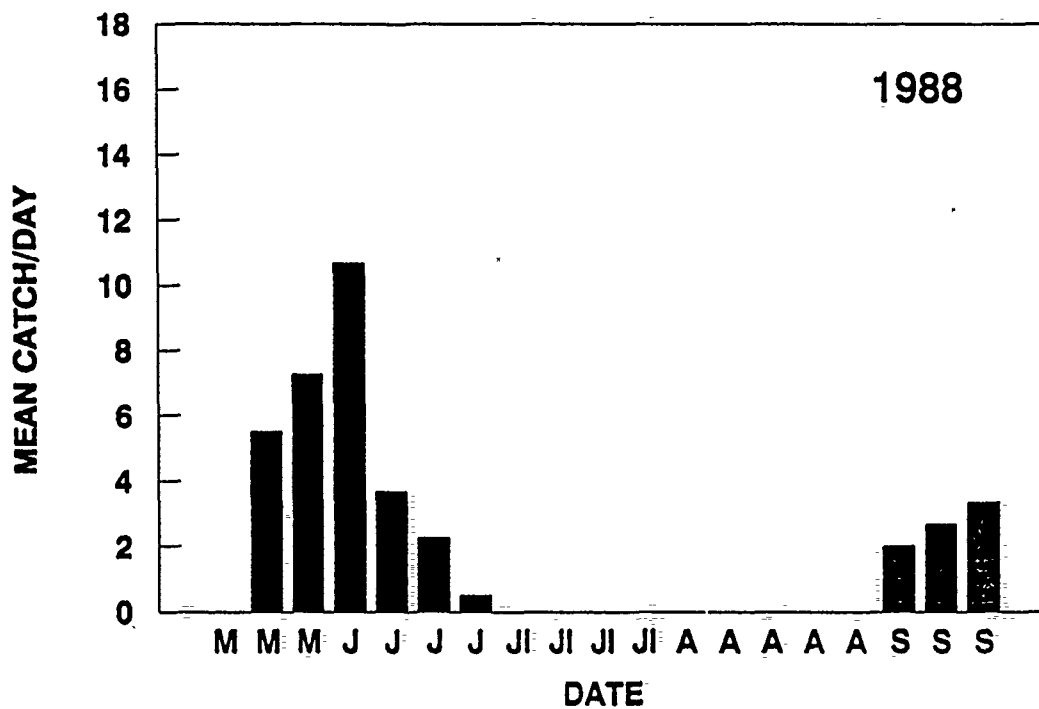


Figure 8.1c. Mean daily catch of brook trout plotted on a weekly basis at FCD from 1988 and 1989.

period.

Movement in the upstream direction was significantly higher than downstream movement in all years at all sites (Mann-Whitney U Test,  $p < 0.05$ ) although the intensity and timing varied from year to year. If the ELF operation interferes with the migratory pattern of brook trout, we should be able to observe disoriented behavior through decreased upstream movement or random movement patterns at the FEX site.

Brook trout movements were directed from FEX and FCD upstream to a coldwater tributary, Two Mile Creek. nineteen brook trout marked at FEX were recaptured at TM during the pre-operational period from 1984-1988 (Table 8.2). In 1989 (operational period) two trout were observed to have made this movement. Pre-operational movement from FCD to FEX was observed for twelve brook trout. One fish made this movement in 1989. Movement from FCD to TM was observed for forty-five brook trout from 1984-1988. One fish moved this distance in 1989. Post-operational data are not sufficient at this time to do a log rank test. As more data are collected, further analysis will be done. Movement from site to site was observed to be significantly greater for fish above 190 mm than those below 190 mm (Chi-Square Test,  $p < 0.05$ ). Only six clipped fish under 190 mm were captured at TM in 1984 and no clipped fish under 190 mm were collected from 1985 through 1989. In addition, only one fish was observed moving from Two Mile Creek to FCD or FEX from 1984 through 1989 during the summer sampling period. Three fish marked at the TM site in 1984 were collected in 1985 at FCD indicating that some downstream movement occurred between late fall and early spring.

Further analysis of movement emphasizing the number of days it took individual fish to move from the point of marking to another site was set up for future analysis as more post-operational movement data are obtained. A range of individual movement times for pre-operational years was set up in Figure 8.2. In addition, a cumulative frequency distribution of days it took individual fish to move was set up for future analysis using the Kolmogorov-Smirnov test (Figure 8.3). At this time, no conclusions can be drawn as to ELF effects on movement, however, it appears that this could be an excellent test. We would expect to see similar distributions of days since tagged values in post-operational years as pre-operational years.

From a bioenergetic standpoint, brook trout in the Ford River appear to utilize Two Mile Creek for thermal refuge since temperatures there, as opposed to the Upper Ford River, stay closer to optimum growth temperature. Groundwater inputs may have kept TM at or near 16 C during all years except 1987 when reduced groundwater inputs from abnormally low precipitation during winter and spring may

Table 8.2. Brook trout movement rate summary for 1984 through 1989.

| Year | Recapture Type                  | Site Marked<br>to<br>Site Recaptured | Distance<br>(km) | N  | Mean Rate<br>(km/day + 1SD) | Mode<br>(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              |
|      | Angler Returns                  | FEX                                  | 7.0              | 1  | 2.5                         |                  |
|      |                                 | FCD                                  | 14.4 ± 9.0       | 18 | 2.4 ± 2.6                   | 1.3              |
| 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              |
|      | Angler Returns                  | FCD                                  | 8.7 ± 9.9        | 3  | 1.1 ± 1.1                   | 1.0              |
| 1986 | No Recaptures or Angler Returns |                                      |                  |    |                             |                  |
| 1987 | Recaptured Fish                 | FEX- TM                              | 12.7             | 1  | 1.8                         | 1.8              |
|      | Angler Returns                  | FCD-FS1                              | 19.1             | 1  | 3.8                         | 3.8              |
| 1988 | Recaptured Fish                 | FCD-FEX                              | 14.1             | 2  | 2.3 ± 0.7                   | 1.0              |
|      | No Angler Returns               |                                      |                  |    |                             |                  |
| 1989 | Recaptured Fish                 | FEX-TM                               | 12.7             | 2  | 0.7                         |                  |
|      |                                 | FCD-TM                               | 26.8             | 1  | 4.5                         |                  |
|      |                                 | FCD-FEX                              | 14.1             | 1  | 2.8                         |                  |
|      |                                 | FEX-FCD                              | 14.1             | 2  | 1.9                         |                  |
|      |                                 | TM-FCD                               | 26.8             | 1  | 6.7                         |                  |
|      | No Angler Returns               |                                      |                  |    |                             |                  |

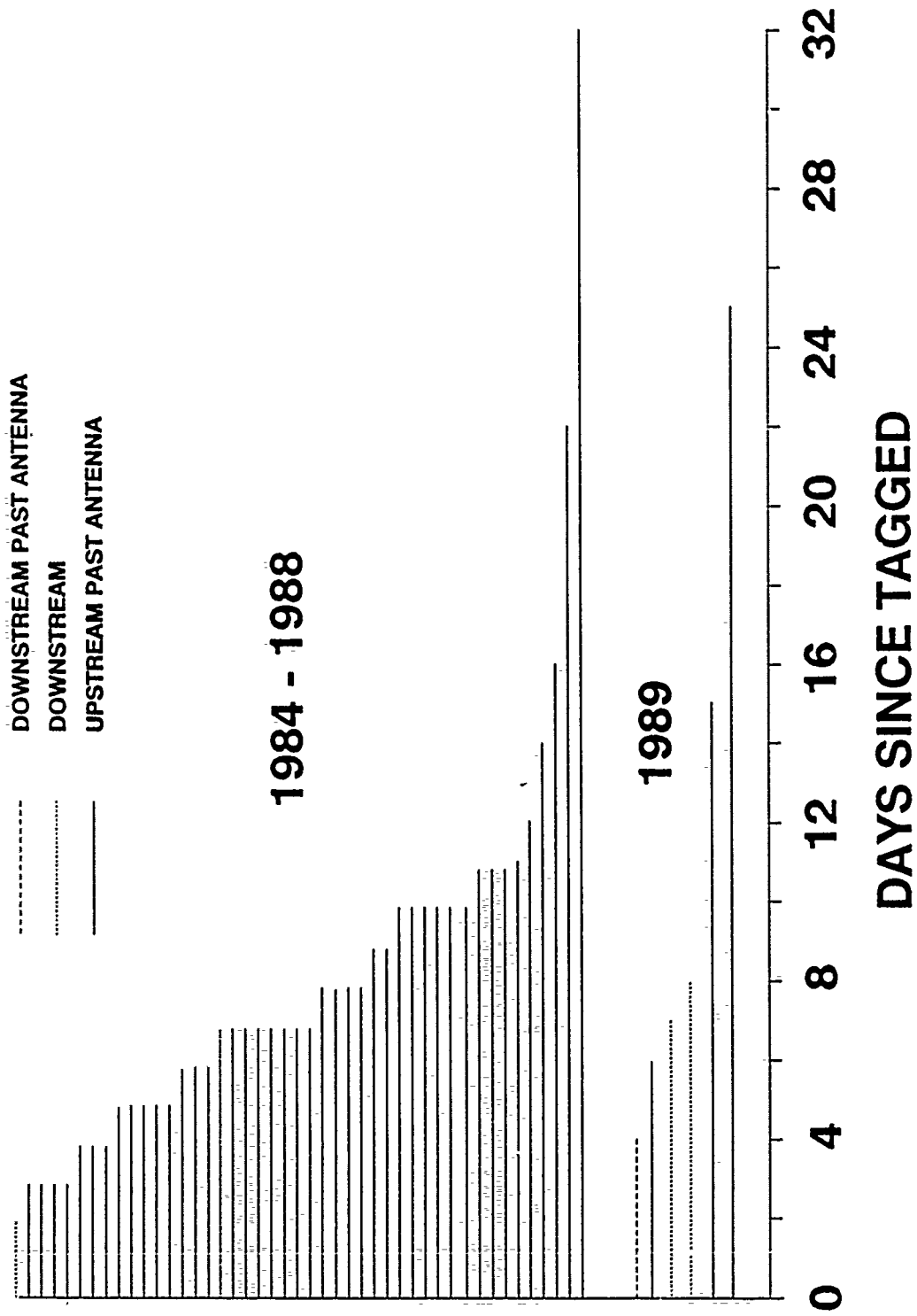


Figure 8.2. Range of individual movement times of brook trout during pre-operational (1984-1988) and post-operational (1989) study periods.

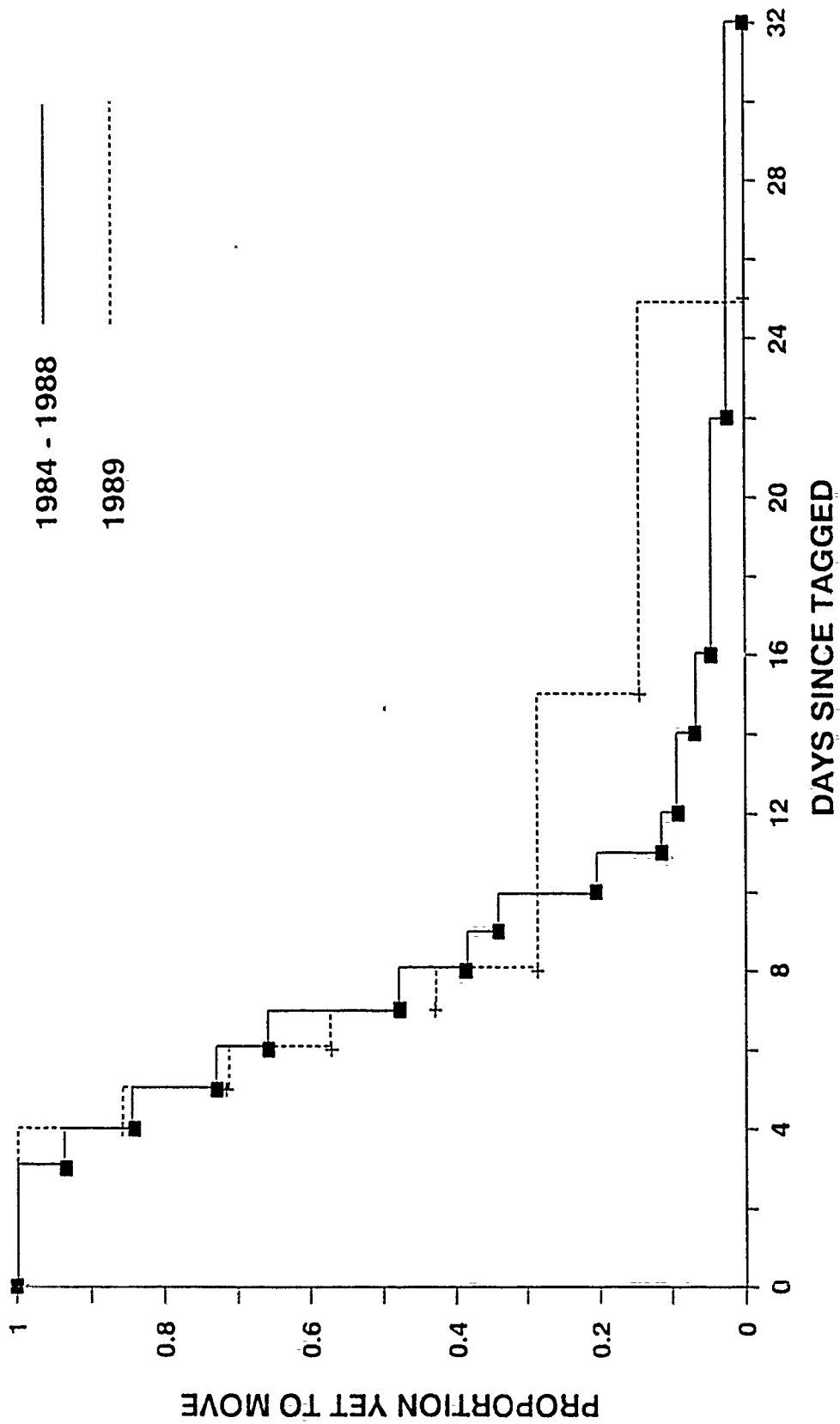


Figure 8.3. Movement distribution, in days since tagging, for individual brook trout during the pre- and post-operational study periods.

have resulted in higher temperatures. Temperatures in all years were significantly lower at TM than at FCU (paired t-test,  $p < 0.001$ ).

### C. Proximate Causes of Brook Trout Movement

Mean daily water temperature patterns showed no significant difference between years (Freidman's Test with Multiple Comparisons  $p > 0.05$ ) at FEX and FCD. Temperature patterns between years, however were highly variable, especially during late spring and early summer (Figure 8.4) In all years peak movement times coincided with mean daily temperatures exceeding the optimum for brook trout growth (16 C). In 1984 temperatures exceeded the optimum during the first week of June and the subsequent peak in mean daily catch occurred during that week. For 1985 and 1989 mean daily temperatures peaked past the optimum during the last week of June and peak movement times for these two years were the first week of July for 1985 and the last week of June for 1989. Mean daily temperatures in 1986 and 1988 peaked during the last week of May and movements in both years peaked during the first week of June. In 1987, water temperature and movement peaked during the third week of June.

Two additional factors which influenced brook trout movement patterns were discharge and population size. Analysis of discharge during the spring - early summer movement period at FCD showed there was variability between years (Freidman's Test,  $p < 0.05$ ). There were no significant differences in discharge between 1984, 1985, and 1987. Discharge in 1986 and 1989 was significantly lower than all other years except 1988 which was significantly lower than all other years (Freidman's Test with multiple comparisons,  $p < 0.05$ ) (Figure 8.5). Discharge patterns in 1984 showed periodic peaks throughout the year indicating that evenly spaced precipitation events occurred. Patterns for 1985, 1987, and 1989 displayed high spring - early summer discharge and low values during summer. 1986 and 1988 patterns showed low spring and summer values and increased flow in fall. Upstream directed movements occurred during all years despite different flow patterns. However, daily movements were strongly associated with peaks in daily discharge.

Fewer fish moved in 1986, 1988 and 1989, probably due to low trout populations during these years. When populations are low, individuals may be able to find adequate coldwater microhabitats without intra or interspecific competition from other fishes. In summary, it appears that when the brook trout population is abundant, water temperatures are suboptimal ( $> 16$  C) and flows are high, substantial upstream movement, characterized by high daily catches in







spring and/or early summer occur.

#### D. Brook Trout Movement Rates

The rates and direction of brook trout movement have the potential to be a very sensitive indicator of ELF effects. If trout have difficulty orienting through the ELF corridor, we would expect to observe disoriented behavior and decreased movement rates, particularly at FEX. From 1984 through 1988 (pre-operation), fish moved at a mean rate of 3.07 km/day. Movement rates in 1989 (mean = 2.73 km/day) showed no significant difference from the pre-operational mean (Paired t-test,  $p > 0.05$ ) (Table 8.3). Fish moving from FEX to TM (12.7 km) moved at a mean rate of 1.42 km/day (range = 0.7 to 1.8 km/day). Movement rates observed between FCD and TM (26.8 km) averaged 3.21 km/day while movement between FCD and FEX (14.1 km) averaged 2.3 km/day. Angler tag return data supported the above trends and indicated that brook trout move at a mean rate of 2.3 km/day in an upstream direction, similar to rates recorded from our sampling gear.

#### E. Gear Calibration and Brook Trout Population Estimates.

It was determined through analysis of length frequency distributions from fyke net catches that all brook trout 120 mm and greater are vulnerable to the gear. Length frequency distributions from two brook trout population estimates taken by the Michigan Department of Natural Resources at a site approximately 0.62 miles upstream of FCD in 1985 were compared to length frequency distributions from fyke net catches in that year. In addition, brook trout population estimates were obtained 1 mile downstream from FCD in 1986, 1987, 1988 and 1989 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 and 1989 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 so these data are not presented in this report.

Population estimates were obtained 1.6 miles downstream of the FEX site in 1987, 1988 and 1989. Analysis of the length frequency distributions of net catches at FEX and

Table 8.3. Paired t-test between pre-operational brook trout movement rates (1984-1988) and operational (1989) rates.

| t = 0.54    58 d.f.    p > 0.05 |           |        |
|---------------------------------|-----------|--------|
|                                 | 1984-1988 | 1989   |
| N                               | 53        | 7      |
| MEAN                            | 3.07      | 2.73 * |
| VARIANCE                        | 2.15      | 4.83   |
| * NO SIGNIFICANT DIFFERENCE     |           |        |

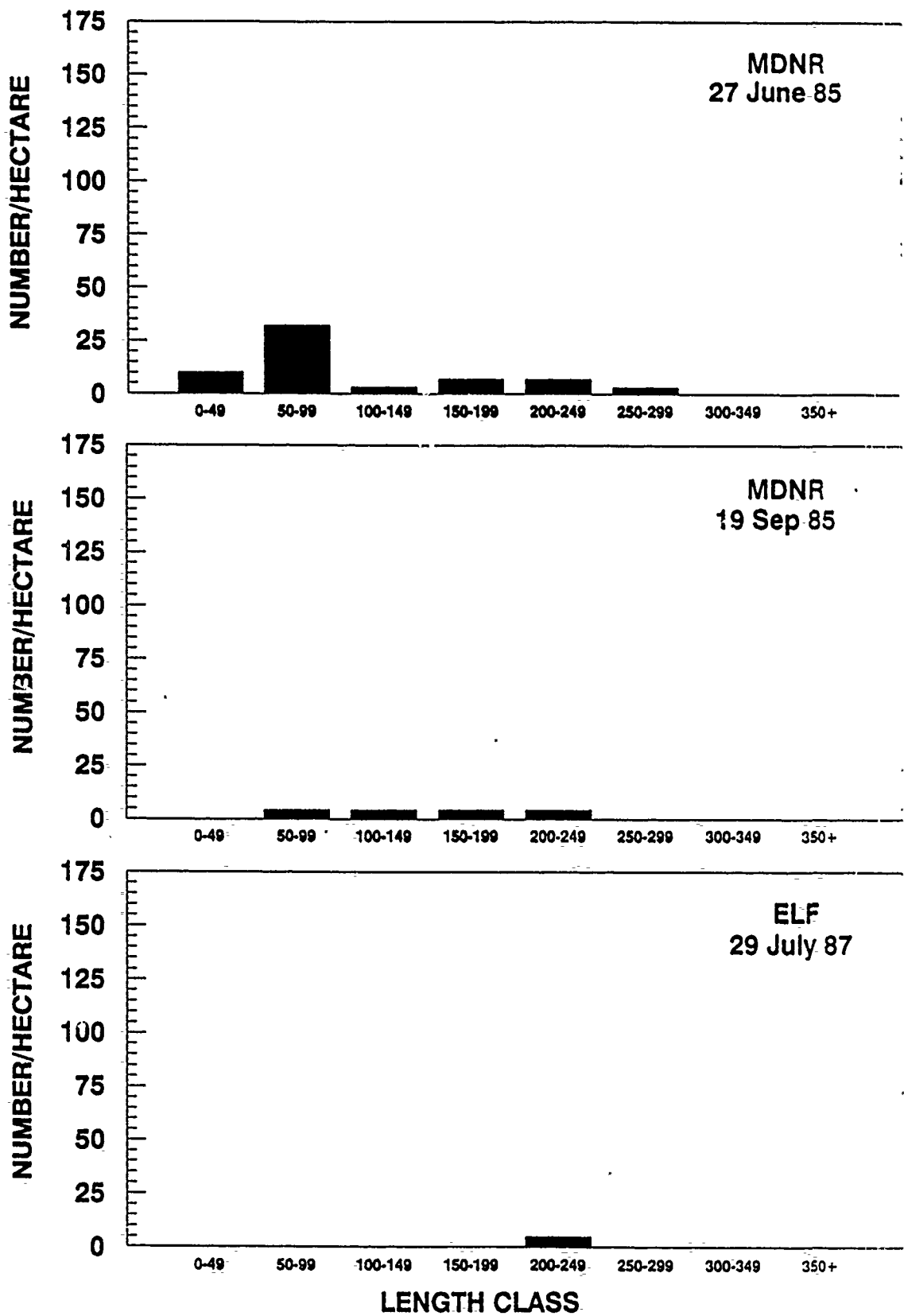


Figure 8.6a. Length frequency of brook trout taken by MI DNR and ELF personnel at FCD. Dates are included on graphs.

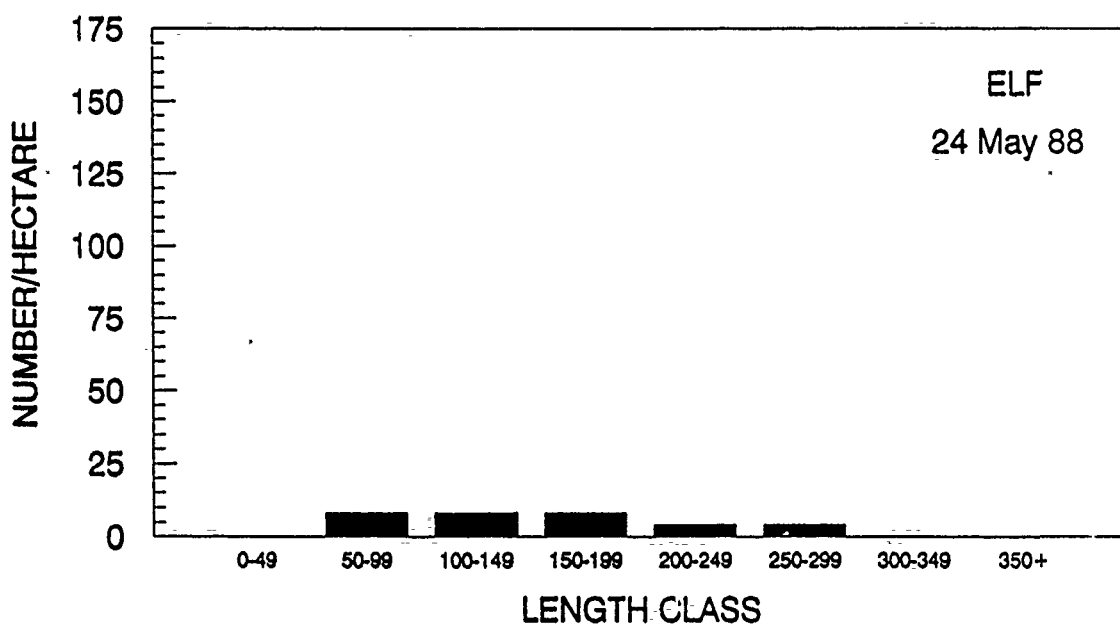
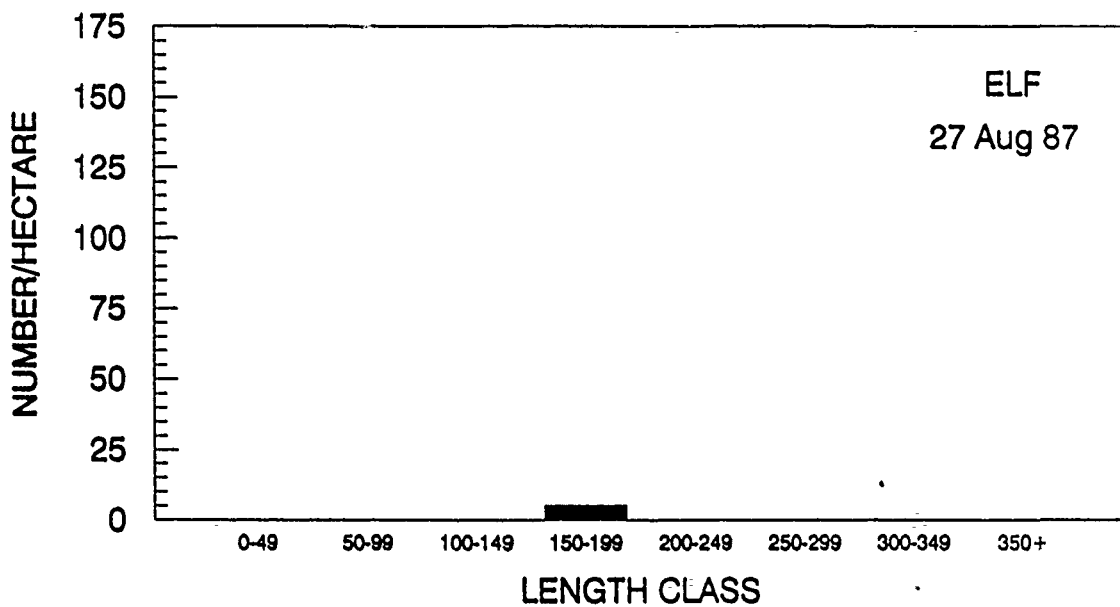


Figure 8.6b. Length frequency of brook trout at FCD taken by ELF personnel.

Table 8.4. Percent of the brook trout population vulnerable to the gear at FCD and FEX for years when population estimates were obtained. Assumes all fish > 120 mm are vulnerable to the gear.

| DATE         | SITE<br>NEAR | PERCENT OF POP<br>LESS THAN 120 mm | EXPECTED<br>PROPORTION OF<br>POP. VULNERABLE<br>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 %                                                     |
| 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 %                                                     |

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.

#### F. Brook Trout Age and Growth

Age and growth analysis of Ford River brook trout have the potential to be very sensitive indicators of ELF effects. Brook trout in the Ford River show excellent growth when compared to populations in Carlander (1969). Regression equations of brook trout data pooled from FEX and FCD are reported in Table 8.5 and plotted on Figure 8.8. Analysis of length at annulus data between years has not been done at this time. Discrepancies in 1987 and 1988 data need to be observed before further analysis can be done. Analysis of differences in the slopes and intercepts of regression equations for length versus total scale radius data between FEX and FCD over all years are reported in Table 8.6. No significant differences between sites were seen in 1983, 1985 and 1987 (regression analysis,  $p > 0.05$ ). Data from 1984, 1986 and 1988 showed significant differences between FEX and FCD (regression analysis,  $p > 0.05$ ). Significant differences in length at total scale radius were seen between all years at FCD (Table 8.7). No significant difference between 1983, 1986 and 1987 were observed at FEX (Table 8.7). All other years showed significant differences in the slopes of the regression lines of total length versus total scale radius. Plots of all regression lines used in this analysis are shown on Figure 8.9(a-c).

Lee's phenomena (Ricker, 1975) was not seen in any year for Ford River brook trout. Brook trout age structure and growth analysis will be a key to defining any significant ELF effects. Decreased growth in brook trout, especially at FEX, is expected if the ELF system excludes fish from reaching cold water refuge areas. Further analysis of age and growth data has been proposed in response to reviewer request. Consideration will be given to analysis of size increments at length in addition to length at age. Data from pre-operational years will be pooled and compared to pooled post-operational data for the final assessment of ELF effects.

#### G. Brook Trout Condition

Examination of brook trout condition was done using the



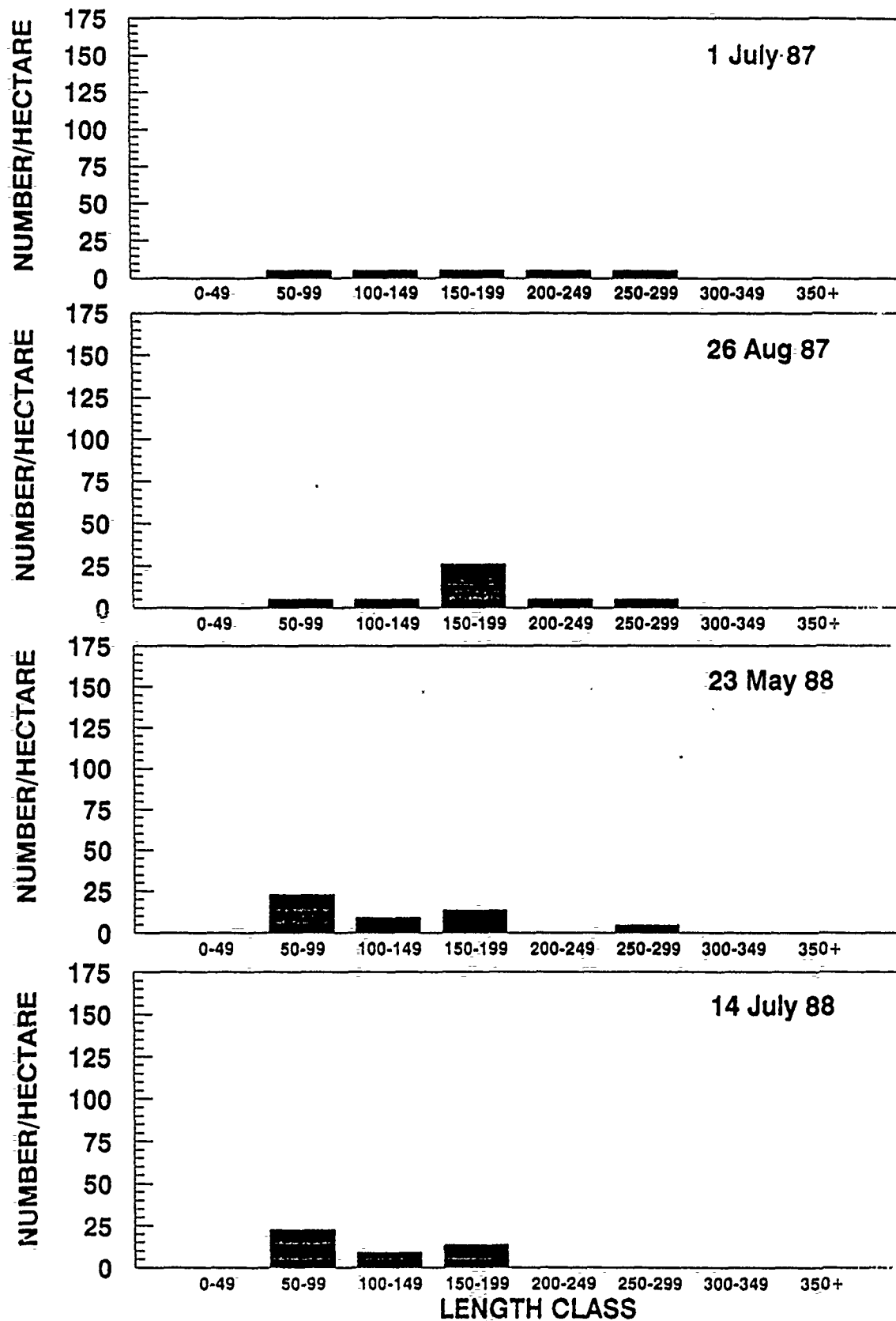


Figure 8.7. Length frequency of brook trout taken by ELF personnel at FEX.

Table 8.5. Regression equations used in analysis of brook trout length at annulus between years from 1983-1988.

| EQUATION |                          | Length = a + b(Scale Radius) |
|----------|--------------------------|------------------------------|
| YEAR     | EQUATION                 |                              |
| 1983     | $y = 4.970 + 473.897x$   |                              |
| 1984     | $y = -13.379 + 520.760x$ |                              |
| 1985     | $y = 4.598 + 491.507x$   |                              |
| 1986     | $y = -3.719 + 506.890x$  |                              |
| 1987     | $y = -12.352 + 536.539x$ |                              |
| 1988     | $y = 24.956 + 375.450x$  |                              |

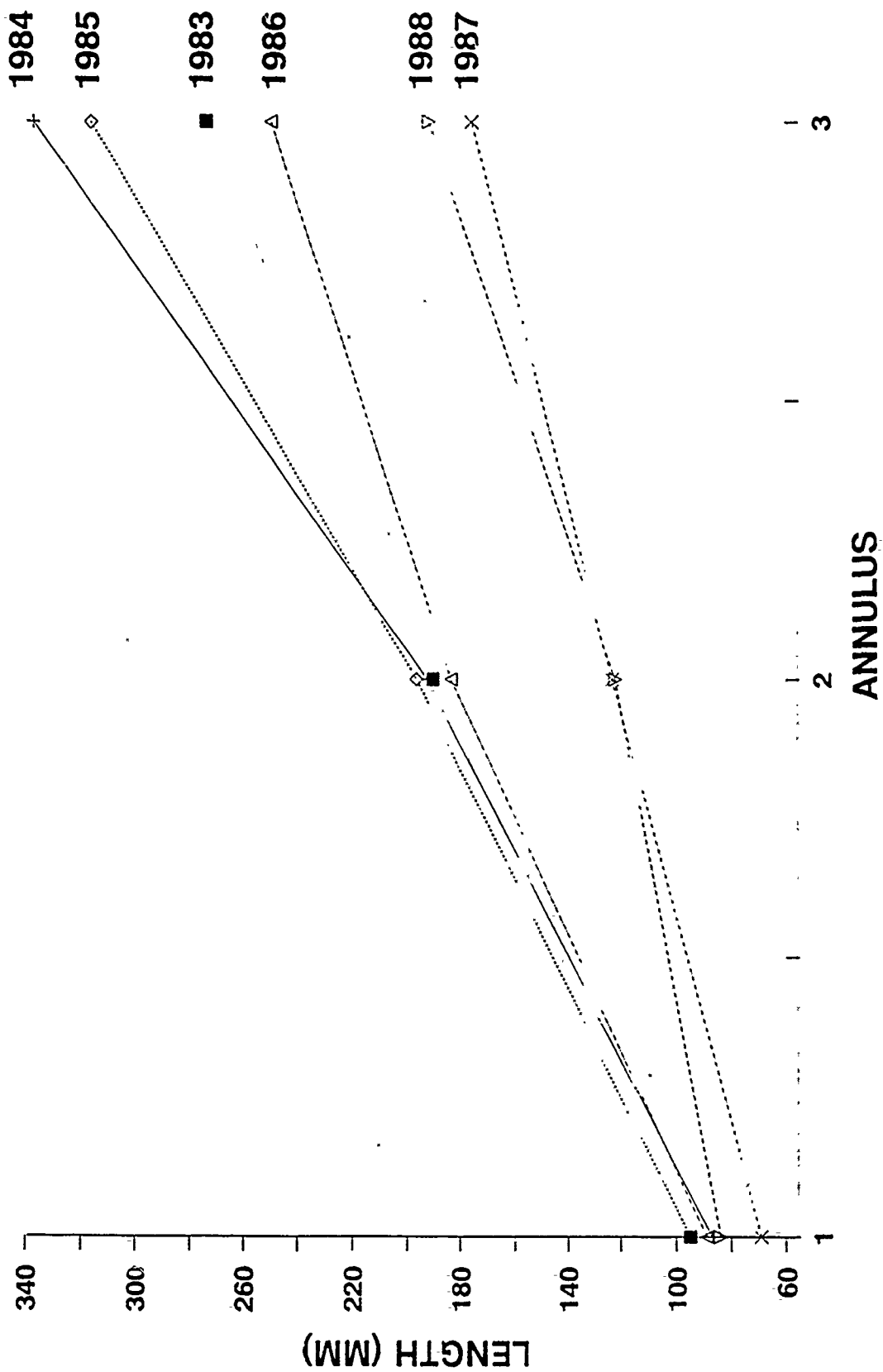


Figure 8.8. Length at annulus plots for brook trout over all years using data pooled from FCD and FEX.

Table 8.6. Regression equations used in between site comparison of length versus total radius data for 1983 through 1988.

| YEAR<br>SITE | REG EQUATIONS         | SLOPE(df)<br>(F) | INTRCPT(df)<br>(F) |
|--------------|-----------------------|------------------|--------------------|
| 1983         |                       |                  |                    |
| FCD          | $y=60.177 + 324.962x$ | NS(1,142)        | NS(1,143)          |
| FEX          | $y=57.025 + 352.025x$ | (0.51)           | (2.59)             |
| 1984         |                       |                  |                    |
| FCD          | $y=62.255 + 343.975x$ | *( 1,49)         | no test            |
| FEX          | $y=-10.11 + 518.964x$ | (4.39)           |                    |
| 1985         |                       |                  |                    |
| FCD          | $y=45.662 + 416.331x$ | NS( 1,28)        | NS( 1,29)          |
| FEX          | $y= 9.556 + 489.439x$ | (0.71)           | (0.15)             |
| 1986         |                       |                  |                    |
| FCD          | $y=18.448 + 443.314x$ | *(1,101)         | no test            |
| FEX          | $y=47.408 + 356.639x$ | (4.36)           |                    |
| 1987         |                       |                  |                    |
| FCD          | $y=89.657 + 284.874x$ | NS(1,230)        | NS(1,231)          |
| FEX          | $y=58.296 + 351.143x$ | (3.11)           | (0.77)             |
| 1988         |                       |                  |                    |
| FCD          | $y=91.162 + 197.896x$ | *( 1,17)         | no test            |
| FEX          | $y= 3.186 + 435.569x$ | (10.09)          |                    |

\* SIGNIFICANT  $p < 0.05$

NOTE - No test of intercept can be done if slopes are significantly different.

Table 8.7. Regression equations used in analysis of between years comparison of length versus total scale radius at FCD and FEX.

| YEAR | FCD                 | EQUATIONS | SLOPE | INTERCEPT |
|------|---------------------|-----------|-------|-----------|
| 1983 | y=60.177 + 324.962x |           | a     | NT        |
| 1984 | y=62.255 + 343.975x |           | b     | NT        |
| 1985 | y=45.662 + 416.331x |           | c     | NT        |
| 1986 | y=18.448 + 443.314x |           | d     | NT        |
| 1987 | y=89.657 + 284.874x |           | e     | NT        |
| 1988 | y=91.162 + 197.896x |           | f     | NT        |
| FEX  |                     |           |       |           |
| 1983 | y=57.025 + 352.025x |           | a     | NT        |
| 1984 | y=-10.11 + 518.964x |           | b     | NT        |
| 1985 | y=.9.556 + 489.439x |           | c     | NT        |
| 1986 | y=47.408 + 356.639x |           | a     | NT        |
| 1987 | y=58.296 + 351.143x |           | a     | NT        |
| 1988 | y= 3.186 + 435.569x |           | d     | NT        |

NOTE - Same letters indicates that years are similar in slope. No test can be done on intercepts if slopes are significantly different.

Tukey - Kramer Multiple Comparison Test, alpha=0.05 (Miller 1986)..

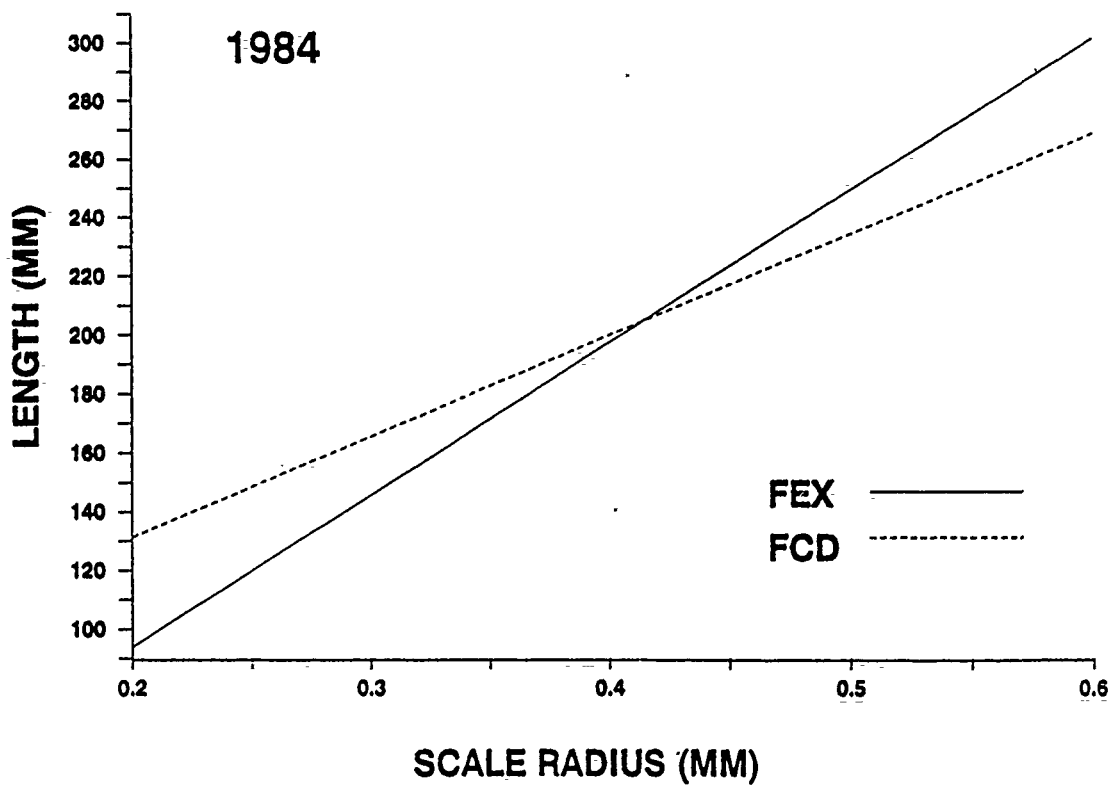
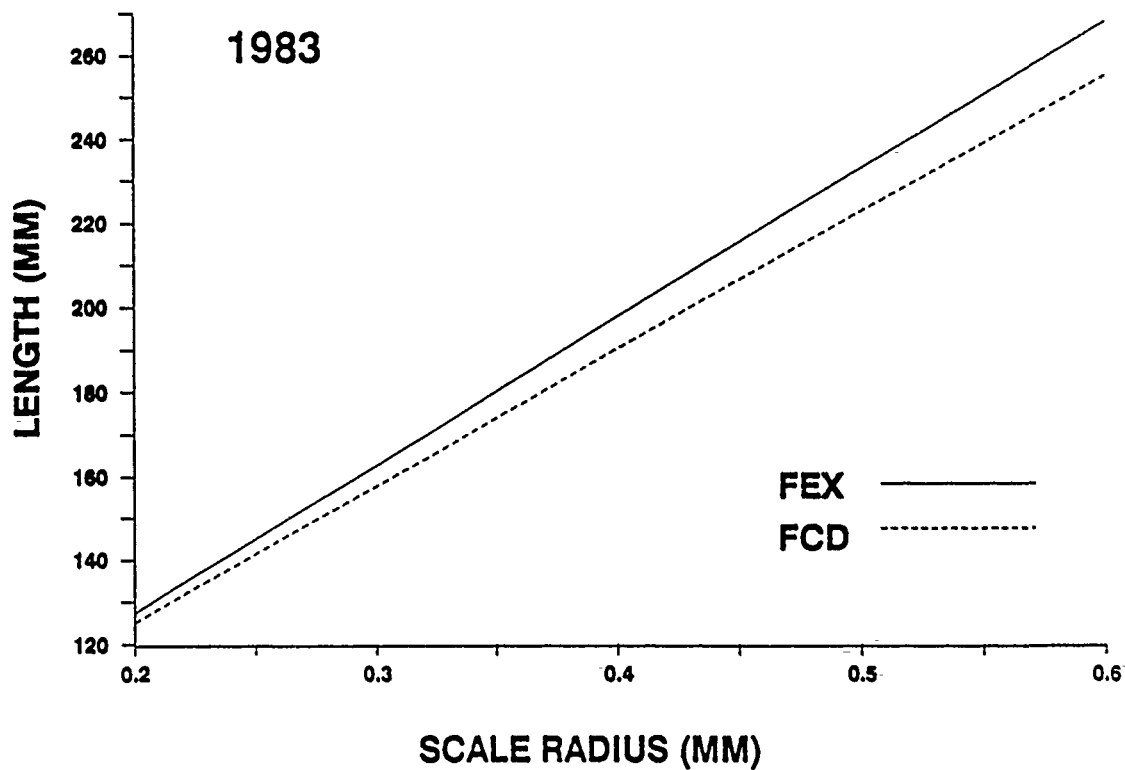


Figure 8.9a. Plots of the regression lines used in analysis of total fish length versus total scale radius between sites in 1983 and 1984.

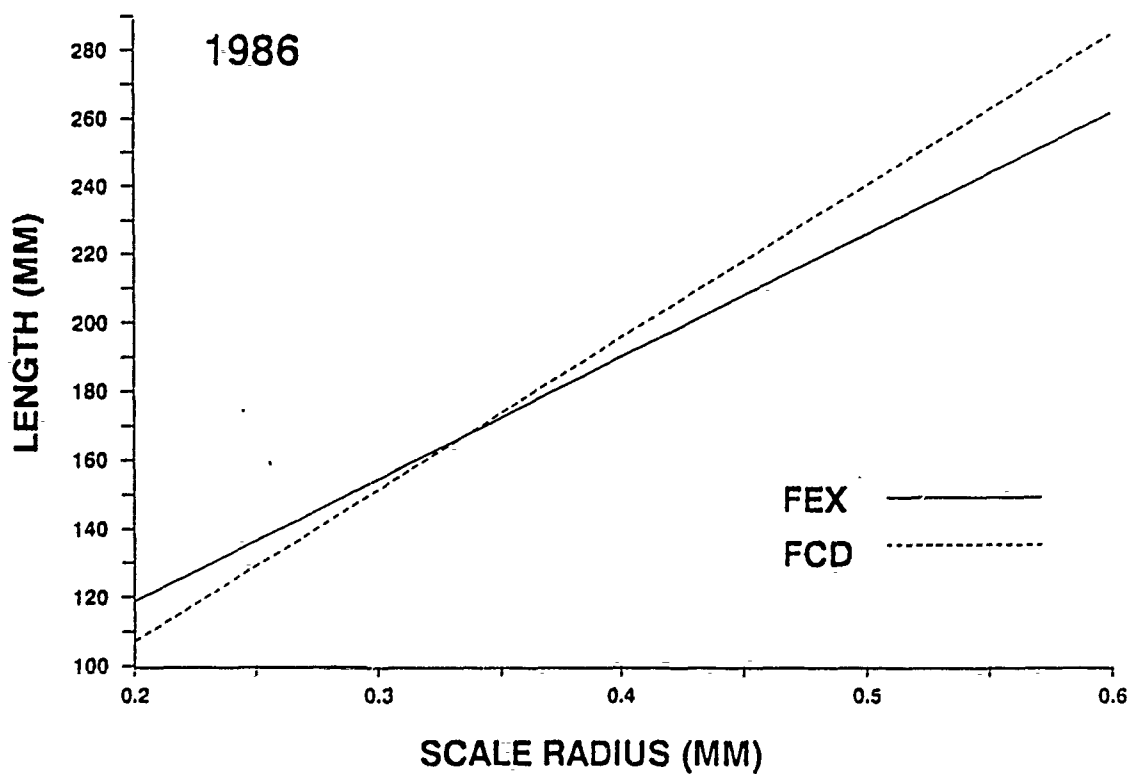
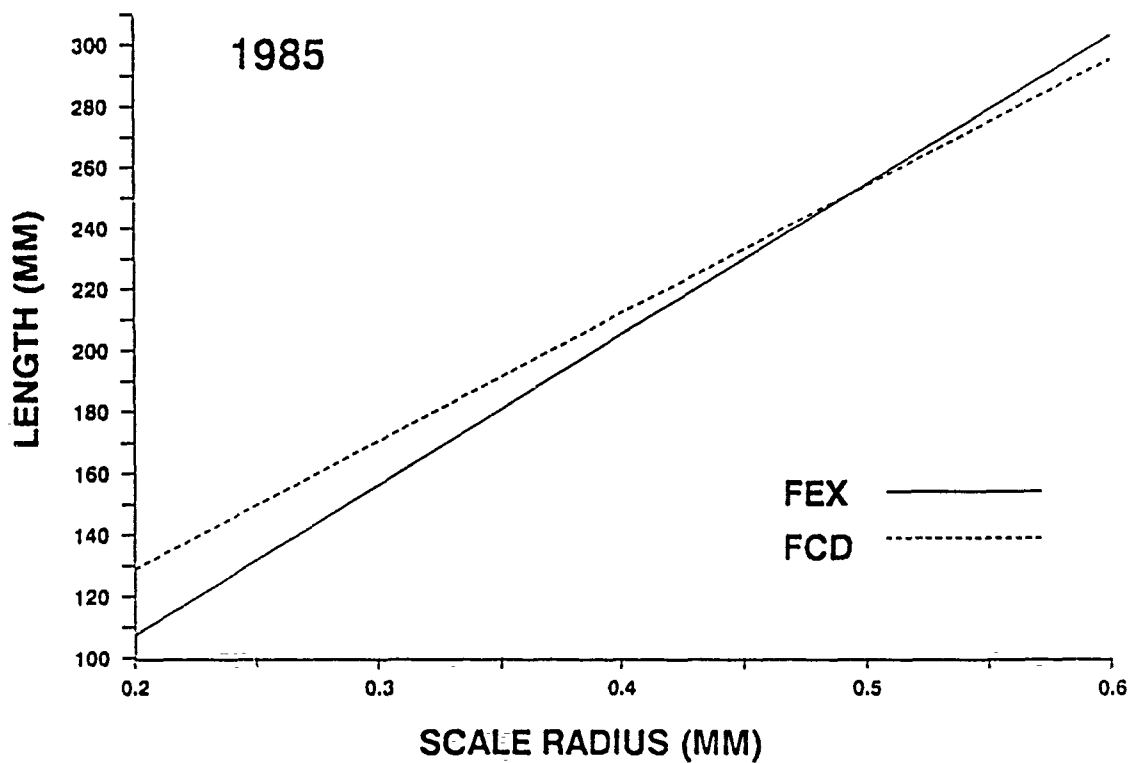


Figure 8.9b. Plots of the regression lines used in analysis of total fish length versus total scale radius between sites in 1985 and 1986.

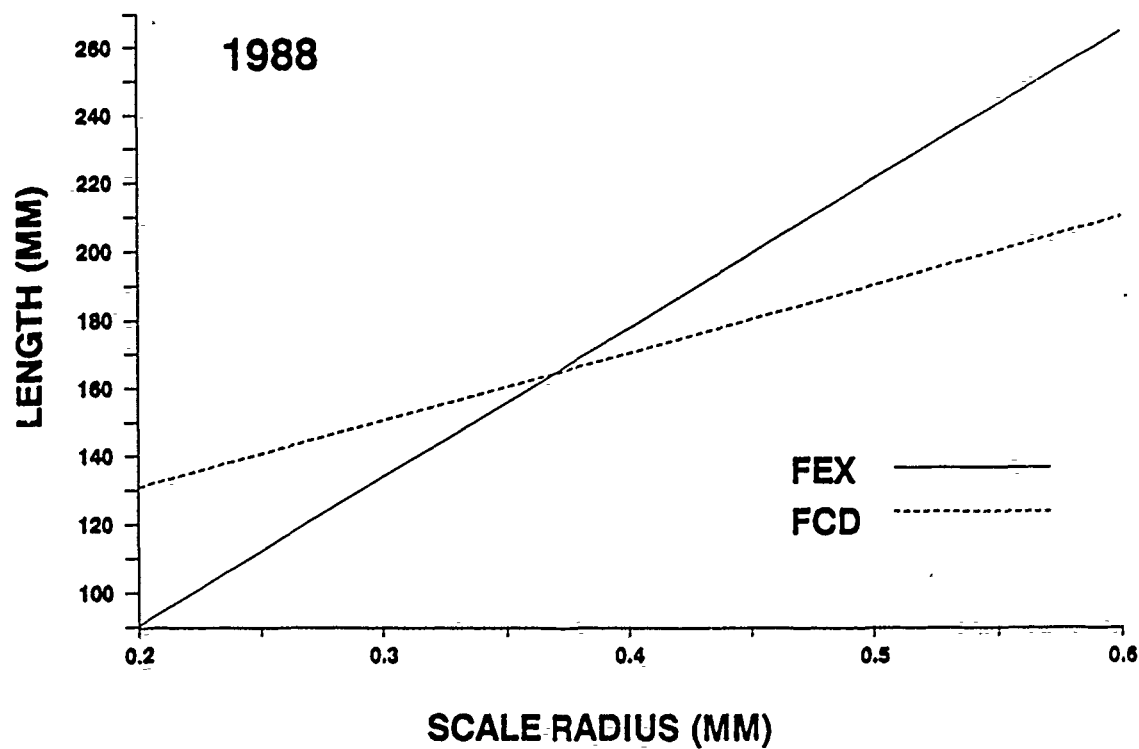
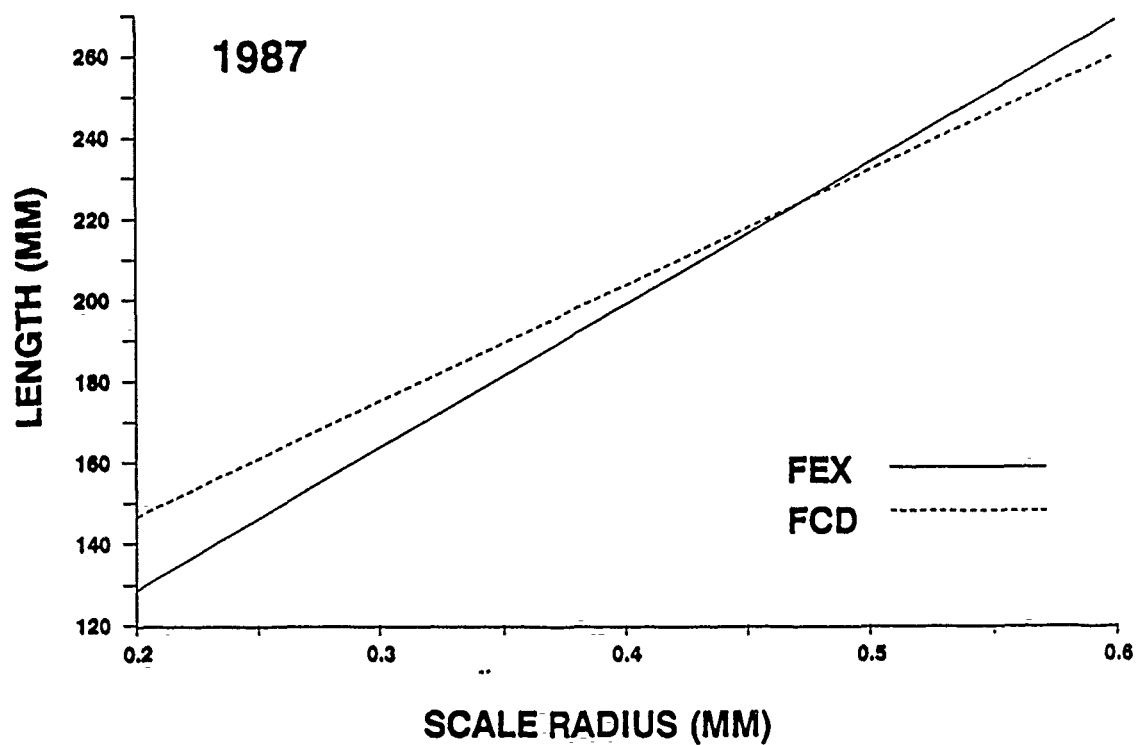


**Figure 8.9c. Plots of the regression lines used in analysis of total fish length versus total scale radius between sites in 1987 and 1988.**



relative weight methodology as described in element 7. The standard weight formula:

$$\log_{10} wt = -5.085 + 3.043 * \log_{10} tl \quad (r=.999),$$

was determined using the 50th percentile equation from 45 brook trout populations reported in the literature.

Brook trout relative weight ranged from average to slightly below average from 1983 to 1988 when compared to values obtained from the above equation (Figure 8.10). 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 (103.7) increased back to levels seen in 1983.

Length/weight regression analysis was also used to compare brook trout condition between FEX and FCD over all years (Table 8.8). No significant differences in the slopes of the regression lines were observed between sites over all years except 1985 (Analysis of Covariance,  $\alpha = 0.05$ ) (Figure 8.11a-c). Condition was also compared for each year for each site (Table 8.9). No significant differences were observed between years at FCD (Analysis of Covariance,  $\alpha = 0.05$ ) (Figure 8-12a and b). Multiple comparison analysis between years at FEX, however, indicated that no significant differences were seen between 1984, 1985 and 1987. In addition, no difference was observed in the slopes of the regression lines between 1986 and 1988 and 1989 was significantly different than all other years. No intercept analysis was done if slopes were different.

In response to reviewer request, we have reevaluated our condition analyses and will shift our emphasis to the regression analysis in our impact assessment. Further breakdown into size classes should strengthen our condition analysis.

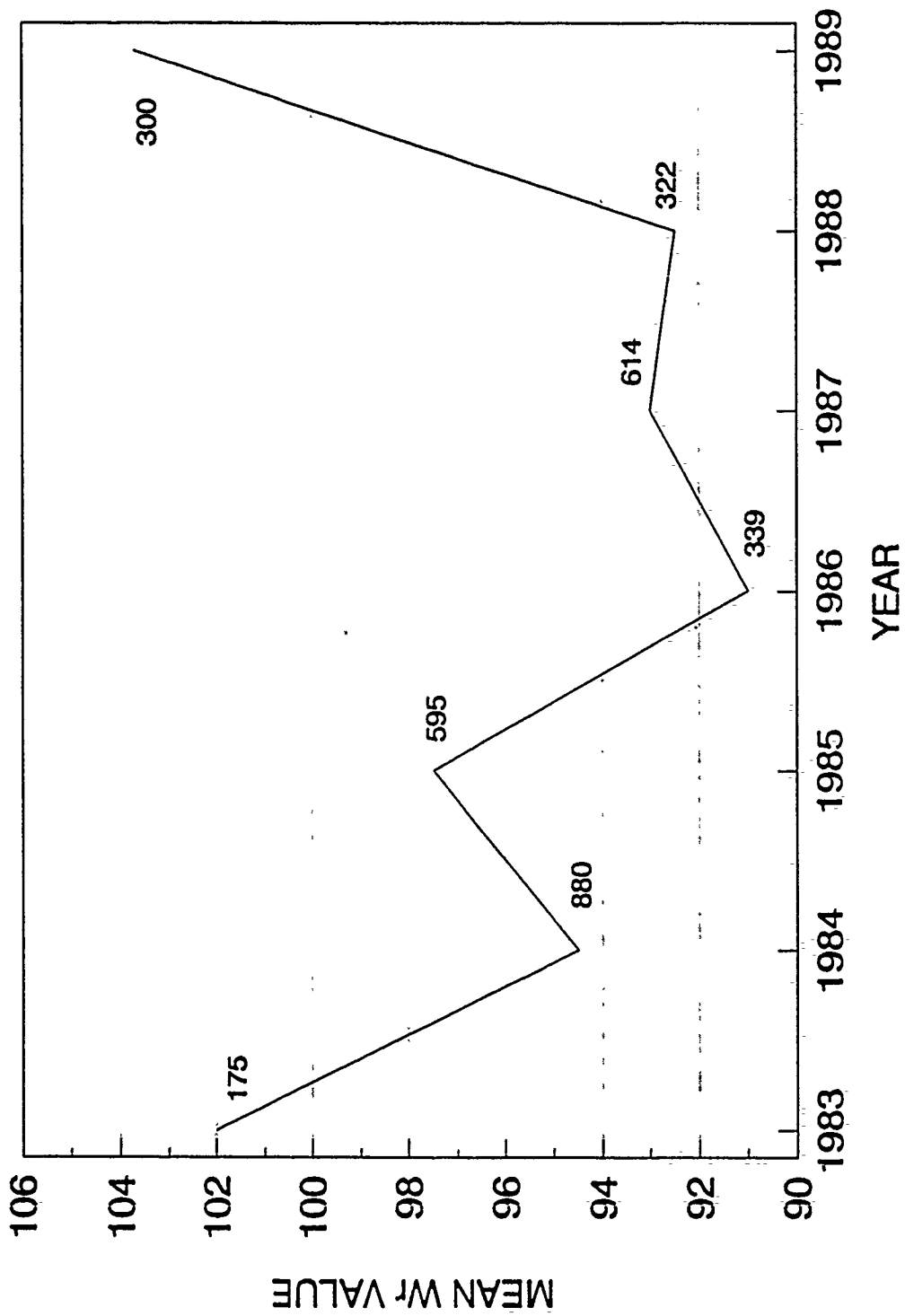


Figure 8.10. Brook trout mean yearly  $W_t$  values from the Ford River. Numbers adjacent to means refer to sample size used in calculation.

Table 8.8. Regression equations used in brook trout condition analysis between FEX and FCD in each year.

| EQUATION $\text{LOG}(\text{weight}) = a + b\text{LOG}(\text{length})$ |                       |                       |                       |                       |
|-----------------------------------------------------------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| $y = \text{log}(\text{weight})$                                       |                       |                       |                       |                       |
| $x = \text{log}(\text{length})$                                       |                       |                       |                       |                       |
| YEAR                                                                  | FEX                   | FCD                   | Slope(df)<br>(F)      | Intrcpt(df)<br>(F)    |
| 1984                                                                  | $y = -5.358 + 3.143x$ | $y = -6.203 + 3.507x$ | NS (1,114)<br>(0.082) | NS (1,115)<br>(0.001) |
| 1985                                                                  | $y = -5.767 + 3.328x$ | $y = -5.528 + 3.220x$ | *(1,233)<br>(4.930)   | NT<br>NT              |
| 1986                                                                  | $y = -5.181 + 3.056x$ | $y = -5.391 + 3.160x$ | NS (1,133)<br>(0.081) | NS (1,139)<br>(3.710) |
| 1987                                                                  | $y = -5.314 + 3.134x$ | $y = -5.434 + 3.185x$ | NS (1,387)<br>(1.030) | NS (1,105)<br>(0.170) |
| 1988                                                                  | $y = -5.192 + 3.073x$ | $y = -5.200 + 3.077x$ | NS (1,147)<br>(0.002) | *(1,148)<br>(0.001)   |
| 1989                                                                  | $y = -5.464 + 3.216x$ | $y = -5.510 + 3.225x$ | NS (1,147)<br>(0.020) | *(1,148)<br>(9.560)   |

\* SIGNIFICANT  $\alpha = 0.05$

NOTE - All F tests from analysis of covariance. If the slopes are the same then a test for a common intercept was performed. If the slopes are different a test for a common intercept cannot be done.

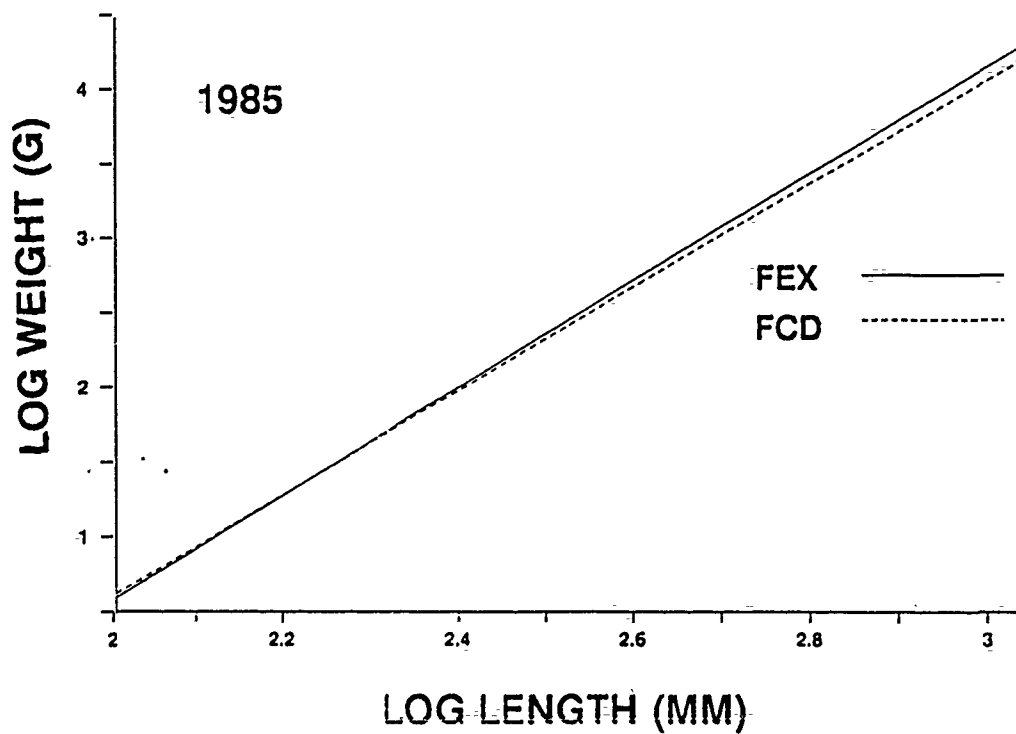
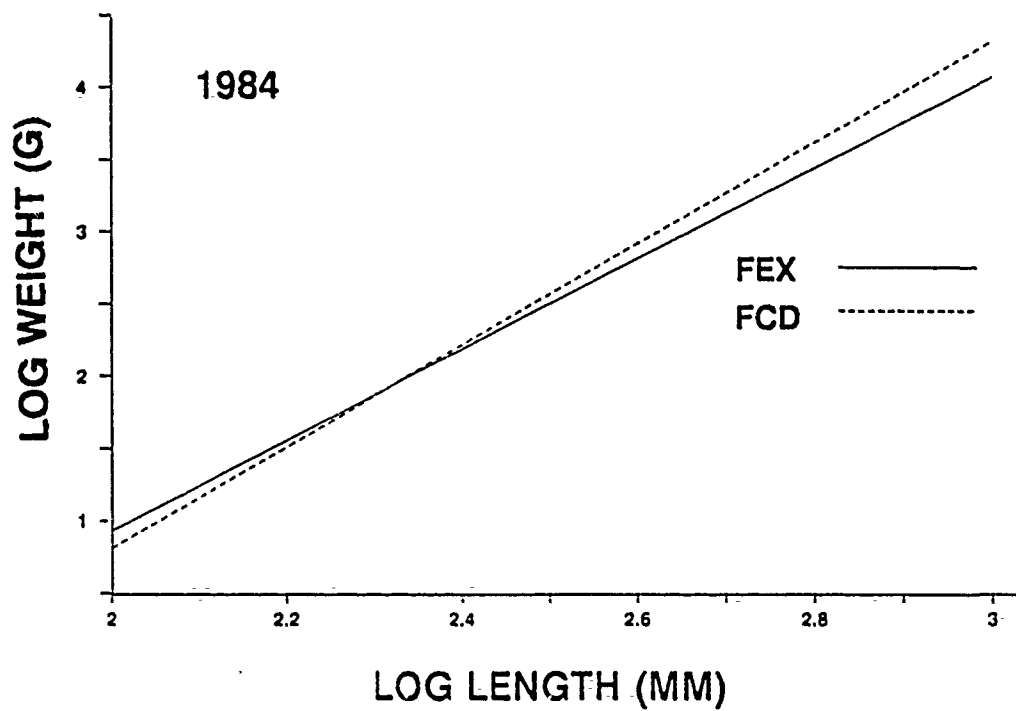


Figure 8.11a. Plot of the regression lines (log weight vs. log length) used in brook trout condition analysis between FCD and FEX in 1984 and 1985.

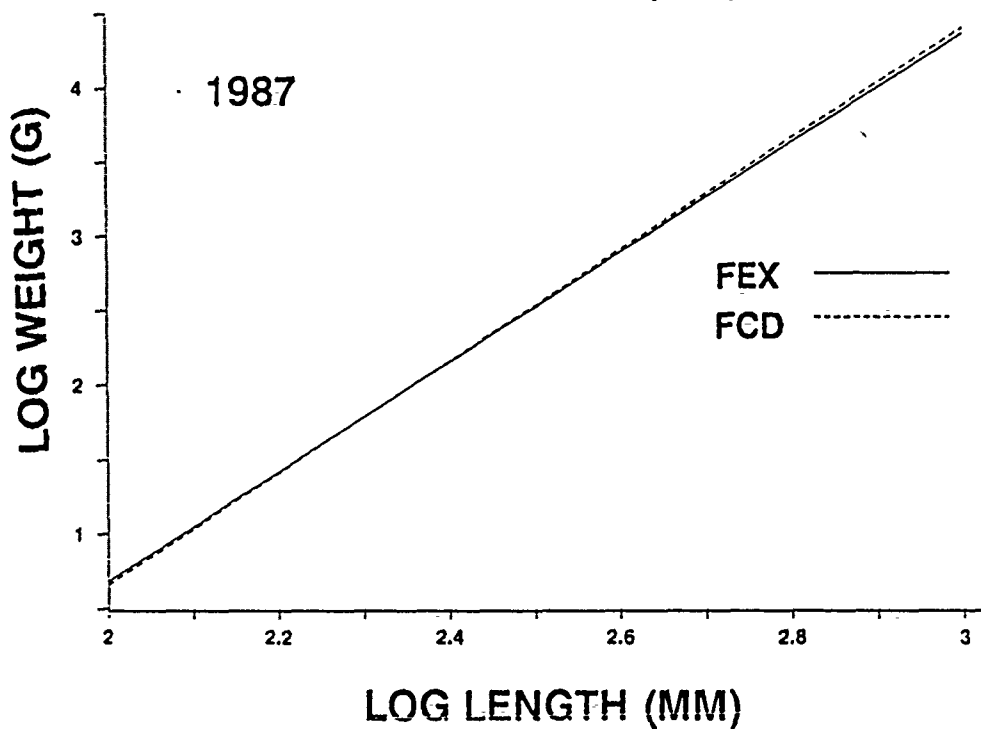
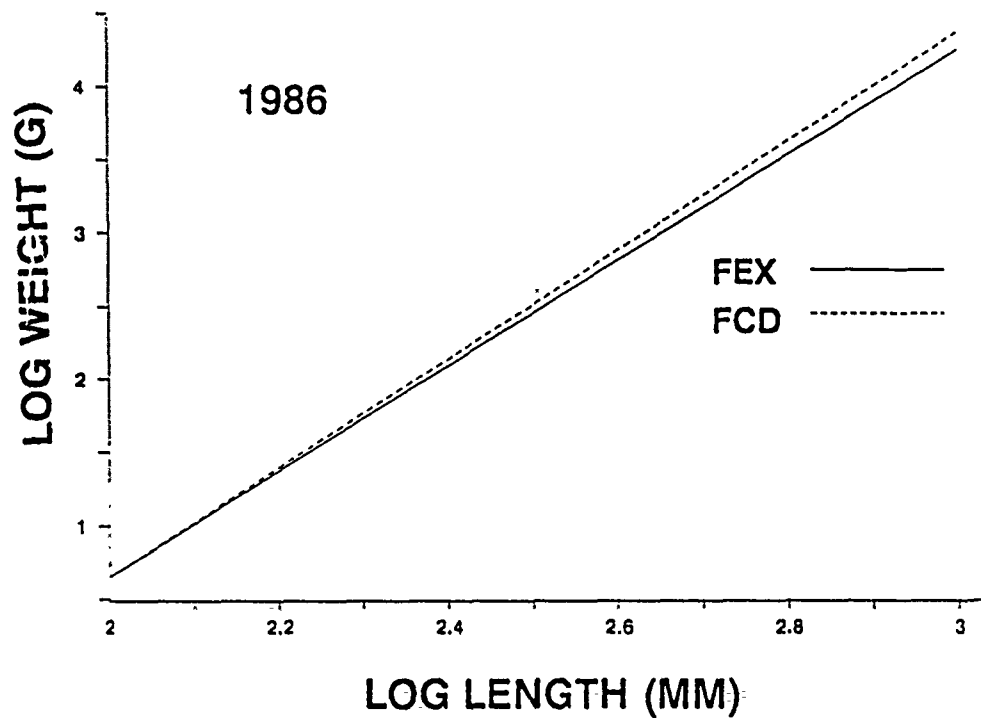


Figure 8.11b. Plot of the regression lines (log weight vs. log length) used in brook trout condition analysis between FCD and FEX in 1986 and 1987.

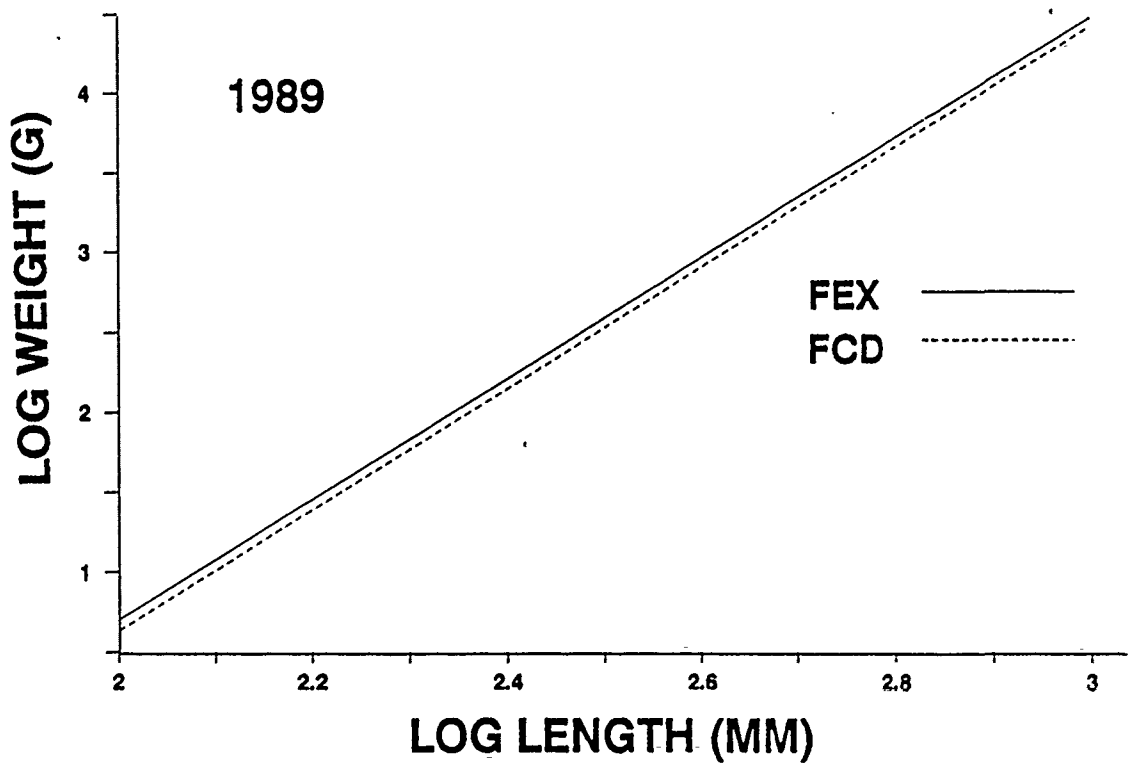
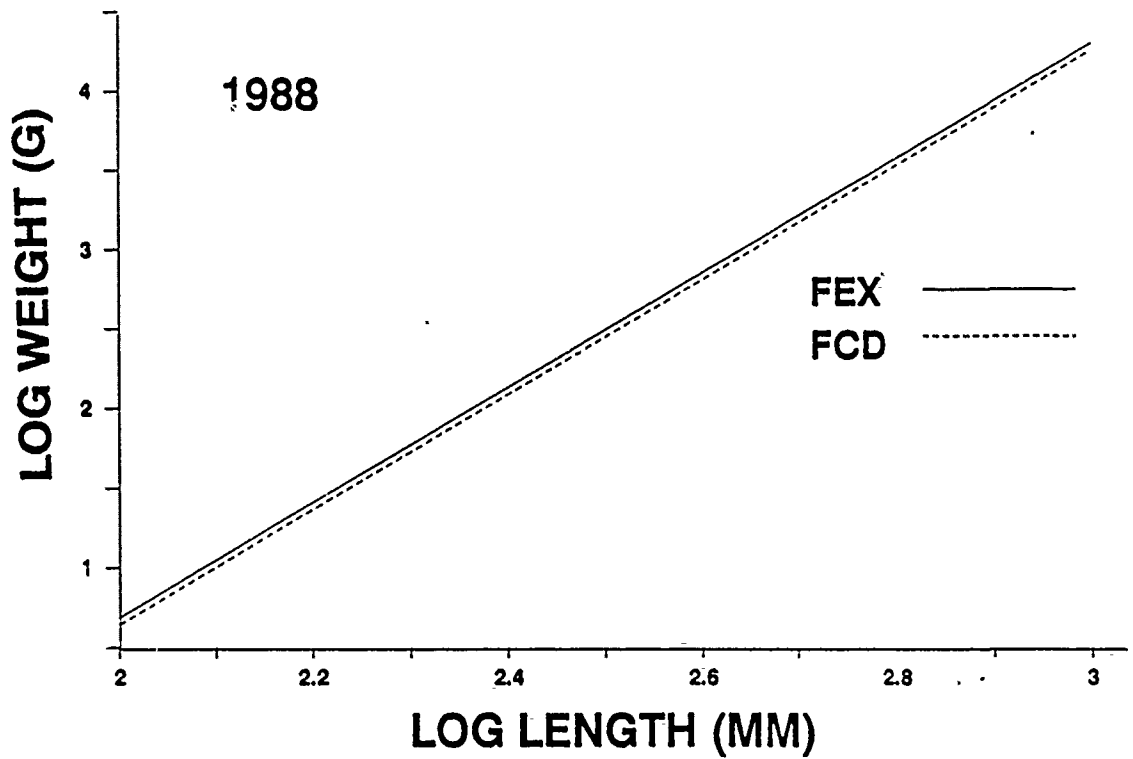


Figure 8.11c. Plot of the regression lines (log weight vs. log length) used in brook trout condition analysis between FCD and FEX in 1988 and 1989.

Table 8.9. Length/weight regression equations used in brook trout condition analysis between years at FEX and FCD.

|       | FEX                   | SLOPE | INTERCEPT |
|-------|-----------------------|-------|-----------|
| 1984  | $y = -5.358 + 3.143x$ | a     | NT        |
| 1985  | $y = -5.767 + 3.328x$ | b     | NT        |
| 1986  | $y = -5.181 + 3.056x$ | c     | NT        |
| 1987  | $y = -5.314 + 3.134x$ | a     | NT        |
| 1988  | $y = -5.192 + 3.073x$ | c     | NT        |
| ----- |                       |       |           |
| 1989  | $y = -5.464 + 3.216x$ | d     | NT        |
|       | FCD                   | SLOPE | INTERCEPT |
| 1984  | $y = -6.203 + 3.507x$ | a     | a         |
| 1985  | $y = -5.528 + 3.220x$ | a     | b         |
| 1986  | $y = -5.391 + 3.160x$ | a     | c         |
| 1987  | $y = -5.434 + 3.185x$ | a     | d         |
| 1988  | $y = -5.200 + 3.077x$ | a     | e         |
| ----- |                       |       |           |
| 1989  | $y = -5.510 + 3.225x$ | a     | f         |

NOTE - Years within a site having the same letter do not differ at  $\alpha=0.05$  (Tukey - Kramer Multiple Comparison Test, Miller 1986).

If slopes are significantly different, no test was done on intercept.

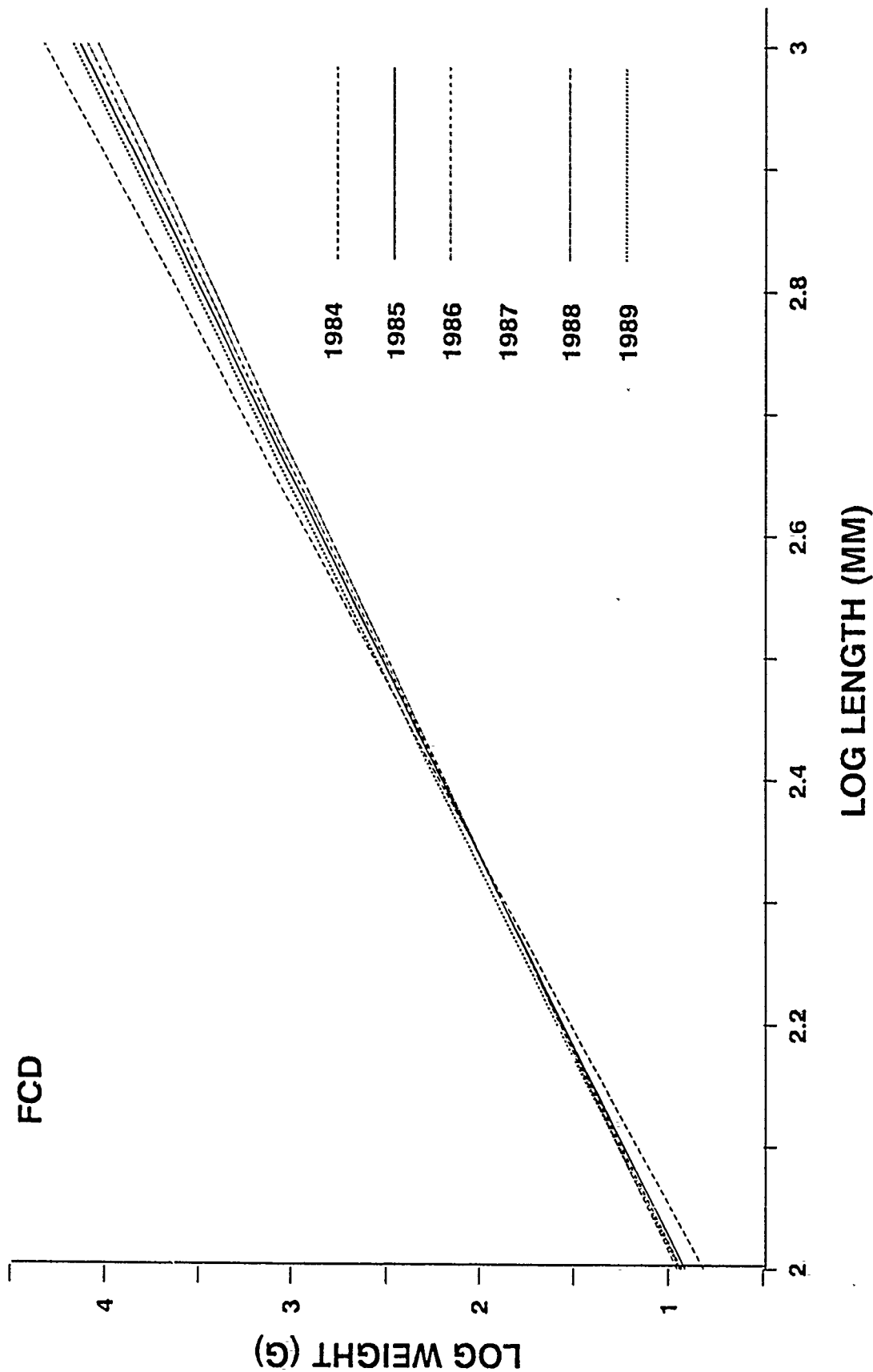


Figure 8.12a. Plots of the regression lines for analysis of brook trout condition at FCD over all years.



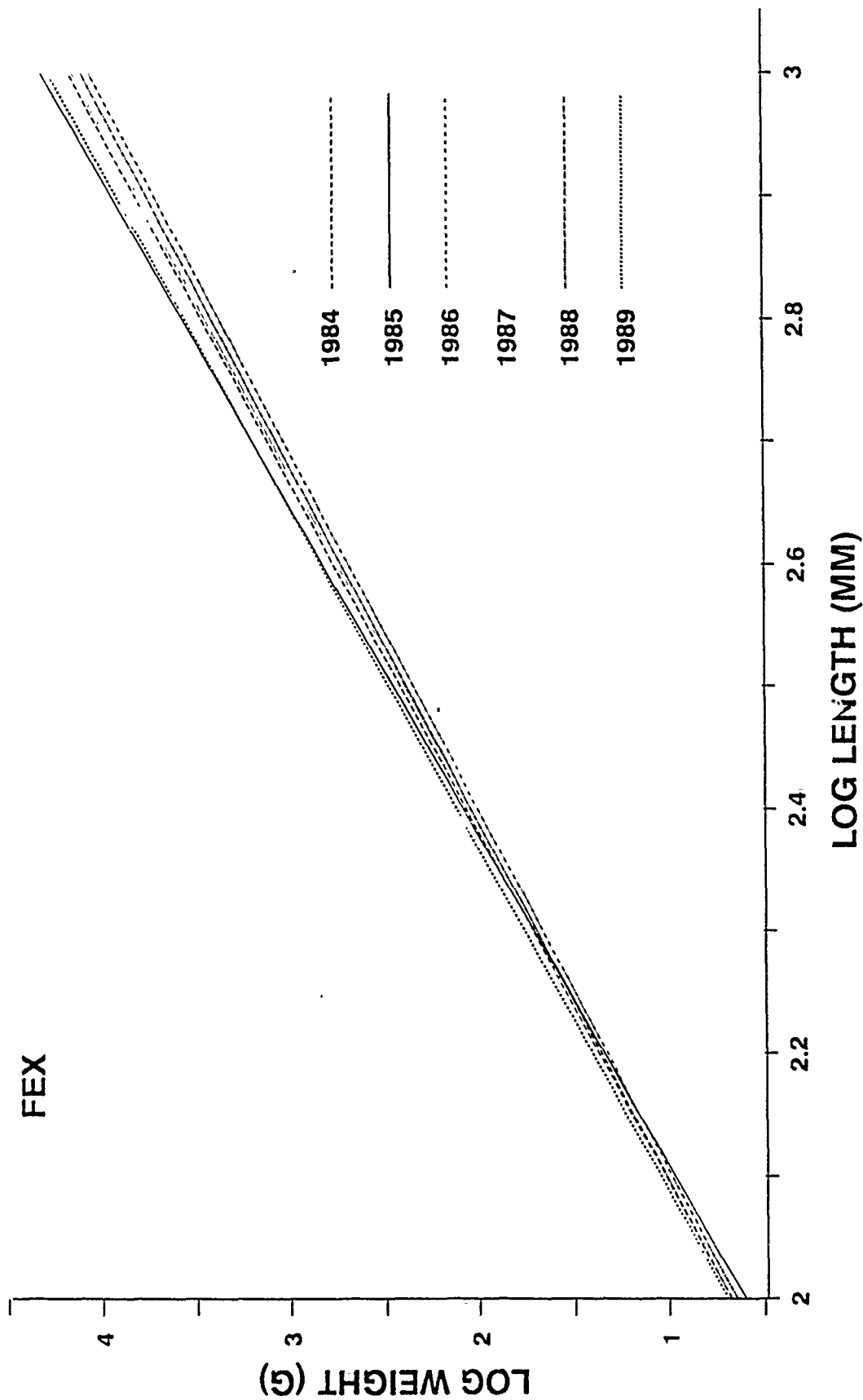


Figure 8.12b. Plots of the regression lines for analysis of brook trout condition at FEX over all years.

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