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Compilation of 1987 Annual Reports of the Navy ELF Communications System Ecological Monitoring Program

Volume 3 of 3 Volumes:
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This is the sixth compilation of annual reports for the Navy's ELF Communications System Ecological Monitoring Program. The reports document the progress of ten studies performed during 1987 at the Wisconsin and Michigan Transmitting Facilities. 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.

See reverse for report titles and authors.

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     Michigan State University
     Burton, T. M.; Stout, R. J.; Taylor, W. W.; Oemke, M. P.;
     Whelan, G.

I.   Wetland Studies
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J.   Bird Species and Communities
     University of Minnesota-Duluth
     Hanowski, J. M.; Niemi, G. J.; Blake, J. G.

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FOREWORD

The U.S. Navy is conducting a long-term program to monitor for possible effects from the operation of its Extremely Low Frequency (ELF) Communications System to resident biota and their ecological relationships. The program is being implemented by IIT Research Institute (IITRI) under contract to the Space and Naval Warfare Systems Command (SPAWAR). IITRI provides engineering support and coordinates the efforts of investigators. Monitoring projects are being carried out through subcontract arrangements between IITRI and study teams at several universities.

This is the sixth compilation of annual reports prepared by university study teams. Each report chronicles the data collection and data analysis activities for a monitoring project during 1987. As in the past, each report has been reviewed by four or more scientific peers. Investigators have considered and addressed reviewer critiques prior to providing their report for printing. Reports have been printed from original copies without change or editing by either IITRI or SPAWAR.

Reports other than this compilation document electromagnetic exposures at study sites and summarize the annual progress of the program. These reports have been prepared on an annual basis since the inception of the program in 1982. All have been provided to the National Technical Information Service for unlimited distribution. The results of monitoring studies have also been presented at scientific meetings and as articles in peer reviewed, scientific journals.

IIT RESEARCH INSTITUTE

IITRI E06595-2

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    Whelan, G.

I. Wetland Studies
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J. Bird Species and Communities
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    Hanowski, J. M.; Niemi, G. J.; Blake, J. G.

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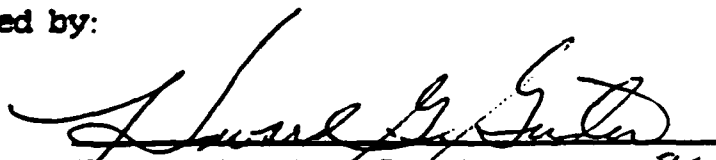AQUATIC ECOSYSTEMS - TASKS 5.8, 5.9, 5.10

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Contract and Grant Administration

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IV. 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 analysis 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.

Element 1- <u>Conduct Ambient Monitoring Program</u>

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 was true for hardness, nitrate, and organic nitrogen. These differences 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 intersite differences in productivity. We initiated experiments in 1987 to determine the impact of N and P inputs on the algal community and should be able to determine if the slight differences in nitrate and organic N are likely to result in increased productivity as soon as analyses of these experiments are completed. In addition, productivity between the two sites was not significantly diferent (see Element 2).

Dissolved oxygen was only slightly below saturation at both sites and was slightly but significantly higher at FEX than it was at FCD. This difference was probably related to differences in sample times between the two sites. We expected to pair dissolved oxygen data on a time basis using the automatically acquired data to test whether these differences were real or not. However, one of the two meters proved to be unreliable in 1987 making this comparison impossible.

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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. Even at FEX, chloride levels were only slightly higher than typical rainfall values. Thus, chloride should have little effect on the biota at either site.

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

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

1.   <u>Chlorophyll a</u>

Annual patterns for chlorophyll <u>a</u> standing crop and acorual 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 1986-87 data showed no site differences, although the five year three way ANOVA indicated a small but significant difference between sites.   Combining all sample periods in a single paired t-test, however, showed no significant differences existed between sites. Likewise, in 1986 and in 1985, no between site differences were detected (yearly paired t-tests). Differences between sites occurred in 1983 and 1984 only. This parameter may be better used to test single point, or single sample period differences between sites when production is high and the coefficients of variation for chlorophyll <u>a</u> also low. Additionally, this parameter seems suitable for testing with the new BACI technique to detect differences between sites once ELF exposure begins.

2.   <u>Organic Matter</u>

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Organic matter (AFDW-biomass) standing crop and accrual rates showed considerable year to year variability similar to chlorophyll a. These parameters have consistently been characterized by showing no significatnt differences between sites since 1983. The combined paired t-test and three way ANOVA showed very close agreement, analyzing all the data available, to indicate no between site differences. The only trend has been for a July-August peak in standing crop and accrual rates and winter lows for both standing crop and accrual.

3.   Chlorophyll a to Phaeophytin a Ratios

This ratio continued to vary widely throughout the year in 1986-87. The random nature of the fluctuations appear to indicate that this parameter will not be useful for detection of ELF effects.

4.   Diatom Cell Density

Diatom cell density continued to be characterized by no statistical difference between sites, regardless of length of data set compared or type of analyses performed. Density appears to be high throughout the summer periods with some tendency towards a June peak. Density was always lowest during the winter periods.

5.   Species Diversity and Evenness

Diatom species diversity and evenness were not significantly different in 1987. This continues the trend seen in 1983, 1984, 1985 and, 1986. Annual trends show a high diversity and evenness during winter (except winter of 1987) and lower values during the summer periods.

6.   Total Biovolume and Individual Cell Volume

Individual cell volume comparisons of diatoms between sites showed no significant differences. Total biovolume was also not significantly different between sites for 1987. Combined data from 83-87 used in both paired t-tests and three way ANOVA's showed no between site differences for these two parameters. Individual

cell volume generally is larger during the winter periods and smallest in the summer periods.

7.   **Before and After, Control and Impact (BACI) Analyses**

Stewart-Oaten et al. (1986) developed this procedure for just the type of comparison we wish to conduct. We further illustrated the applicability of this procedure by comparing our AFDW-biomass and chlorophyll a data between hypothetical 'before and after' years. No significant differences were observed between the years examined. This procedure will likely be used to examine both species changes, as well as community level changes in our final report.

8. **Correlation with Environmental Variables**

A correlation matrix was generated using all the available data collected from each individual site over the past five year period. Although some water chemistry parameters appeared to influence the biological parameters at one site more than another, there was generally close agreement between sites regarding the influences of either environmental factors or water chemistry constituents. The results of the correlations also agreed with our previously reported analyses using multiple regression analyses.

9. **Photosynthesis-Respiration Studies**

Net production, respiration, and gross production of the community on rock surfaces did not differ greatly between sites. The lack of significance reported in last year's report between sites for 1984, 1985, and 1986, plus the data from 1987, indicate that this parameter may offer a precise 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.

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Specifically, Glossosoma nigrior (Banks), a grazing
caddisfly, caused a shift in dominance within the diatom
community 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 but was
not as significant as in 1985. This difference between
years may be related to different amounts of organic
matter on the colonized tiles at the start of the
experiment. Nevertheless, results are consistent enough
to suggest that this pattern of response is typical of
the pre-E.L.F. exposure period and offers a baseline for
comparison of results after the E.L.F. antenna becomes
fully operational.

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

     Structural community parameters, diversity (H'),
evenness (J'), and richness (S) had their highest values
in the summers and their lowest values in the winters
from 1983 to mid 1987. Values for S were very high in
the summer of 1986. Although they fell during the winter
of 1986-87, the drop was not as steep as in previous
winters. An unusually mild winter that year is proposed
as being the major factor. Taxon diversity (H') and
evenness from 1983 to 1987 were highly correlated with
one another, owing to high chironomid abundances relative
to other taxonomic categories.

     Distinct seasonal patterns were found for various
functional community parameters. Total biomass had
summer peaks and winter troughs; however, in the winter
of 1986-87, the total biomass values did not drop as in
past winters. Again, an unusually mild winter is
proposed as being the major factor involved. Regressions
of insect biomass against water temperatures and insect
biomass against diatom density were high in all years
except in the 1986-87 season as well. Functional feeding
groups including collector-gatherers, collector-filter
feeders, and predators were highly correlated with diatom

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densities until 1986-87. Shredder biomass values were never highly correlated with diatom densities.

Mean dry weight per individual values (MDW/IND) were plotted against time for seven taxa. Five of the seven taxa showed distinct growth patterns with the largest individuals being found in late spring-early summer. They are: Paraleptophlebia mollis, Ephemerella invaria, Epehemerella subvaria, Glossosoma nigrior, and Protoptila sp. One taxon, Optioservus is holobiotic. Major adult numerical peaks and major larval numerical peaks were in mid-summer. MDW/IND values were highest in the fall and winter months. The last taxon, Chironomidae, encompasses many species. Even so, the largest individuals were found in May for all years; the smallest individuals were found in October and November for all years.

Element 5 - Movement Patterns of Selected Aquatic Insects

Naiads of a dragonfly predator, Ophiogompus colubrinus, travelled in a downstream direction at both FEX and FCD for all mark-recapture studies (1984 through 1987). Percent recapture success was usually 40 to 50 %, making us confident that the data reflect movement patterns of this predator rather well. Chi square tests for distances moved showed that animals tend to be found in the upper reaches of FEX and tend to be found in the lower reaches of FCD over time. The data across years are consistent. If this pattern changes after E.L.F. is activated, we should be able to detect the change. The animals' numerical abundance in the stream,"markability", and rather sedentary behavior make them appropriate for movement pattern studies aimed at detecting the effect of E.L.F. radiation on thier movements.

Element 6 - Leaf Litter Processing

Fresh tag alder (Alnus rugosa) leaves were processed significantly faster than were autumn-abscissed leaves for all the studies (1982-87). The mean processing coefficient, -k, for fresh leaves at FEX was 0.0170 (s.d. = .0089, n = 5); at FCD the mean was 0.0134 (s.d. =.0020, n = 4). The -k values for autumn-abscissed leaves at FEX was 0.0068 (s.d. = .0023, n = 4); at FCD the mean was 0.0046 (s.d. = .0016, n = 3). Both fresh and autumn-abscissed leaves were processed slightly faster at

FEX than at FCD. The slightly faster current and higher
numbers of shredders at FEX may be two important factors
for these differences.

Taxon diversity (H') values for insect colonizing
leaves over time were similar across years. H' decreased
over time after the initial conditioning phase, 9 days.
The same was true for evenness (J'). Taxon richness
patterns were similar for all years. After an initial
increase through the first three weeks of incubation,
richness declined. Chironomidae abundance steadily
increased over time for all treatments, sites, and years.

Total insect biomass was higher on leaves at FEX
than at FCD for 1984 through 1986. Shredders are an
important functional feeding group found on leaves, as
they process leaf fragments. Shredder biomass was higher
on fresh leaves than on autumn leaves in all years where
both fresh and autumn leaves were used. It appears that
fresh leaves are more "attractive" to shredders than
autumn-senescent leaves. Three species were anlayzed
according to changes in MDW/IND. A collector-gatherer,
Ephemerella invaria, and a predator, Isoperla
transmarina, showed increases in size over time. The
third species, Paraleptophlebia mollis showed no
consistent change over time. This species is
univoltine with its major growth peak occurring in June
of each year, as determined in studies on insects from
substrate samples (Element 4). For all Element 6
parameters, except for numbers of individuals, total
biomass and functional feeding group biomasses,
coefficient of variation values were below 18 %.

Element 7 - Fish Community and Abundance

1. Species Composition

Sixteen species from five orders and eight families
were collected at FEX in 1987. This represents a net
decrease of two families and one order from previous
years. Fourteen species from eight families and five
orders were collected at FCD in 1987 with a decline of
two species, four families, and two orders from previous
years. Overall, the species composition was similar at
the two sites with the only changes seen in rare species.

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2. Species Abundance

Numerically and by biomass, the fish community was
dominated by five species. Numerically, common shiners
and creek chubs made up over 45 % of the catch at both
sites. Burbot catch was the least variable, and common
shiner and brook trout catches were the most variable.
By biomass, white suckers and brook trout were the
dominant species, making up 60 % of the catch at both
sites. 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. Species diversity was increased
at both sites in 1987 from previous values. No
significant differences were found between sites, and the
diversity values ranged between 1.6 to 2.2.

3. Catch Statistics

Catch rates (catch per day) were variable for all
species and were seasonally dependent. Catch rates for
common shiners and creek chubs increased from 1984-1987
at FEX. White sucker catch rates increased in 1987 at
FEX. Brook trout and burbot showed negative trends in
catch rates at FCD. Brook trout, creek chubs, 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 showed no consistent year to year trends at
either FCD or FEX, and fish at FCD were significantly
larger for all species except for burbot.

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 11
%. Recapture percentages were similar to previous years
except for a decline in creek chub recaptures. Overall,
site to site movements were lower in 1986 and 1987 than
the previous years. These lower movement rates may be
related to significant discharge changes in these years.

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5. Individual Species Analyses

Age, growth, and condition factor analyses using
common shiners, creek chubs, northern pikes, and white
suckers were initiated as section of this element in 1986
with the premise that these factors are good indicators
of the fish stress. Growth analysis using scales
indicated that common shiners and creek chubs show better
than average growth when compared to literature values.
White suckers and northern pike both displayed poor
growth when compared to literature values. Fish
condition was examined using relative condition factors.
Standard weight formulae 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 = 80-96). Creek chub
condition factors declined from 1983-1987 by 5 %. Common
shiner condition showed a cyclic trend with a modulation
of 7 % per year. White sucker condition improved by 4 %
in 1987.

6. Fixed Gear Calibration

This new 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.
Regression analysis of the relationships in this section
will be reported after the 1988 season.

Element 8 - Brook Trout Movement

1. Movement Patterns and Rates

Brook trout catches peaked in spring-early summer at
all sites except FCU. The peak occurred in June in 1984
and 1987, and in July in 1985 with the movement in an
upstream direction. Peak catches of 1984, 1985, and 1987
were not seen in 1986. Brook trout movement appeared to
be caused by mean water temperature exceeding the optimal
growth temperature (16° C) and the rate of this increase
which is related to acclimation time. Low groundwater
discharge and river flow volumes also may create thermal

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barriers to movement. Groundwater recharge and spring
precipitation are also important variables. Brook trout
(>190 mm) move from FCD and FEX upstream to the TM site
based on a total of 520 tagged and branded fish. In 1984
and 1985, 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 1987. Movement rates were
found to range between 1.1 to 5.0 km/day. Ranges from
FEX to TM were similar between 1984, 1985, and 1987 with
no catches between these sites in 1986. Brook trout
movement rates were greater in 1985 than in 1984 from FCD
to TM with no movement detected in 1986 and little in
1987. Angler tag return data verified the above movement
rates indicating the fish move at a constant measureable
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 FS1 in June 1985 was
269 ± 47.5 trout 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 were
estimated at 60.7 fish/ha (biomass = 1.28 kg/ha) in June
1985, 15.7 fish (biomass = 0.31 kg/ha) in August 1985 and
0 fish in August 1986. These densities were 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. Calibration studies conducted as
part of the ELF monitoring on this project determined
that the brook trout densities ranged from 4.2 fish/ha at
FCD to 364.3 fish/ha at TM and that biomass ranged from
0.3 kg/ha at FCD to 10.3 kg/ha at TM. Overall, values
are below Michigan averages and show that recruitment is
low at the sites sampled (except TM). Statistical
analysis of the population characteristics will be
reported in the 1988 report.

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 literture 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 thir data is in progress
and will be reported in the next report. Brook trout
condition was examined using relative weight condition
factors (Wr). 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 = 89-101). Condition factors declined from 1983 to
1986 and improved in 1987. Statistical analysis of this
data is in progress and will be reported in the next
report.

Element 9 - Fish Parasite Studies

This element was dropped from the work plan in 1987.
Progress was made in finalizing the data from previous
years for publication and for comparison with studies to
be conducted after the ELF antenna becomes fully
operational.

V.   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, and fish pathogen and parasite loads. 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 are more likely to be important in stream orgainisms; 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). 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.

For each site 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 organism processes which will help clarify a number of important aspects of current conceptual models of stream ecosystem structure and function.

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FORD RIVER

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FORD RIVER STUDY AREA

FCD

1KM
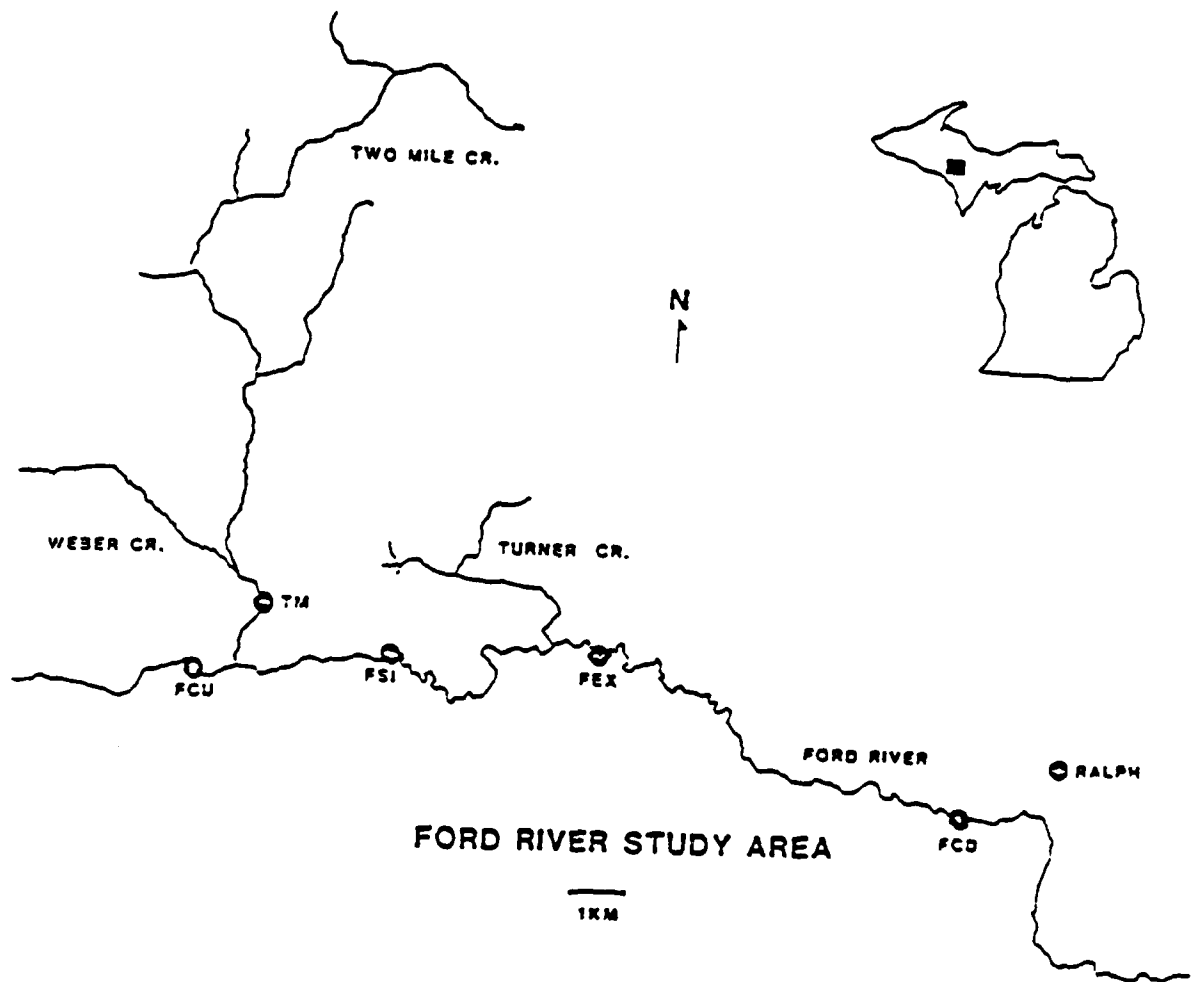
A. Map of the Ford River study sites for the Aquatic Studies Group.

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VI. 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 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 packs 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 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 coridor that occur as a result of ELF electromagnetic fields;
   (3) To quantify any changes in the rates of parasitism of one mobile species (longnose dace) and one sessile species (mottled (sculpin) of fish that occur as a result of ELF.

VII. 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 and suspended solids, 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, total dissolved solids, chloride, etc.). As correlations between many of these parameters are to be expected, it should be possible to eliminate some of them.
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) to document trends and variability in each parameter. We will also emphasize correlations between related measurements (e.g. turbidity and suspended solids, total dissolved solids and specific conductance, etc.) and will suggest changes in the future monitoring program based on these correlations.

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 (models DP 211 and DP 213) 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 constantcy of solar input between the two sites, led to the decision to cease measurement of solar radiation at one of the 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 plan to return these meters and probes to the manufacturer for repair over the winter.

(3) pH using the Altex (Beckman) Monitor II System with specially built long term, gel-filled submersible pH probes from Fisher Scientific. These meters continue to give us problems as reported in the last annual report. Again, the meters will be sent back to the manufacturer for repair over the winter.

(4) 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.

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

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 were read and summarized every two weeks throughout the April to October period. Daily summary data were supplied to each task investigator (periphyton, insects, fish tasks) as computer printouts and were archived on the Apple diskettes at 30 minute intervals throughout each day.

In addition to the manual determinations of pH,

dissolved oxygen, water and air temperature as described
above, samples were taken twice weekly for turbidity and
suspended and dissolved solids. Once per week,
alkalinity, hardness, and specific conductance were
determined in the field laboratory. 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 Kjehldahl N minus
ammonium), chloride, and dissolved silicate-Si (Si
samples were refrigerated instead of being frozen since
freezing can cause interference with this procedure).
The N, P, Si, and Cl samples were analyzed during the
winter months after preparation of the annual report.
Thus,there is a one year lag time in reporting these
data. Quality control was assured as reported in the
last annual report by addition of known quantities of
each chemical constituent to duplicates of samples from
at least one of the two sites each week. Recovery of
these spikes indicated that analytical procedures were
precise (see last year's report). Recoveries are
calculated each year to insure the integrity of the
analytical procedures. During winter months, samples
were taken at one month intervals for all of the
parameters discussed above. This interval will be
decreased to once every other month starting in 1987-88
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
1979a). Quality control procedures follow the
recommendations of the EPA also (U.S. EPA 1979b).

Stream discharge was determined from stage (water
level) - discharge relationships determined for each
station using 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 20 of these determinations have
been made at various stage heights each season to insure
that the relationship has not changed from previous
years. Discharge values were highly predictable from
stage height data using calculated regressions with R^2

values greater than 0.98 for FEX and 0.99 for FCD.

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.

Results and Discussion

A. Field Chemistry

The dissolved oxygen (DO) data for the last 4.5 years followed a highly predictable pattern at both sites with winter highs and summer lows (Fig. 1.1). In general, winter values were higher than 11 mg/L and summer values never dropped below 7 mg/L. 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 was highly, negatively correlated with temperature at each site ($r = -0.96$ and -0.94 at FCD and FEX respectively, $p<0.05$ at both sites). Daily values of DO for 1987 at each site showed the expected relationship with temperature (Fig. 1.2) with decreases to lows in June, July, and August correlated with times of warmest water temperatures. There was a significant ($p<0.01$) correlation ($r = 0.97$) in dissolved oxygen values between the two sites (Table 1.1) as illustrated by Figure 1.1. Despite this high degree of correlation, paired t tests indicated that there were significant differences ($p<.001$) between the two sites (Table 1.1) with FEX generally having slightly higher values than did FCD. These slight differences were probably related to the use of manually acquired data in these correlations. Travel time between sites would lead to some warming or cooling leading to these differences. The ideal is to match values for the two sites based on time of collection from the automatically acquired data. However, automatically acquired data from the first two years still have to be summarized, since summaries were not prepared routinely at that time. We expect to complete these summaries
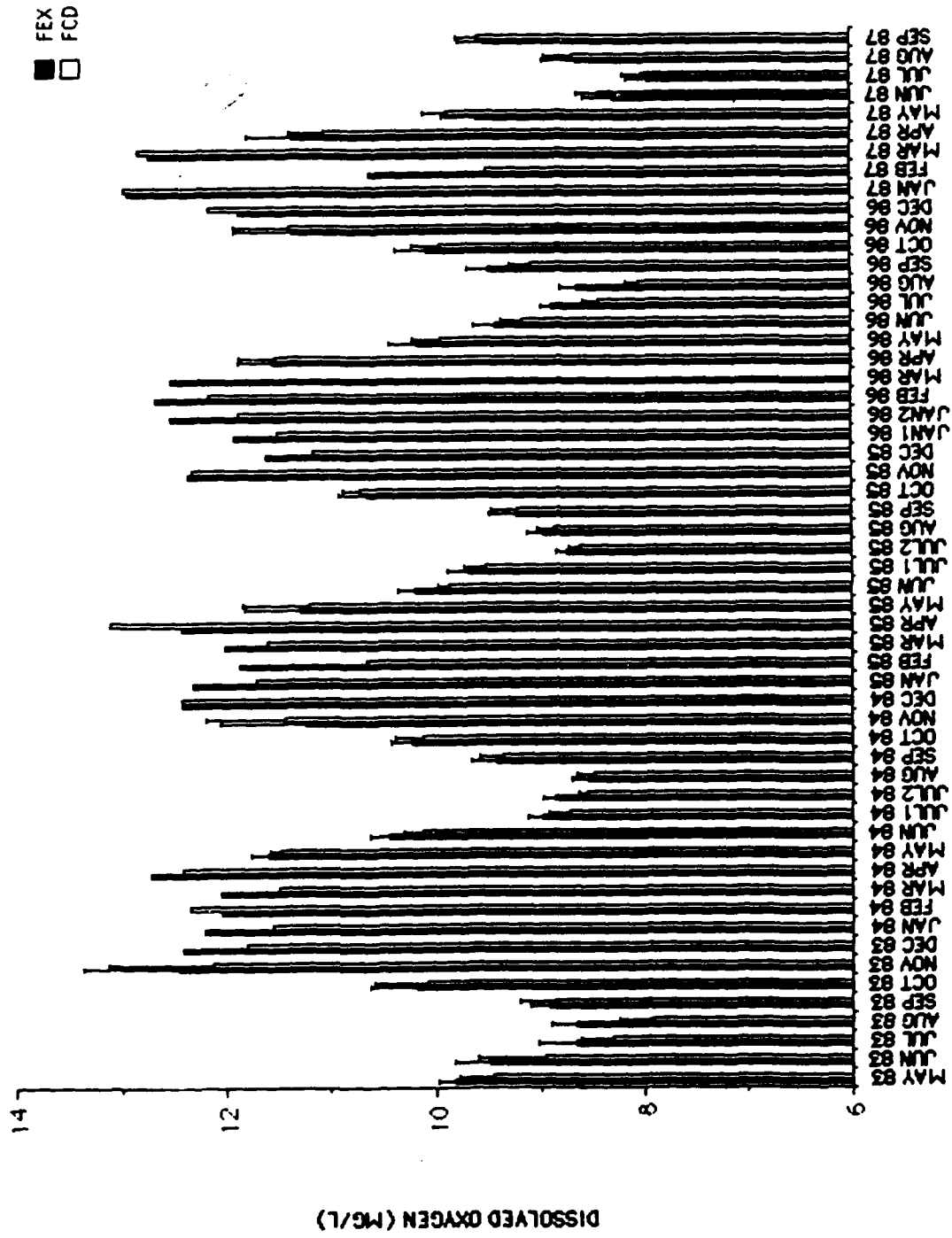
FIGURE 1.1   Mean Dissolved Oxygen Levels (+ S.E.) over 28 Day
Sampling Periods for Experimental (FEX) and
Control (FCD) Sites from the Ford River, 1983-87.

during the coming year. Even so, data from 1987 will
still probably have to be derived from manual
determinations since the probe at FEX gave highly
variable results (Fig. 1.2). Differences between the two
sites, even if real, are 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 pH data for the two sites followed a pattern of
summer highs and winter lows (Fig. 1.3) probably related
to higher levels of primary production in the summer (see
element 2) coupled with higher temperatures, lower stream
discharge, and higher values for alkalinity and hardness
(pH was significantly ($p<0.05$) correlated with all these
parameters with r values of 0.6 or higher for both sites
in all cases). Because of the large number of samples
taken since 1983, any r value greater than 0.3 is
significant at the $p<0.05$ level for all of the water
quality parameters. The most highly correlated
parameters with pH were alkalinity with r's greater than
0.96 at both sites and discharge with r's greater than
-0.84 at both sites. The pH values at the two sites were
significantly correlated with each other, and there were
no significant differences between sites (Table 1.1).
Automatically acquired data for the two sites for 1987
were of poor quality as they had been in 1986 and are not
presented. Thus, the data presented in Fig. 1.3 are data
from the manual, twice per week determinations.
Hopefully, repair of the pH meters will lead to higher
quality, automatically acquired data in 1988.

Alkalinity and hardness followed similar trends for
the two sites (Table 1.2. Figs. 1.4, 1.5) with high
values occurring during times of low flows and low values
occurring during times of high flows (Fig. 1.6, 1.7).
Correlation coefficients support these observations with
r values between discharge and either alkalinity or
hardness greater than -0.84 at both sites for both
parameters ($p<0.05$). Since these parameters are
correlated with discharge, other parameters correlated
with discharge also are correlated with hardness and
alkalinity. These include significant ($p<0.05$) positive
correlations with specific conductance, pH, temperature,
and dissolved solids amd significant negative
correlations with dissolved oxygen and turbidity for both

Table 1.1 Correlation Coefficients and t-test Values (Paired-t) for Water Chemical Constituents and Ambient Parameters Between Control (FCD) and Experimental Sites (FEX) and From 1983-87 (N ≥ 50).

Parameter	Correlation Coefficients r	Paired t-Value
Conductivity	.79**	-.006
Dissolved Oxygen	.97**	4.75***
Hardness	.99**	-2.39*
pH	.90**	.99
Alkalinity	.99**	1.36
Dissolved Solids	.77**	-1.36
Suspended Solids	.56**	1.17
Turbidity	.88**	-1.15
Water Temperature	.99**	-2.10*

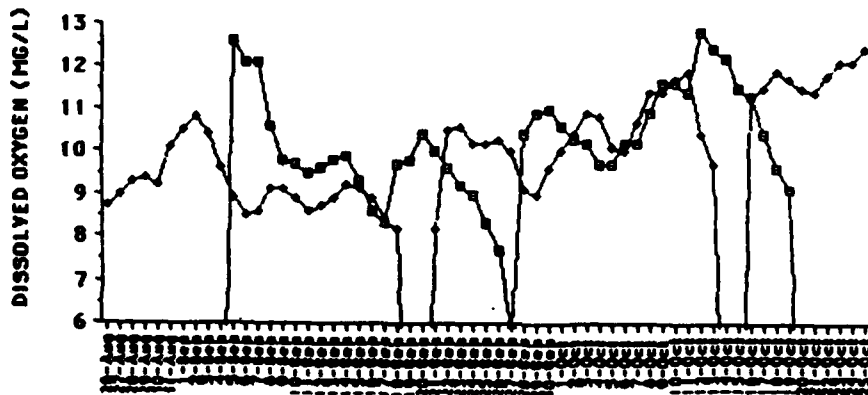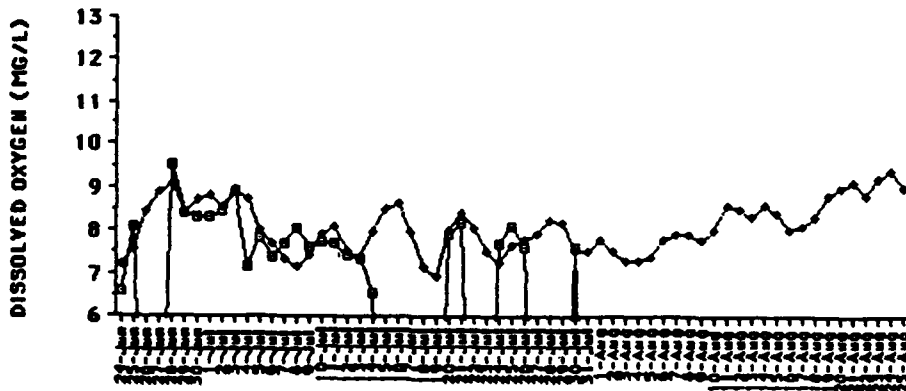*, p < 0.05; **, p < 0.01; ***, p < 0.001

23
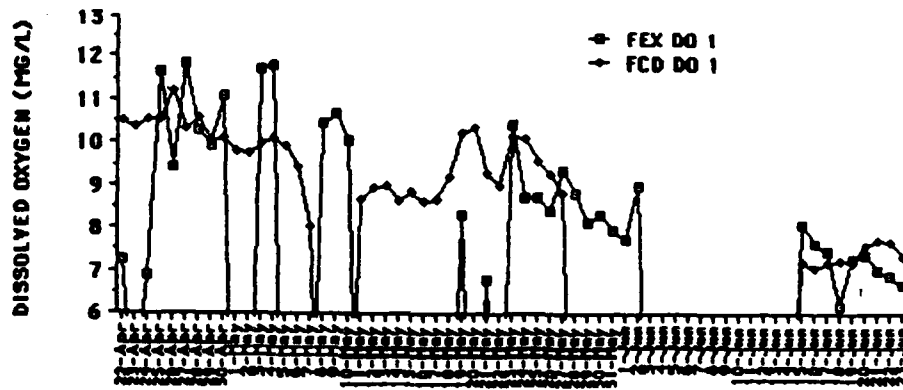
FIGURE 1.2   Mean Daily Dissolved Oxygen Levels for
Experimental and Control (FCD) Sites from the
Ford River, 1987.

FIGURE 1.3   Mean pH values (+ S.E.) over 28 Day Sampling Periods for Experimental (FEX) and Control (FCD) Sites from the Ford River, 1983-87.

sites. There are significant negative correlations between both alkalinity and hardness and suspended solids at FCD but not at FEX. As expected, hardness and alkalinity are highly correlated with each other (r>0.96, p<0.05) 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 is highly correlated with alkalinity at FEX (r=0.99, p<0.01), and there is no signficant difference between the sites (Table 1.1). Hardness is just as highly correlated between the sites, and there is a significant difference between the sites (Table 1.1). Hardness at FCD is slightly, but significantly, greater than at FEX. This increase may be related to the expected increase in cations in a downstream direction.

Conductivity is significantly (p<0.05) , negatively correlated with discharge at both sites (r = -0.81 and -0.76 at FEX and FCD respectively) and positively correlated with both alkalinity and discharge at both sites (r greater than 0.78). Thus, the pattern for conductivity (Fig. 1.8, Table 1.3) is very similar to the patterns exhibited by alkalinity and hardness (Figs. 1.4, 1.5). Conductivity values at FEX are highly correlated (p<0.01) with conductivity values at FCD, and there are no signifcant diferences between sites (Table 1.1).

Turbidity (Table 1.3, Fig. 1.9) and suspended solids (Table 1.4, Fig. 1.10) should be highly correlated. These correlations are significant (r=0.64 and 0.75, p<0.05 at FEX and FCD respectively), but the r values are not as high as one might expect. These lower r values are probably a function of highly variable suspended solids data collected in 1983 and 1984 (Fig. 1.10). At that time, an insufficient volume of water was being filtered to yield enough dry weight for precise measurement. The volume of sample filtered was increased in the summer of 1984, and the quality of the data increased accordingly (Fig. 1.10). Turbidity and suspended solids values are always relatively low reflecting the excellent water quality of the Ford River. These low values may also be partially responsible for the lowered correlation coefficients between turbidity and suspended solids. Even so, the correlations are robust enough to allow us to drop suspended solids

Table 1.2 Alkalinity and Hardness (mg CaCO$_3$/L) for the Ford River. Values are Means ± S.E., N in Parentheses.

Date	Control Site (FCD)		Experimental Site (FEX)	
	Hardness	Alkalinity	Hardness	Alkalinity
10/9/86	164 ± 3 (4)	147 ± 2 (4)	164 ± 3 (4)	146 ± 1 (4)
11/12/86	144 ± 20 (2)	126 ± 18 (2)	145 ± 20 (2)	122 ± 18 (2)
12/11/86	176 (1)	151 (1)	171 (1)	157 (1)
1/9/87	170 (1)	162 (1)	173 (1)	161 (1)
2/6/87	178 (1)	159 (1)	179 (1)	162 (1)
3/6/87	178 (1)	166 (1)	179 (1)	158 (1)
4/27/87	138 ± 17 (2)	124 ± 17 (2)	133 ± 13 (2)	117 ± 13 (2)
5/1/87	156 ± 6 (3)	131 ± 9 (4)	156 ± 8 (3)	128 ± 10 (4)
6/22/87	142 ± 5 (4)	128 ± 7 (4)	141 ± 5 (4)	127 ± 8 (4)
7/20/87	152 ± 13 (5)	140 ± 19 (4)	154 ± 13 (5)	141 ± 19 (4)
8/31/87	162 ± 9 (4)	144 ± 11 (4)	160 ± 7 (4)	155 ± 2 (4)
9/28/87	178 ± 2 (4)	166 ± 2 (4)	180 ± 2 (4)	166 ± 4 (4)

FIGURE 1.4 Mean Alkalinity (± S.E.) over 28 Day Sampling
Periods for Experimental (FEX) and Control (FCD)
Sites from the Ford River, 1983-87.

ALKALINITY (MG CACO3/L)

28
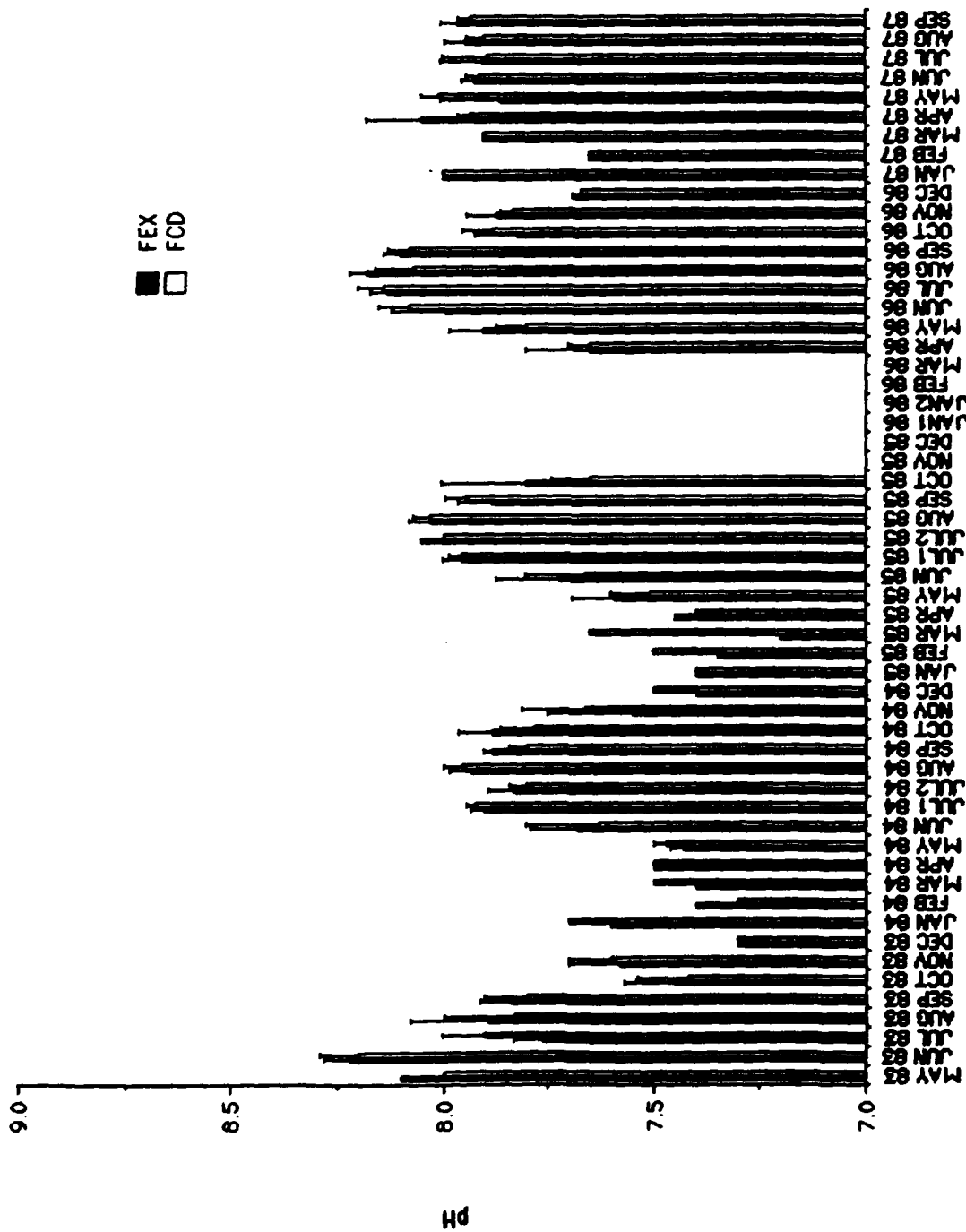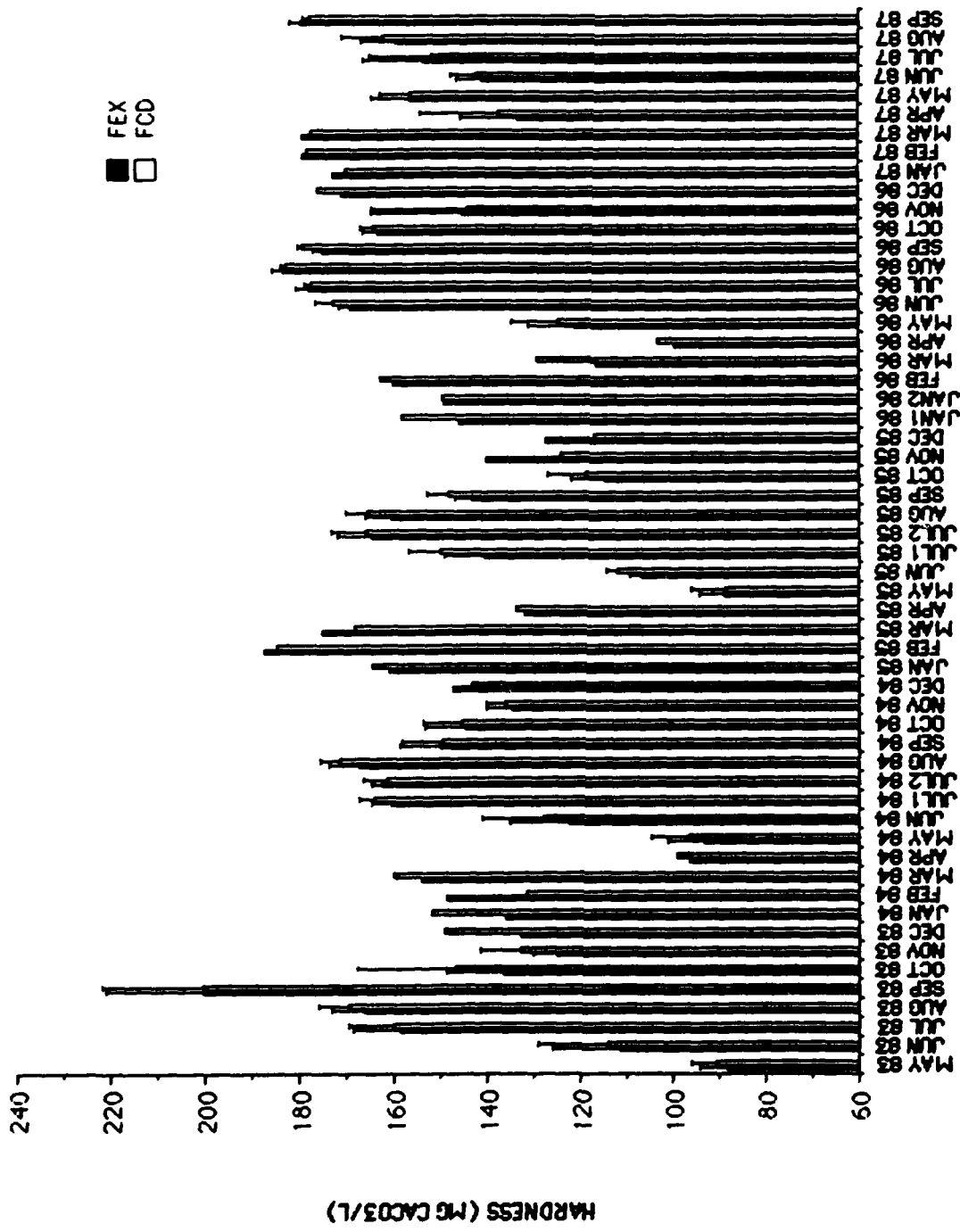
FIGURE 1.5   Mean Hardness (± S.E.) over 28 Day Sampling
Periods for Experimental (FEX) and Control (FCD)
Sites from the Ford River, 1983-87.

29
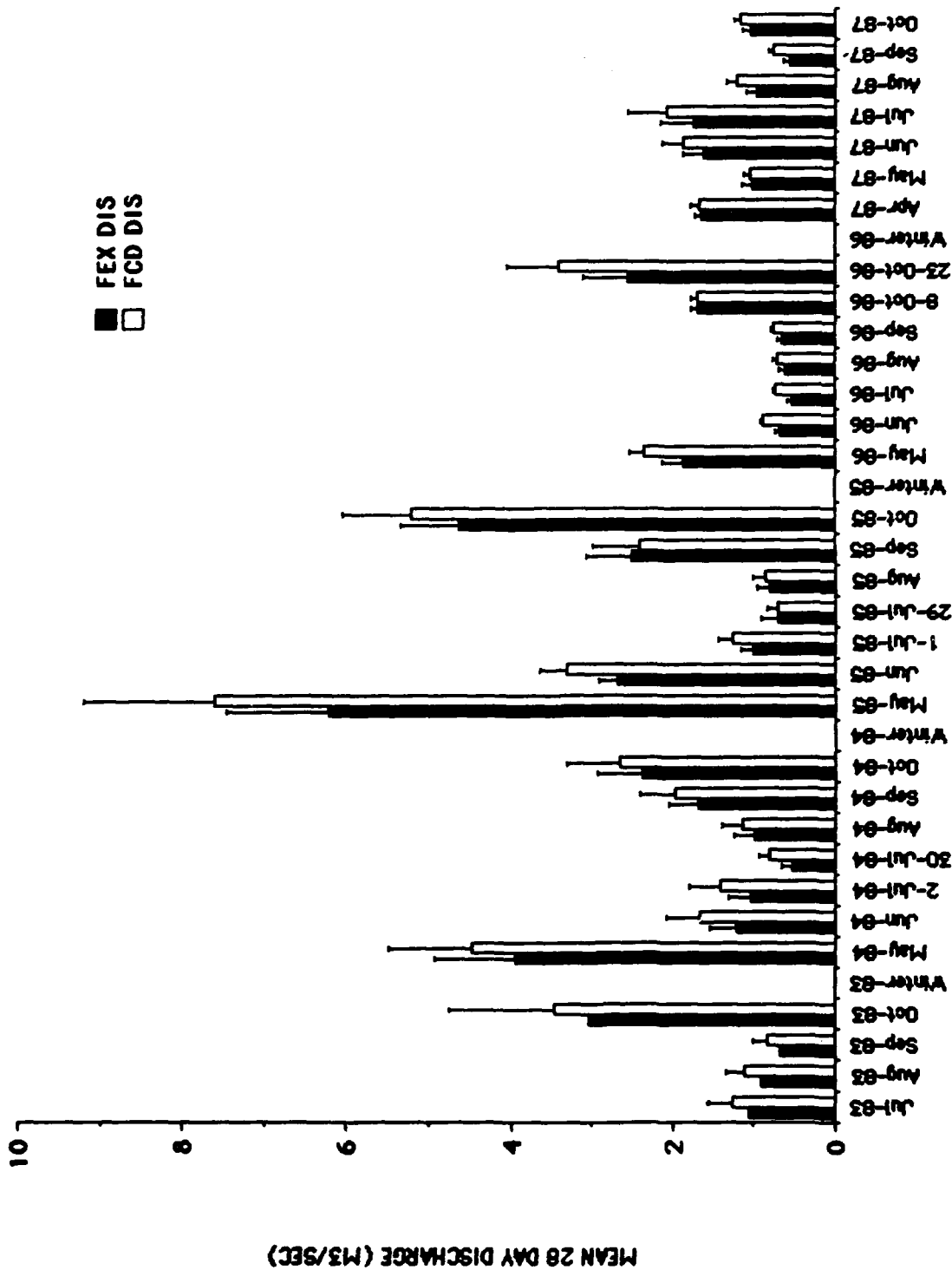
FIGURE 1.6   Mean Discharge (± S.E.) over 28 Day Sampling
Periods for Experimental (FEX) and Control (FCD)
Sites from the Ford River, 1983-87.
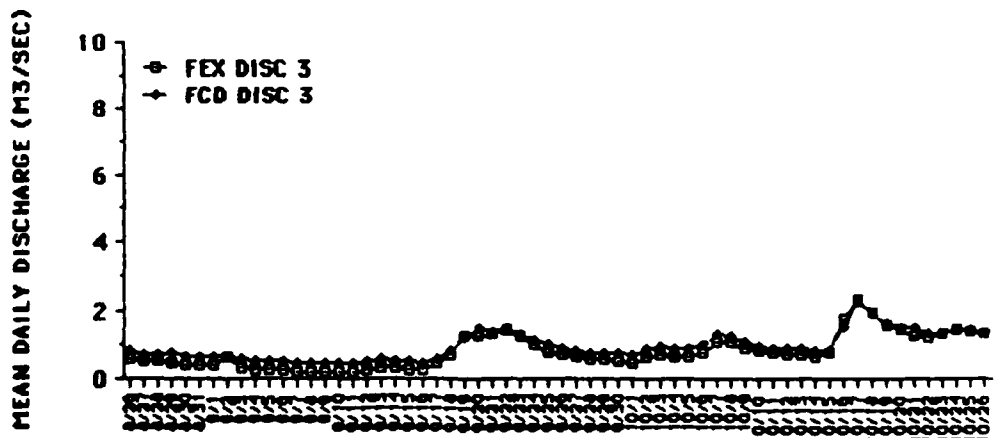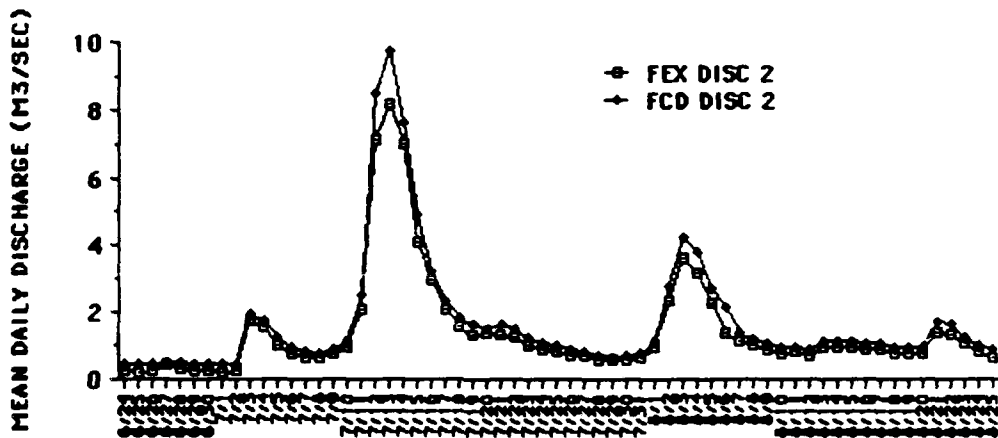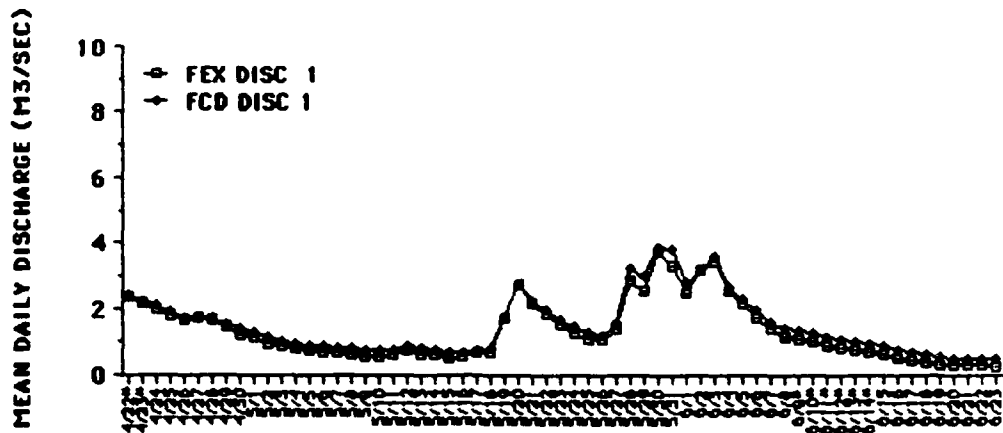
FIGURE 1.7   Mean Daily Discharge for Experimental (FEX) and
Control (FCD) Sites from the Ford River, 1987.
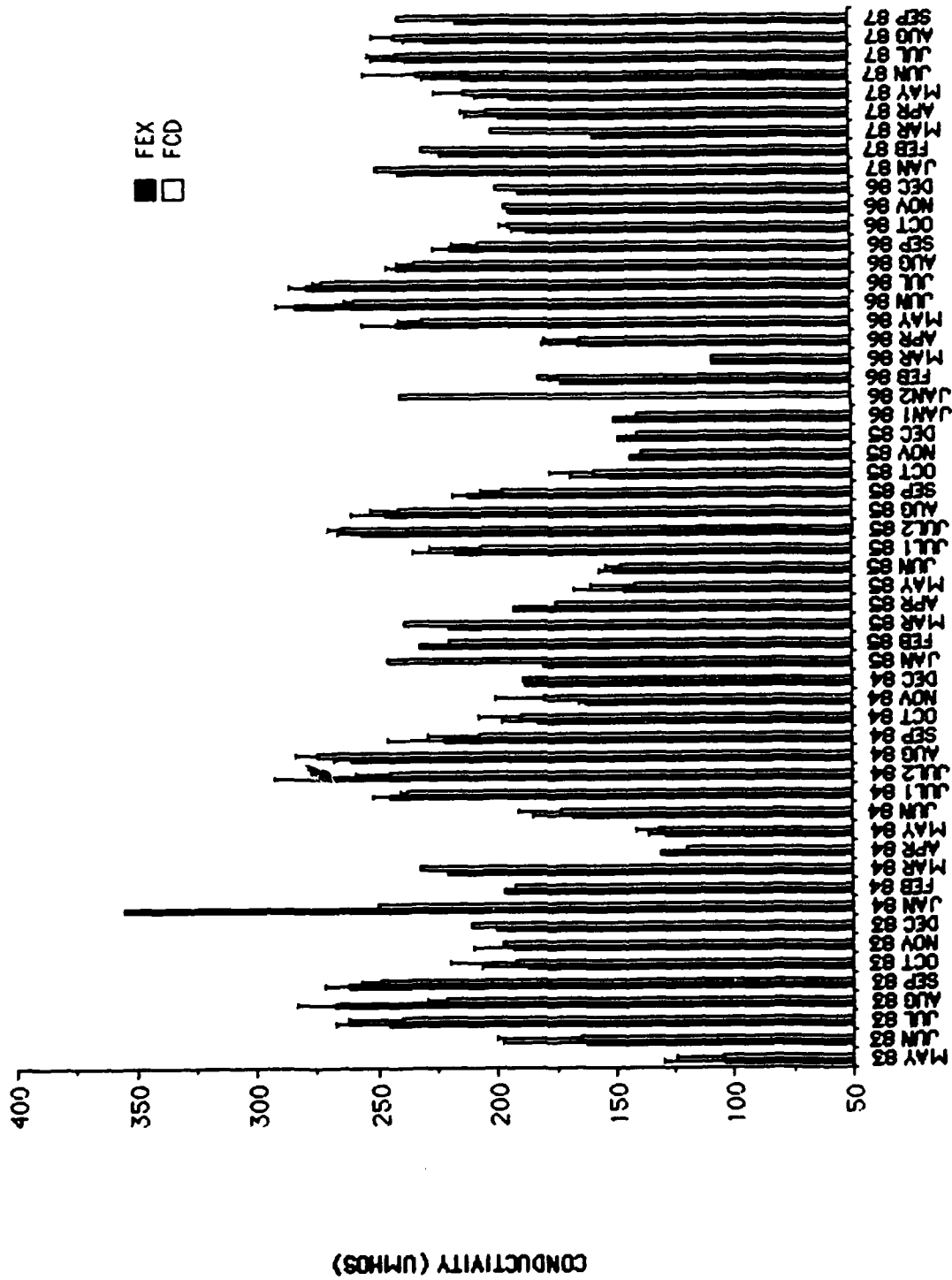
FIGURE 1.8   Mean Conductivity (± S.E.) over 28 Day Sampling
Periods for Experimental (FEX) and Control (FCD)
Sites from the Ford River, 1983-87.

CONDUCTIVITY (UMHOS)

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Table 1.3 Conductivity (umhos/cm) and Turbidity (NTU's) for the Ford River. Values are Means ± S.E., N in Parentheses.

Date	Control Site (FCD)		Experimental Site (FEX)	
	Conductivity	Turbidity	Conductivity	Turbidity
10/9/86	208 ± 10 (4)	1.1 ± 0.1 (7)	219 ± 6 (4)	1.5 ± 0.5 (8)
11/12/86	194 ± 4 (2)	2.5 (1)	186 ± 6 (2)	2.1 (1)
12/11/86	196 (1)	0.9 (1)	194 (1)	0.8 (1)
1/9/87	199 (1)	2.2 (1)	190 (1)	1.7 (1)
2/6/87	250 (1)	1.0 (1)	240 (1)	1.0 (1)
3/6/87	230 (1)	3.0 (1)	222 (1)	2.5 (1)
4/27/87	201 (1)	2.2 ± 1.2 (3)	158 (1)	1.7 ± 0.7 (3)
5/26/87	203 ± 11 (4)	1.3 ± 0.1 (8)	198 ± 14 (4)	1.2 ± 0.1 (8)
6/22/87	212 ± 13 (4)	1.8 ± 0.3 (8)	193 ± 15 (4)	1.7 ± 0.2 (8)
7/20/87	232 ± 22 (5)	1.7 ± 0.3 (8)	213 ± 16 (5)	1.5 ± 0.2 (8)
8/31/87	241 ± 11 (4)	1.1 ± 0.2 (8)	237 ± 14 (4)	1.1 ± 0.1 (8)
9/28/87	242 ± 9 (4)	0.8 ± 0.1 (5)	228 ± 9 (4)	0.8 ± 0.1 (5)

analyses from our work plan for the coming year. Suspended solids analyses are time consuming, do not correlate strongly with biological parameters, and are always well below the 30 mg/L (Fig. 1.10, Table 1.4) that trout are known to tolerate with no problem (McKee and Wolf 1963). The correlation of suspended solids with turbidity will enable us to detect any potential problems from upstream erosion linked to construction or other such activities should they occur in the future. Thus, we will delete this parameter from our work plan in 1988. Turbidity at FEX is highly correlated with turbidity at FCD, and there are no significant differences between the two sites (Table 1.1). Suspended solids at FEX is significantly correlated with suspended solids at FCD but the r value is much lower than it is for other field chemistry parameters (Table 1.1). There are no significant differences in suspended solids between FEX and FCD.

Total dissolved solids (TDS) are generally low at times of high discharge because of dilution effects (compare Figs. 1.11 with 1.6 and Table 1.4 with Fig. 1.7). Thus, the pattern for TDS is similar to the patterns for alkalinity (Fig.1.4), hardness (Fig. 1.5), and conductivity (Fig. 1.8), and the same significant correlations exist between TDS and other field chemistry parameters as has already been discussed for the other parameters above. TDS at FEX is significantly correlated with TDS at FCD, and there are no significant differences in TDS between the two sites (Table 1.1). Given the significant correlations between TDS and conductivity, hardness, alkalinity, and pH, we propose to delete this analysis from our work plan for 1988. Like suspended solids, this analysis is time consuming, correlates well with other field chemistry parameters, and does not correlate well with biological data. Thus, dropping it seems reasonable.

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 1987.

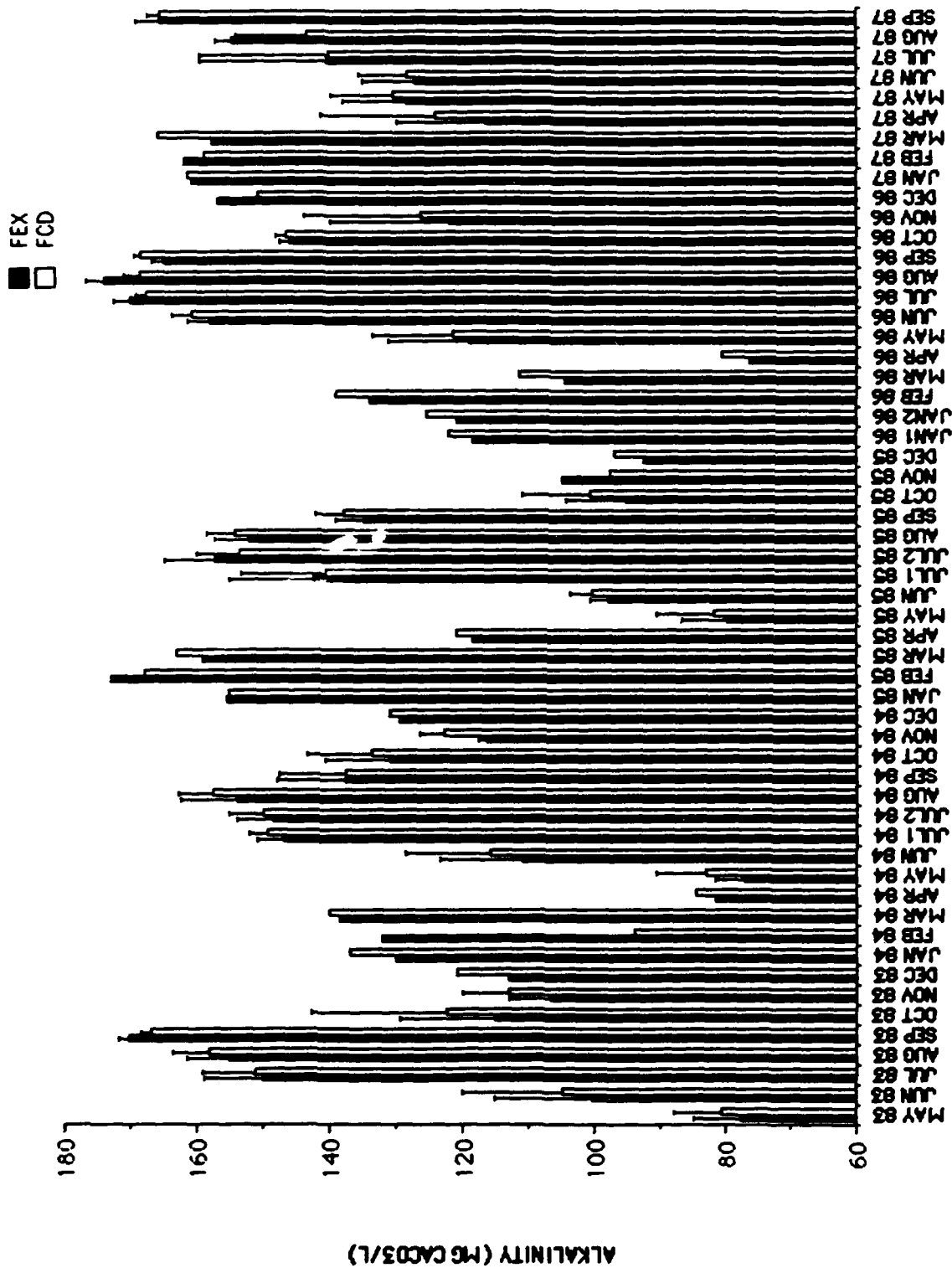Trends in total phosporus were not obvious because of high variablity of this constituent (Fig. 1.12, Table
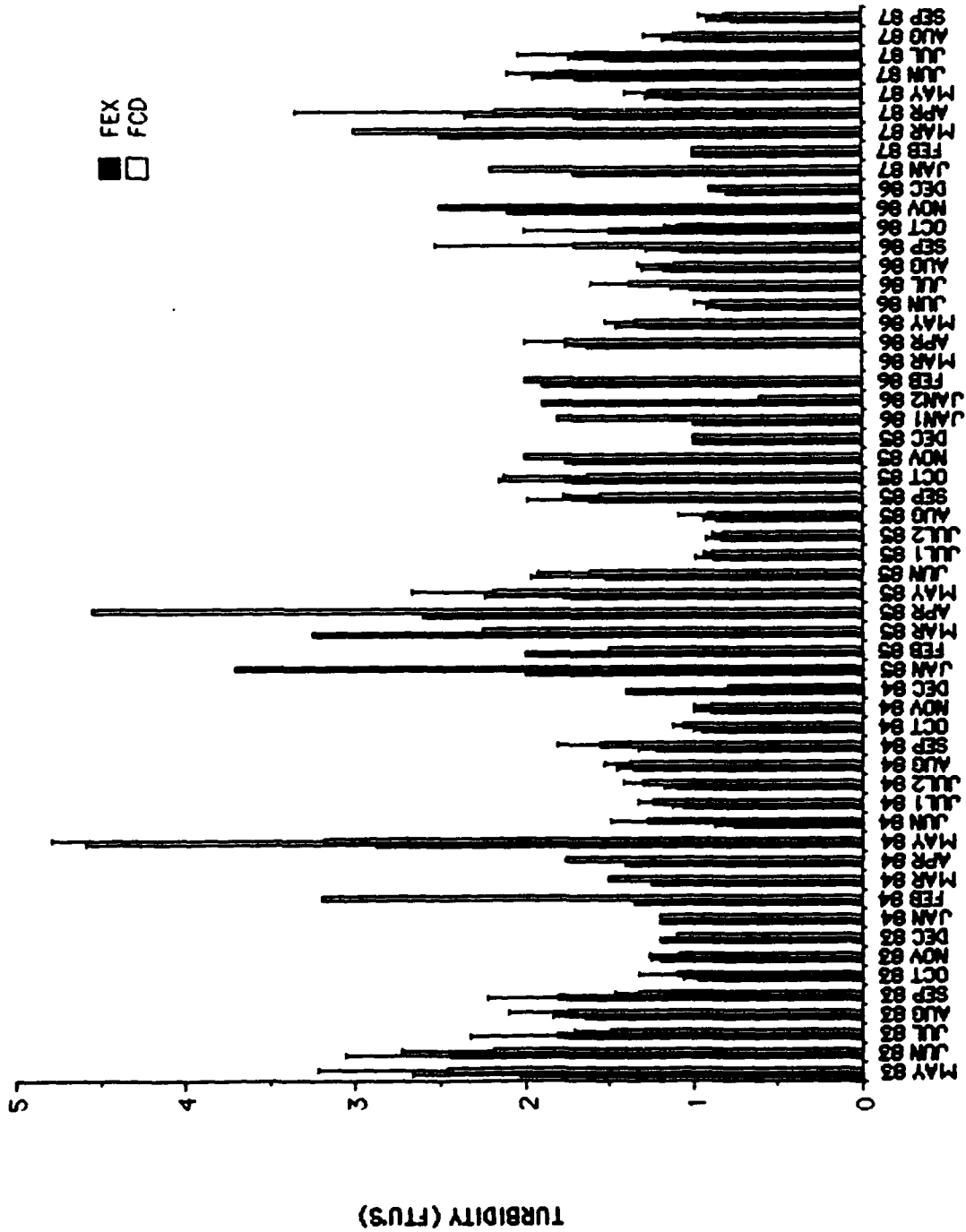
FIGURE 1.9   Mean Turbidity (± S.E.) over 28 Day Sampling Periods for Experimental (FEX) and Control (FCD) Sites from the Ford River, 1983-87.

Table 1.4   Suspended Solids and Dissolved Solids (mg/L). Values are Means ± S.E., N in Parentheses.

Date	Control Site (FCD)		Experimental Site (FEX)	
	Susp. Solids	Diss. Solids	Susp. Solids	Diss. Solids
10/9/86	1.9 ± 1.6 (6)	212 ± 8 (6)	3.3 ± 2.0 (6)	206 ± 2 (6)
11/12/86	1.0 ± 0.3 (3)	182 ± 10 (3)	1.3 ± 0.6 (3)	179 ± 8 (3)
12/11/86	0.8 (1)	209 (1)	0.8 (1)	217 (1)
1/9/87	0.6 (1)	179 (1)	0.1 (1)	194 (1)
2/6/87	0.3 (1)	231 (1)	0.4 (1)	220 (1)
3/6/87	0.8 (1)	209 (1)	0.1 (1)	203 (1)
4/27/87	1.5 ± 0.2 (3)	169 ± 35 (3)	3.0 ± 0.4 (3)	220 ± 69 (3)
5/21/87	2.3 ± 0.4 (8)	165 ± 14 (8)	2.1 ± 0.2 (8)	203 ± 23 (8)
6/22/87	2.8 ± 0.8 (8)	257 ± 73 (8)	2.7 ± 0.5 (8)	184 ± 7 (8)
7/20/87	2.0 ± 0.2 (7)	188 ± 14 (7)	2.0 ± 0.4 (6)	211 ± 22 (6)
8/27/87	1.6 ± 0.8 (6)	247 ± 33 (6)	1.3 ± 0.5 (7)	232 ± 24 (7)
9/28/87	0.6 ± 0.2 (8)	184 ± 10 (8)	0.4 ± 0.1 (7)	180 ± 15 (7)

FIGURE 1.10   Mean Amounts of Suspended Solids (± S.E.) over 28 Day Sampling Periods for Experimental (FEX) and Control (FCD) Sites from the Ford River, 1983-87.

SUSPENDED SOLIDS (MG/L)
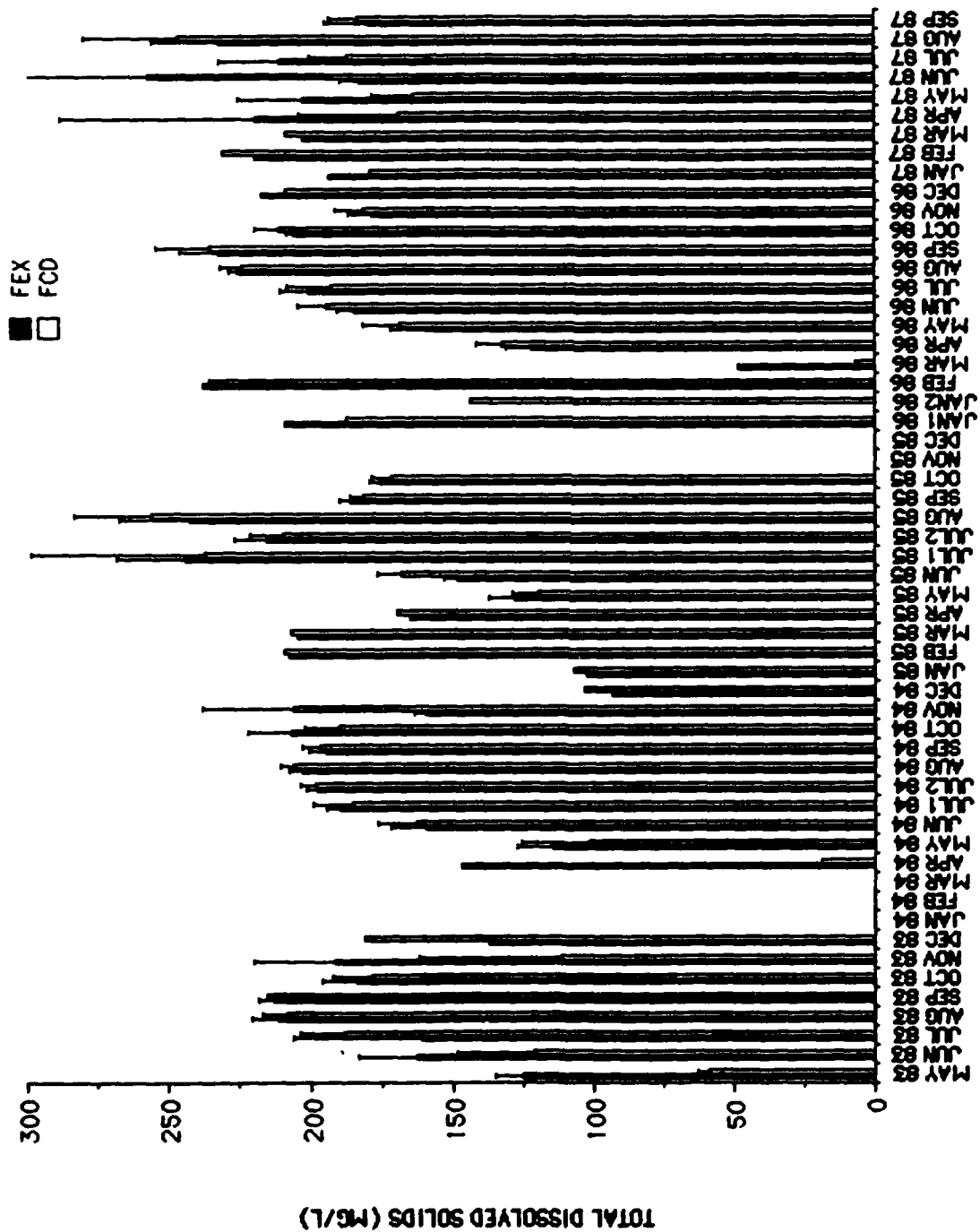
FIGURE 1.11   Mean Total Dissolved Solids (± S.E.) over 28 Day
Sampling Period for Experimental (FEX) and
Control (FCD) Sites from the Ford River,
1983-87.

1.5), although values appeared to be somewhat higher in the winter, spring, and summer in 1986 at FEX than they were in previous years. There was cultivation of a potato field that had been fallow for several years several kilometers upstream from FEX in 1986. However, the Michigan DNR operated a sediment trap between this field and FEX. No other land use changes were obvious, and this field is far enough away that any erosion from it was not likely to have been transported to our sites through this sediment trap and over a beaver dam upstream of FEX. Therefore, the apparent rise in total P at FEX during 1986 cannot be explained at this time. The values for total P were low enough to represent excellent water quality (Fig. 1.12). While we have not calculated land use for the watershed upstream of our two research sites, we know that there is some agricultural activity (potato fields, mink ranch) and some low density urban areas at Channing, Michigan but that most of the watershed is forested. These forests are harvested on relatively short rotation times, since the most common tree harvested is <u>Populus</u> <u>tremuloides</u>, an early successional species. Omernik (1977) related N and P levels in the streams of the U. S. to land use. The total P values of the Ford River were characteristic of values for the eastern U.S. (Omernik placed Michigan in this region) reflecting land use that is 50 to 90 % forest. Total P at FEX was not significantly correlated with total P at FCD (Table 1.6). Despite this lack of correlation and the apparent differences between sites in 1986, there was no significant difference in total P between sites when data from 1983 through 1986 were included in the analyses (Table 1.6).

Soluble reactive phosphorus (SRP) consistently stayed below 10 ug P/L except at FCD in late 1986 (Fig. 1.13, Table 1.5). There did appear to be an increase at FCD in 1986 that did not occur at FEX. Even so, there was no overall significant difference between FEX and FCD, and SRP at FEX was significantly correlated with SRP at FCD (Table 1.6). The SRP values for FEX and FCD (Fig. 1.13, 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. 1.14, 1.15, 1.16, Table 1.7). However, there was a divergence in

Table 1.5   Soluble Reactive Phosphorus (ug P/l) and Total Phosphorus (ug P/l) for the Ford River for 1986. Values are Means ± S.E., N in parentheses.

	Experimental Site (FEX)		Control Site (FCD)	
Dates	Soluble Reactive P	Total P	Soluble Reactive P	Total P
1-3-86	4.30 ± (1)	64.00 ± (1)	4.10 ± (1)	6.00 ± (1)
1-31-86	3.70 ± (1)	26.00 ± (1)	4.50 ± (1)	5.00 ± (1)
2-28-86	3.90 ± (1)	32.00 ± (1)	6.70 ± (1)	7.00 ± (1)
3-28-86	4.20 ± (1)	34.00 ± (1)	6.10 ± (1)	10.00 ± (1)
4-25-86	4.30 ± (1)	55.00 ± (1)	6.30 ± (1)	46.00 ± (1)
5-19-86	4.50 ± (7)	48.00 ± 14.0 (7)	6.50 ± 1.20 (6)	18.00 ± 3.00 (7)
6-16-86	4.60 ± .20 (8)	46.00 ± 11.0 (8)	7.60 ± 1.20 (8)	20.00 ± 3.00 (8)
7-14-86	4.50 ± .20 (7)	44.90 ± 7.53 (8)	7.90 ± 1.70 (7)	16.00 ± 3.00 (8)
8-14-86	4.10 ± .10 (8)	38.00 ± 5.00 (9)	4.90 ± .10 (9)	32.00 ± 3.00 (9)
9-11-86	5.56 ± .36 (7)	17.00 ± 5.00 (8)	5.70 ± .90 (8)	43.00 ± 15.00 (8)
10-9-86	7.30 ± .20 (7)	17.00 ± 5.00 (8)	10.40 ± 1.80 (8)	34.00 ± 4.00 (7)
11-12-86	9.20 ± .70 (4)	15.00 ± 5.00 (4)	15.10 ± 2.20 (3)	23.00 ± 1.00 (4)
12-11-86	6.90 ± (1)	10.00 ± (1)	20.30 ± (1)	21.00 ± (1)

Table 1.6   Results of Paired t-tests and Correlations on Nutrient Chemistry Parameters from 1983-86 Between Control (FCD) and Experimental (FEX) sites.

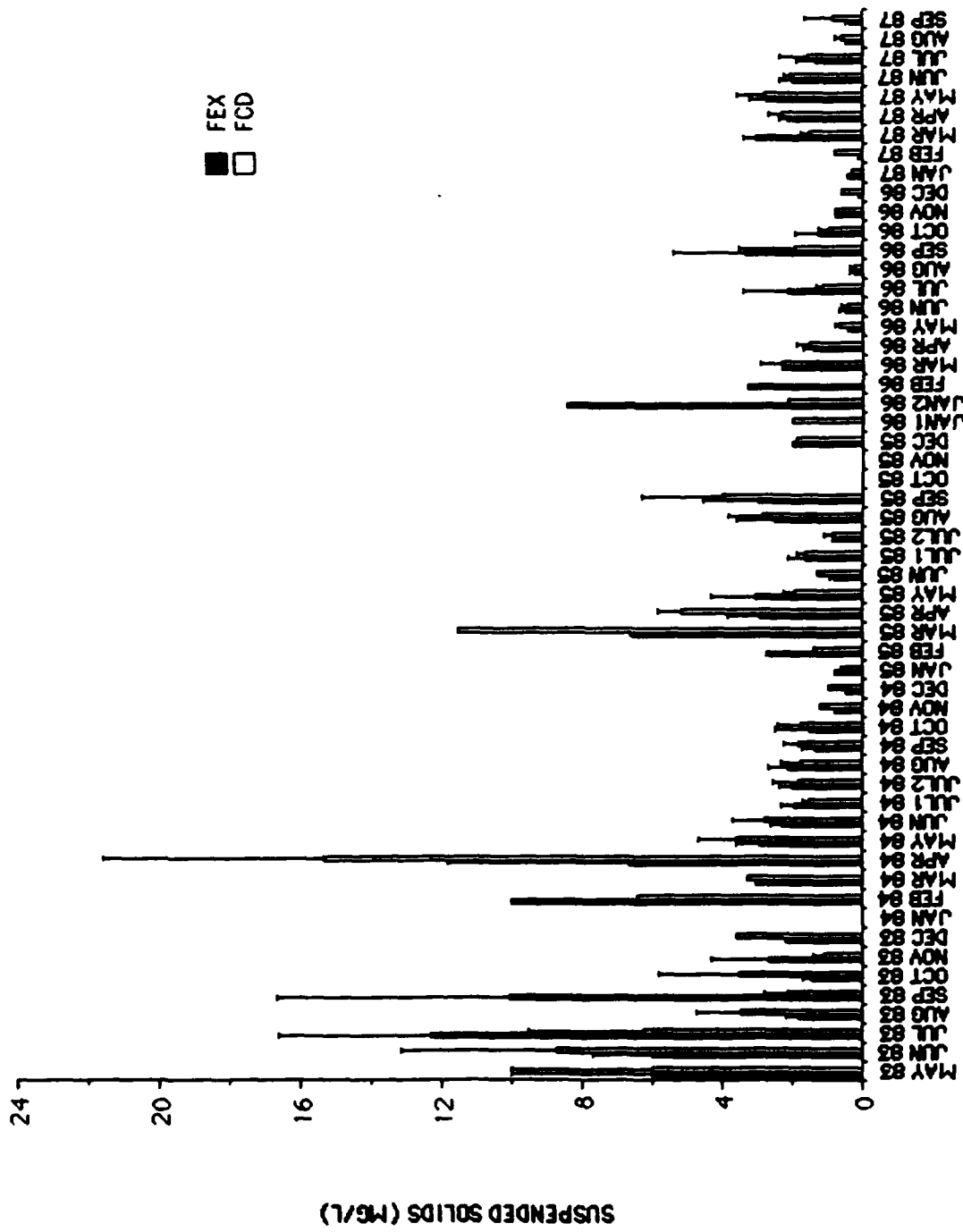| Parameter	Paired t Value	df	Probability	Correlation Coefficient (r)	Probability
Organic Nitrogen	-2.781	41	$P < .01$	.44	$P < .01$
Inorganic Nitrogen	-1.566	37	NS	.72	$P < .01$
Ammonium-N	0.550	41	NS	.30	$P < .05$
Nitrate-N	-2.819	40	$P < .01$	.77	$P < .01$
Nitrite-N	1.248	38	NS	.31	$P < .05$
Total Phosphorus	0.654	39	NS	-.20	NS
Soluble Reactive-P	-0.743	35	NS	.75	$P < .01$
Silicate-Si	0.743	39	NS	.92	$P < .01$
Chloride	2.488	40	$P < .05$	.89	$P < .01$

FIGURE 1.12   Mean Total Phosphorus Values (± S.E.) over 28 Day Sampling Period for Experimental (FEX) and Control (FCD) Sites from the Ford River, 1983-87.
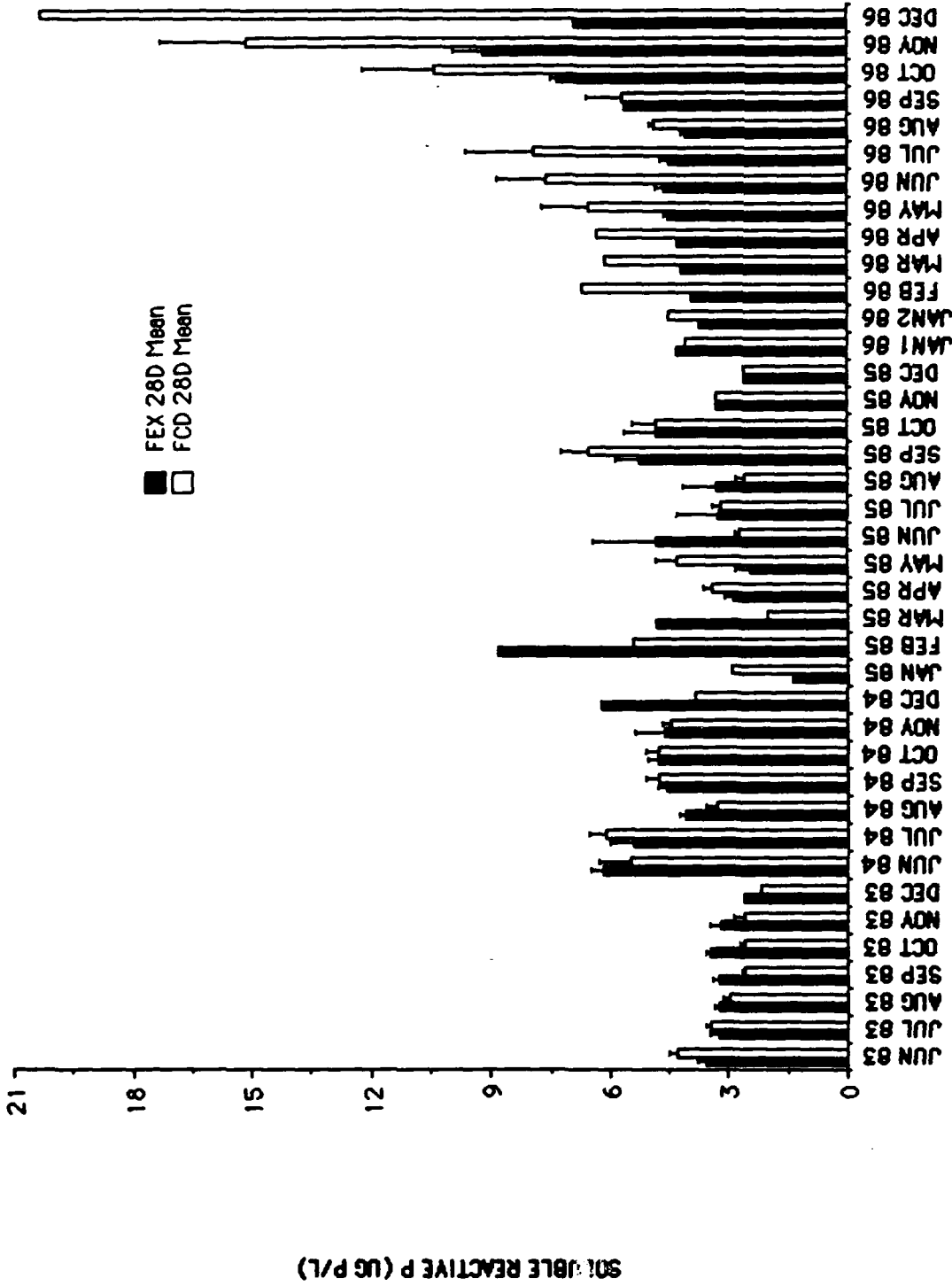
FIGURE 1.13   Mean Soluble Reactive Phosphorus (± S.E.) over 28 Day Sampling Periods for Experimental (FEX) and Control (FCD) Sites from the Ford River, 1983-87.

SOLUBLE REACTIVE P (UG P/L)

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nitrate-N values between the two sites in 1985 (Fig. 1.14), 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 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). Nitrate is the predominant form of inorganic nitrogen present in the Ford River. Thus, calculation of inorganic-N from the three components (Figs. 1.14, 1.15, 1.16) results in trends for inorganic-N very similar to those for nitrate-N (Fig. 1.17, Table 1.8). These patterns 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).

Even though nitrate-N values were significantly correlated between FEX and FCD, there was a significant difference between the two sites (Table 1.6). This significant difference may be related to the increase at FCD in 1985 already discussed above, or it might reflect the tendency for ions to increase in a downstream direction. FCD is downstream of FEX and had slightly higher concentrations of nitrate-N than did FEX both before and after the relatively large differences that were characteristic of 1985 (Fig. 1.14). There were no significant differences between the two sites for either nitrite or ammonium, and correlation coefficients between the two sites were low for these two parameters (Table 1.6, Figs. 1.15, 1.16). Inorganic-N values were not significantly different between the two sites either (Table 1.6) despite the fact that the significant differences in nitrate-N in 1985 led to increases in inorganic-N at FCD as compared to FEX (Fig. 1.17). Concentrations of inorganic-N at FEX were significantly correlated to concentrations at FCD (Table 1.6).

Organic nitrogen at FEX was significantly different from organic-N at FCD (Fig. 1.18, Table 1.6). Even so, differences between the two sites were usually small (Fig. 1.18). As was true for inorganic-N, total P, and SRP values, organic-N values were characteristic of
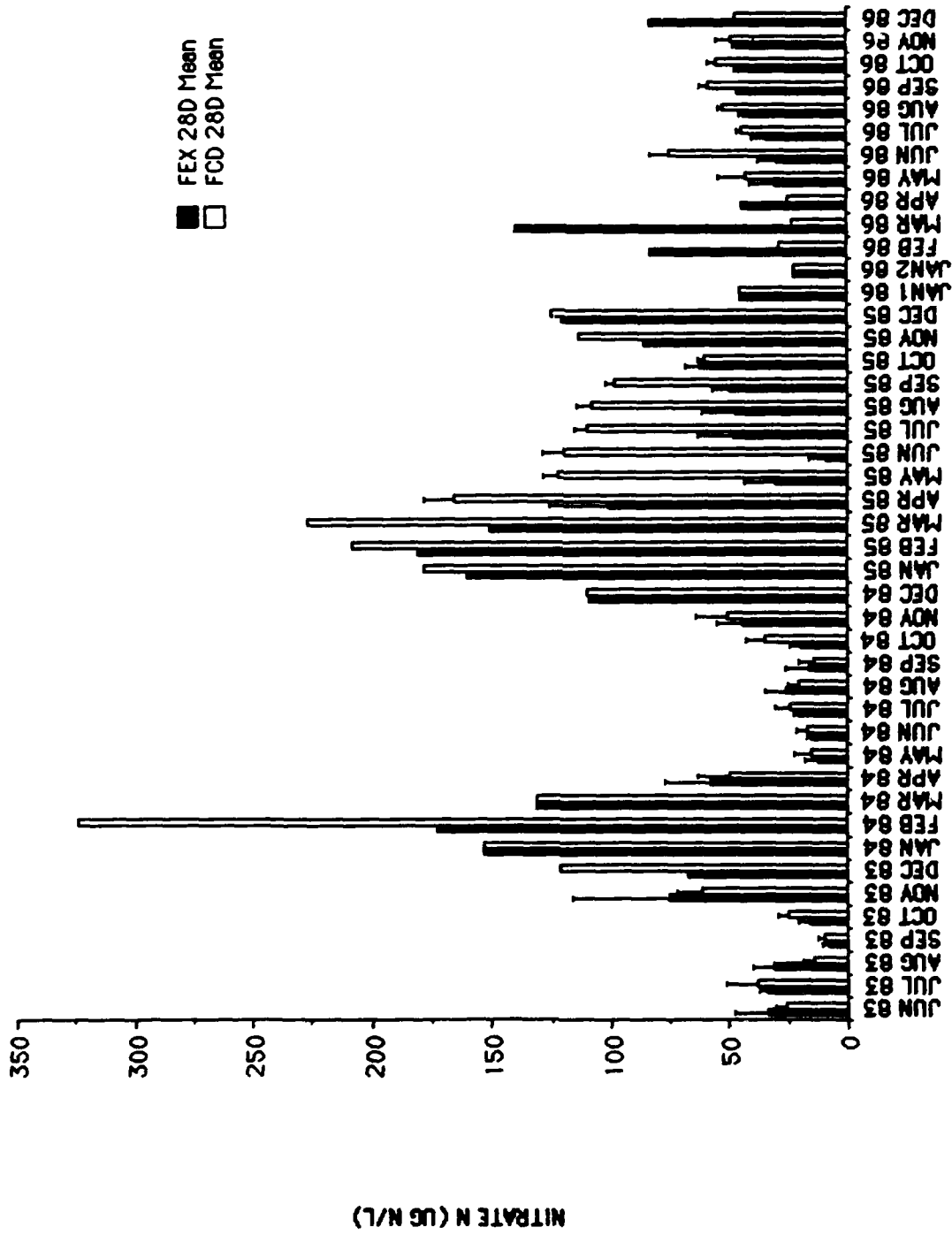
FIGURE 1.14. Mean Nitrate Nitrogen (± S.E.) over 28 Day Sampling Periods for Experimental (FEX) and Control (FCD) Sites from the Ford River, 1983-87.

45
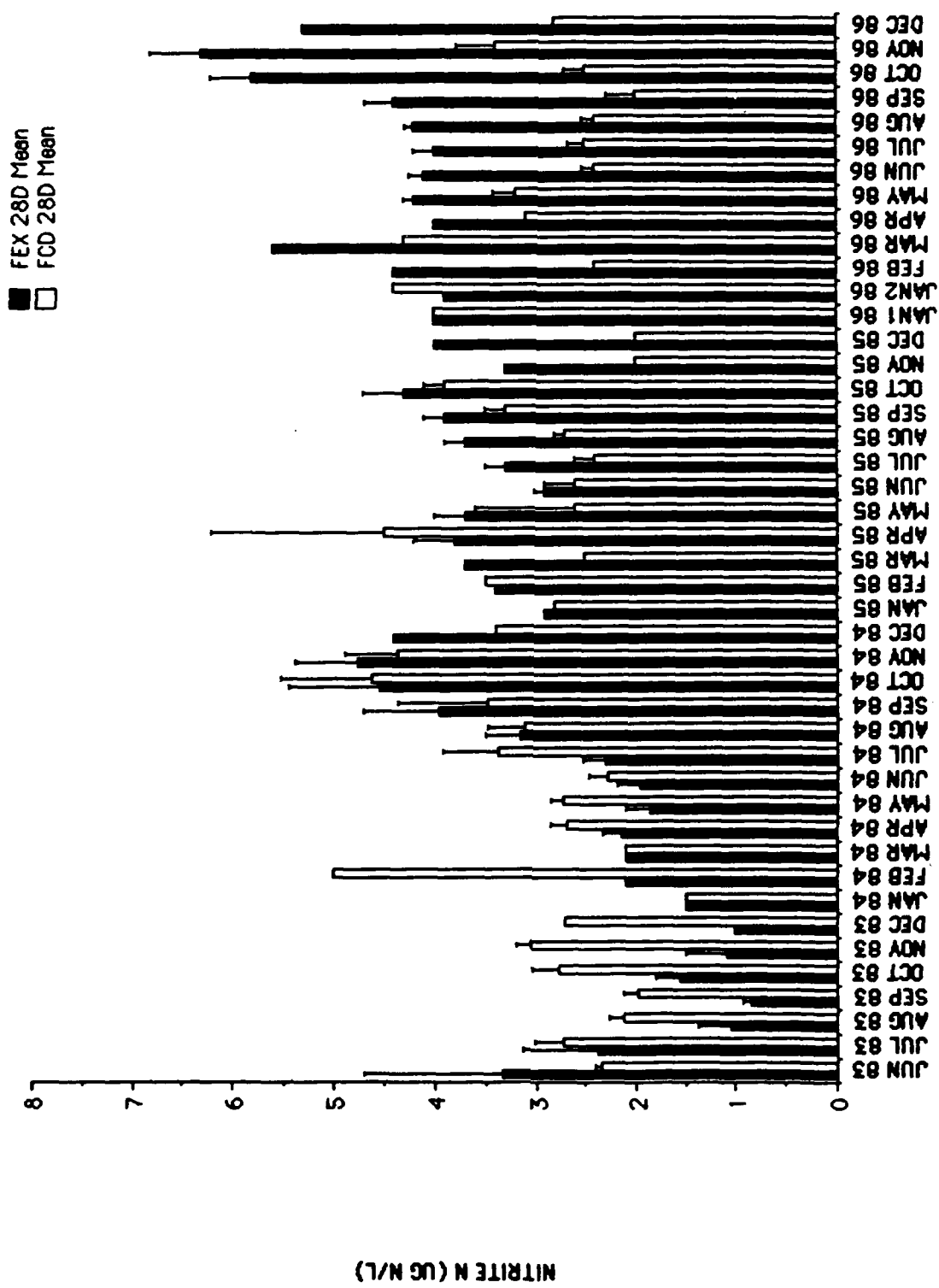
FIGURE 1.15   Mean Nitrite Nitrogen ($\pm$ S.E.) over 28 Day
Sampling Periods for Experimental (FEX) and
Control (FCD) Sites from the Ford
River, 1983-87.

NITRITE N (UG N/L)

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FIGURE 1.16   Mean Ammonium Nitrogen (± S.E.) over 28 Day
Sampling Periods for Experimental (FEX) and
Control (FCD) Sites from the Ford River,
1983–87.

FIGURE 1.17   Mean Inorganic Nitrogen (± S.E.) over 28 Day
Sampling Periods for Experimental (FEX) and
Control (FCD) Sites from the Ford River,
1983-87.

48
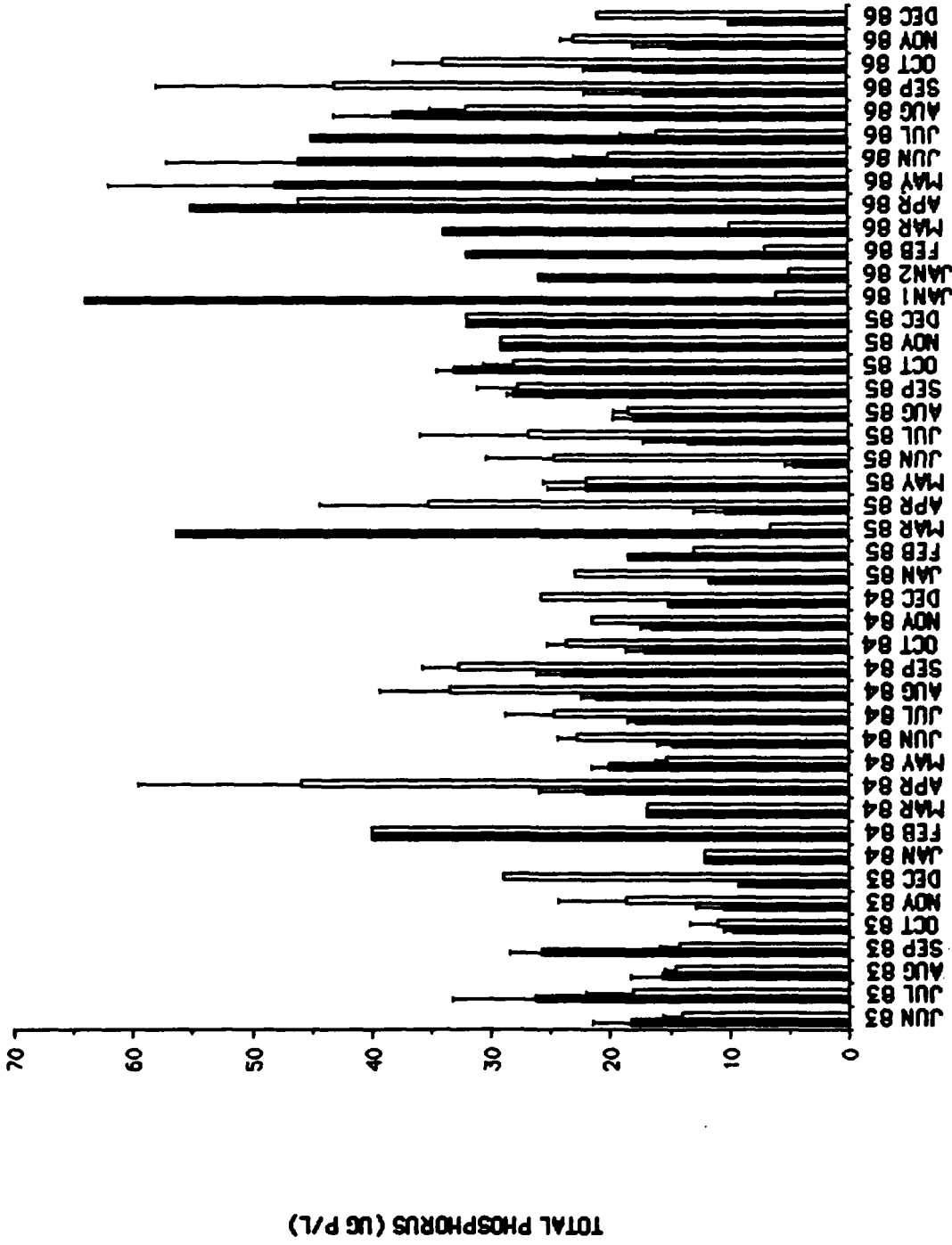
FIGURE 1.18   Mean Organic Nitrogen (± S.E.) over 28 Day
Sampling Periods for Experimental (FEX) and
Control (FCD) Sites from the Ford River,
1983-87.

ORGANIC N (UG N/L)

49

Table 1.7   Ammonium-N (ug N/L), Nitrate-N (ug N/L), and Nitrite-N (ug N/L) for the Ford River for 1986. Values are Means ± S.E., N in Parentheses.

Experimental Site (FEX)

Date	Ammonium-N	Nitrate-N	Nitrite-N
1-3-86	134 (1)	-- (1)	-- (1)
1-31-86	46 (1)	22 (1)	3.9 (1)
2-28-86	43 (1)	83 (1)	4.4 (1)
3-28-86	62 (1)	140 (1)	5.6 (1)
4-25-86	72 (1)	44 (1)	4.0 (1)
5-19-86	41 ± 7.4 (7)	30 ± 11 (5)	4.2 ± 0.10 (7)
6-16-86	38 ± 4.9 (8)	29 ± 8 (7)	4.1 ± 0.15 (8)
7-14-86	50 ± 3.5 (8)	34 ± 6 (8)	4.0 ± 0.20 (8)
8-14-86	38 ± 8.9 (9)	43 ± 2 (8)	4.2 ± 0.08 (9)
9-11-86	38 ± 11.0 (8)	45 ± 1 (8)	4.4 ± 0.28 (8)
10-9-86	18 ± 3.2 (7)	46 ± 1 (7)	5.8 ± 0.41 (8)
11-13-86	27 ± 4.9 (4)	46 ± 2 (4)	6.3 ± 0.50 (4)
12-12-86	32 (1)	83 (1)	5.3 (1)

Control Site (FCD)

Date	Ammonium-N	Nitrate-N	Nitrite-N
1-3-86	24 (1)	45 (1)	4.0 (7)
1-31-86	18 (1)	-- (1)	4.4 (8)
2-28-86	21 (1)	28 (1)	2.4 (8)
3-28-86	65 (1)	23 (1)	4.3 (9)
4-25-86	13 (1)	25 (1)	3.1 (8)
5-19-86	28 ± 3.4 (7)	42 ± 12 (6)	3.2 ± 0.21 (8)
6-16-86	33 ± 4.0 (8)	75 ± 8 (8)	2.4 ± 0.12 (8)
7-14-86	48 ± 11.0 (8)	44 ± 2 (8)	2.5 ± 0.16 (8)
8-14-86	41 ± 2.0 (8)	52 ± 2 (9)	2.4 ± 0.12 (9)
9-11-86	31 ± 6.9 (8)	58 ± 4 (7)	2.0 ± 0.28 (8)
10-9-86	33 ± 11.0 (8)	55 ± 3 (7)	2.5 ± 0.20 (8)
11-13-86	28 (1)	49 ± 6 (4)	3.4 ± 0.38 (3)
12-12-86	28 (1)	47 (1)	2.8 (1)

Table 1.8 Organic-N (ug N/l) and Inorganic-N (ugN/l) for the Ford River for 1986. Values are Means ± S.E., N in parentheses.

Dates	Experimental Site (FEX)		Control Site (FCD)	
	Organic Nitrogen	Inorganic Nitrogen	Organic Nitrogen	Inorganic Nitrogen
1-3-86	1360 (1)		910 (1)	73.0 (1)
1-31-86	900 (1)	72.0 (1)	910 (1)	
2-28-86	1000 (1)	130.0 (1)	760 (1)	51.0 (1)
3-28-86	1080 (1)	208.0 (1)	1000 (1)	92.0 (1)
4-25-86	1200 (1)	125.0 (1)	1260 (1)	41.0 (1)
5-19-86	1280 ± 220 (7)	70.0 ± 13.0 (6)	980 ± 60 (7)	73.0 ± 15.0 (6)
6-16-86	1050 ± 90 (8)	70.0 ± 7.0 (8)	1000 ± 40 (8)	110.0 ± 9.0 (8)
7-14-86	980 ± 110 (8)	89.0 ± 5.0 (8)	1040 ± 40 (8)	96.0 ± 12.0 (8)
8-14-86	940 ± 30 (9)	85.0 ± 12.0 (8)	1320 ± 50 (8)	97.0 ± 2.0 (8)
9-11-86	1080 ± 130 (8)	87.0 ± 11.0 (8)	1200 ± 90 (8)	92.0 ± 10.0 (7)
10-9-86	1220 ± 20 (7)	70.0 ± 4.0 (7)	1550 ± 200 (8)	80.0 ± 3.0 (7)
11-12-86	1170 ± 60 (4)	79.0 ± 6.0 (4)	820 (1)	80.0 (1)
12-11-86	1030 (1)	120.0 (1)	1080 (1)	78.0 (1)

streams draining areas of the eastern U. S. that are 50 to 90 % forested.

There were no significant differences for silicate-Si between FEX and FCD (Tables 1.6, 1.9, Fig. 1.19), and concentrations at FEX were significantly related to concentrations at FCD (Table 1.6). Concentrations were relatively constant throughout the year at about 9 to 10 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. 1.19). In fact, silicate-Si was significantly ($p<0.05$) and negatively correlated with discharge at both FEX and FCD, although r values were low (-0.52 at FEX and -0.39 at FCD).

Chloride at FEX was significantly different from chloride at FCD (Table 1.6, 1.9, Fig. 1.20), although values for the two sites were significantly correlated (Table 1.6). Concentrations of Cl appeared to be larger at the upstream site (FEX) than they were at the downstream site (FCD). This gradient probably 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 and have remained somewhat higher since that time than they were in 1983 through 1985. The reasons for this increase are unknown. However, these values are not much higher than one would expect from rainwater and are certainly much lower than any concentration known to cause problems for fish or other aquatic organisms (McKee and Wolf 1963).

C. Physical and Meteorological Parameters

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

Solar radiation (PAR) was highly variable using the 30 minute interval data. An integrating instrument would have provided more useful data but was not included in our original equipment list. Our 28 day summaries have

Table 1.9   Dissolved Silica (mg Si/l) and Chloride (mg Cl/l) for the Ford River for 1986. Values are Means ± S.E., N in parentheses.

Dates	Silica				Chloride			
	Experimental (FEX)		Control (FCD)		Experimental (FEX)		Control (FCD)	
1-3-86	4.19	(1)	8.56	(1)	12.06	(1)	6.27	(1)
1-31-87	10.76	(1)			8.09	(1)	7.17	(1)
2-28-86			10.18	(1)	6.78	(1)	6.01	(1)
3-28-86	9.91	(1)	9.20	(1)	13.80	(1)	13.47	(1)
4-25-86					5.93	(1)	5.67	(1)
5-19-86	5.42 ± .26	(5)	5.38 ± .33	(5)	7.27 ± .68	(7)	6.36 ± .58	(7)
6-16-86	7.15 ± .34	(5)	7.26 ± .29	(8)	6.56 ± .53	(8)	7.07 ± .79	(8)
7-14-86	8.96 ± .32	(8)	8.68 ± .17	(8)	7.78 ± .42	(8)	7.36 ± .52	(8)
8-14-86	8.42 ± .68	(9)	8.65 ± .40	(9)	8.88 ± .56	(8)	6.65 ± .34	(9)
9-11-86	10.09 ± .30	(6)	8.35 ± 1.05	(7)	8.88 ± .21	(8)	7.04 ± .52	(8)
10-9-86	10.60 ± .38	(8)	9.32 ± .74	(7)	11.10 ± .62	(8)	10.70 ± .64	(8)
11-13-86	8.68 ± 1.16	(4)	8.28 ± .76	(3)	9.68 ± .72	(4)	8.88 ± .59	(4)
12-12-86	11.38	1)	10.95	(1)	9.33	(1)	7.09	(1)

FIGURE 1.19   Mean Silica (± S.E.) over 28 Day Sampling Periods
for Experimental (FEX) and Control (FCD) Sites
from the Ford River, 1983-87.

54
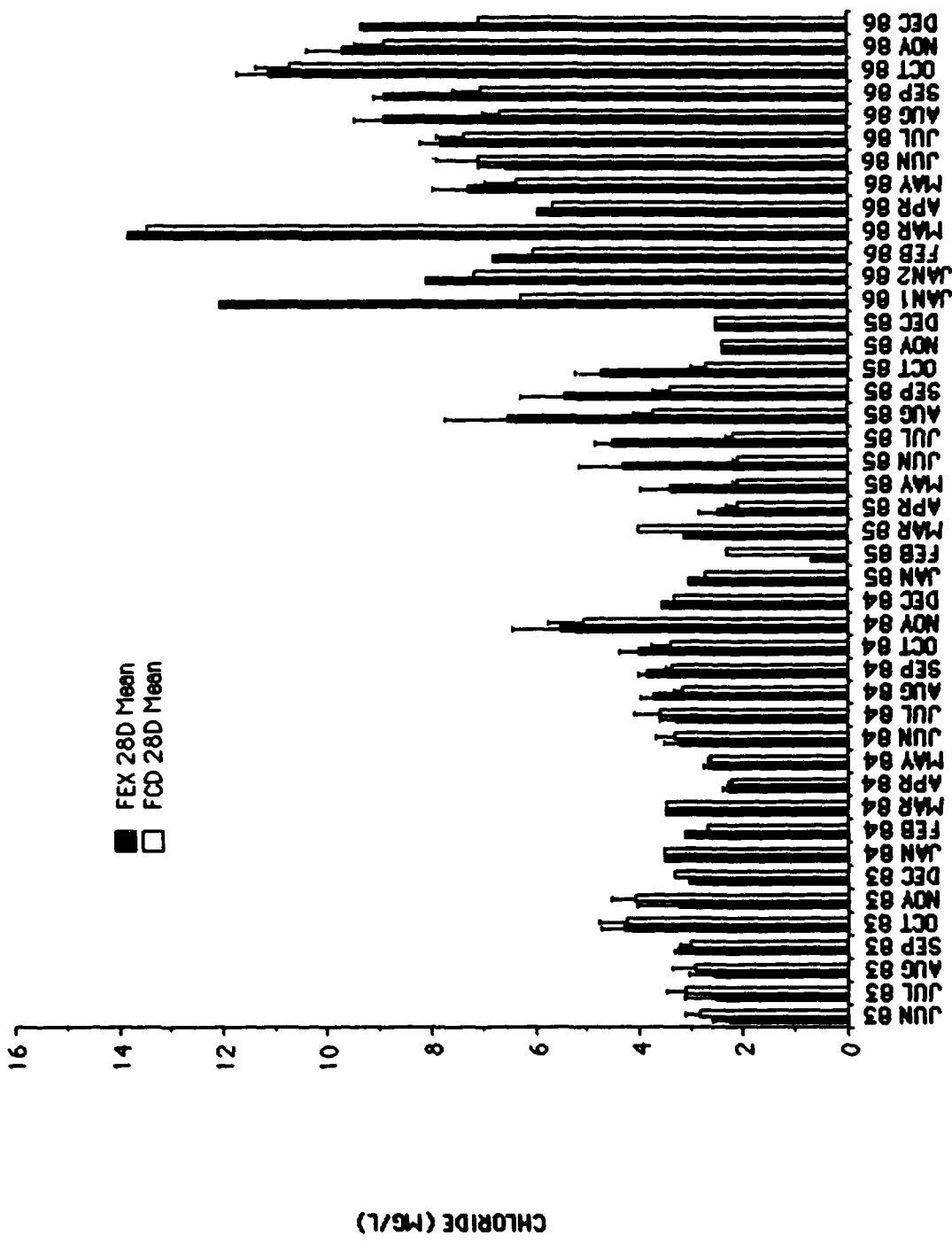
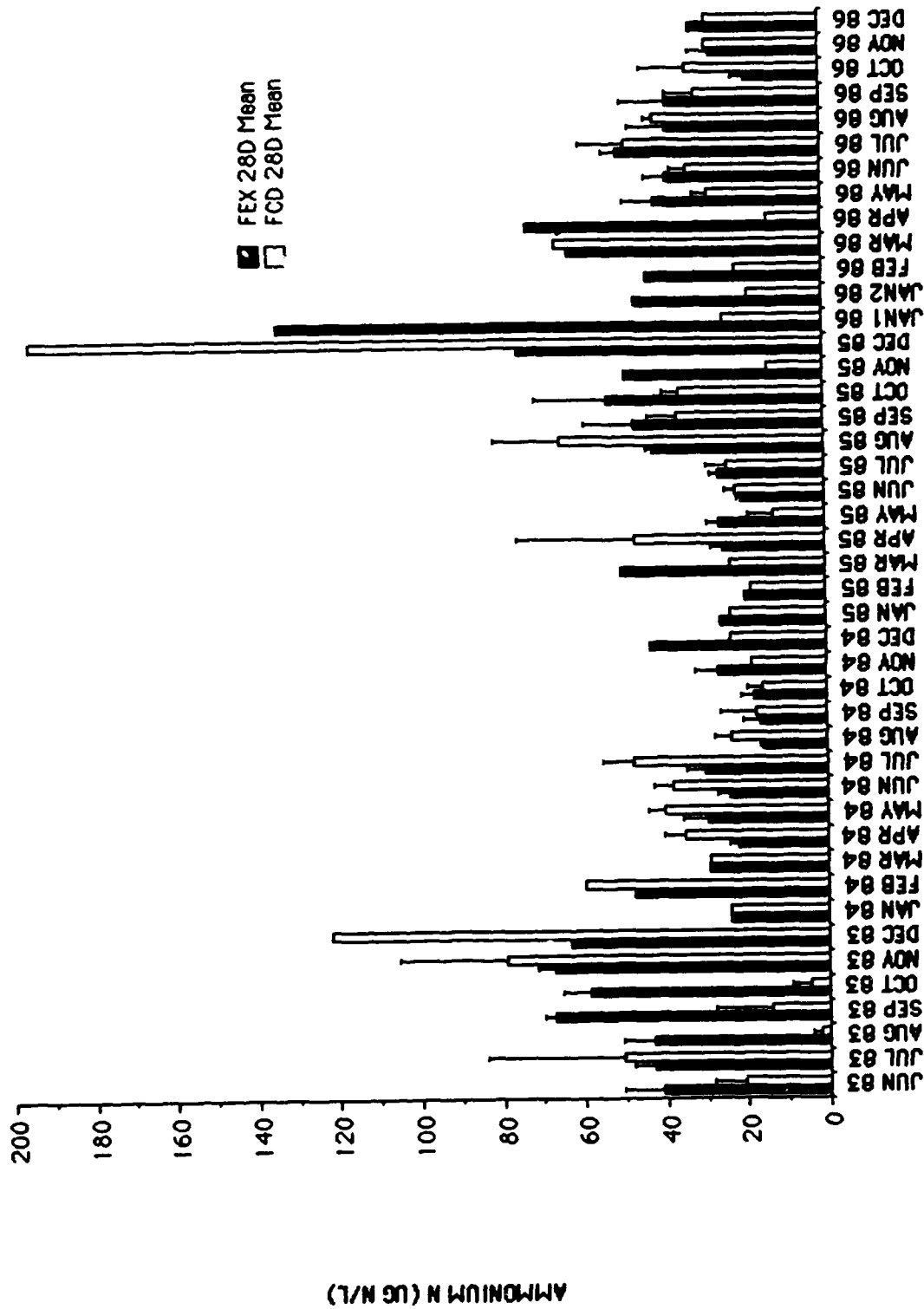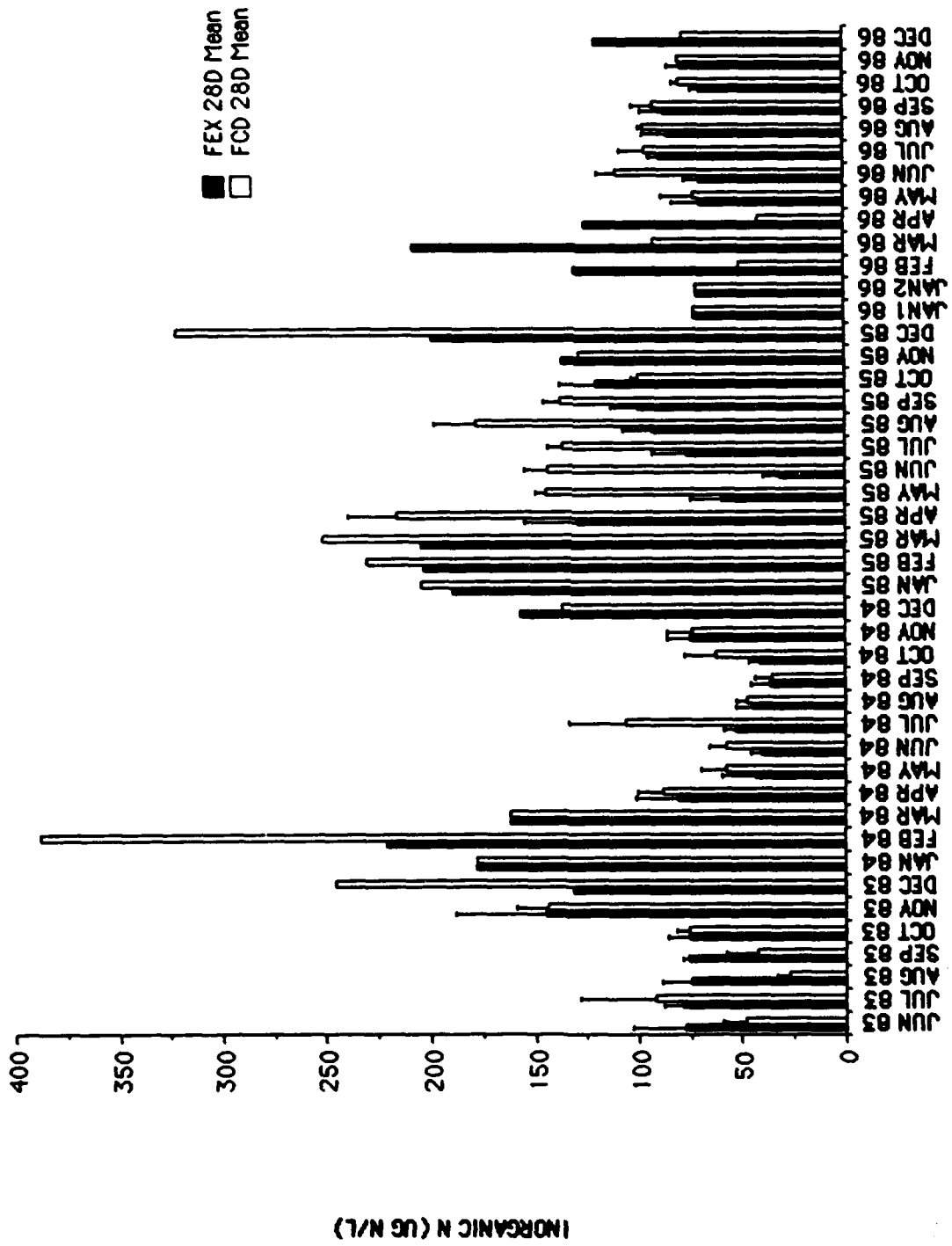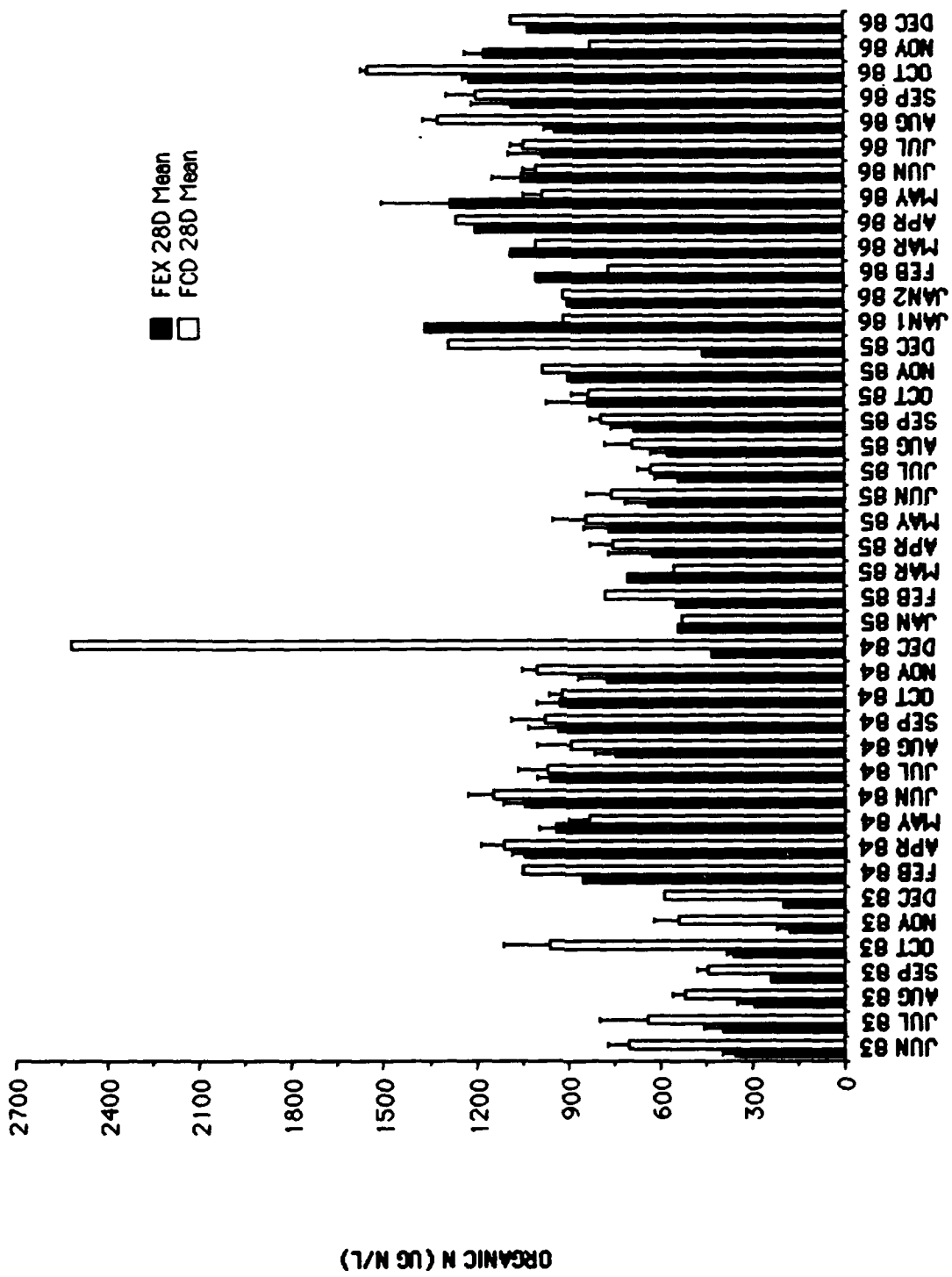FIGURE 1.20   Mean Chloride (± S.E.) over 28 Day Sampling
Periods for Experimental (FEX) and Control (FCD)
Sites from the Ford River, 1983-87.

55
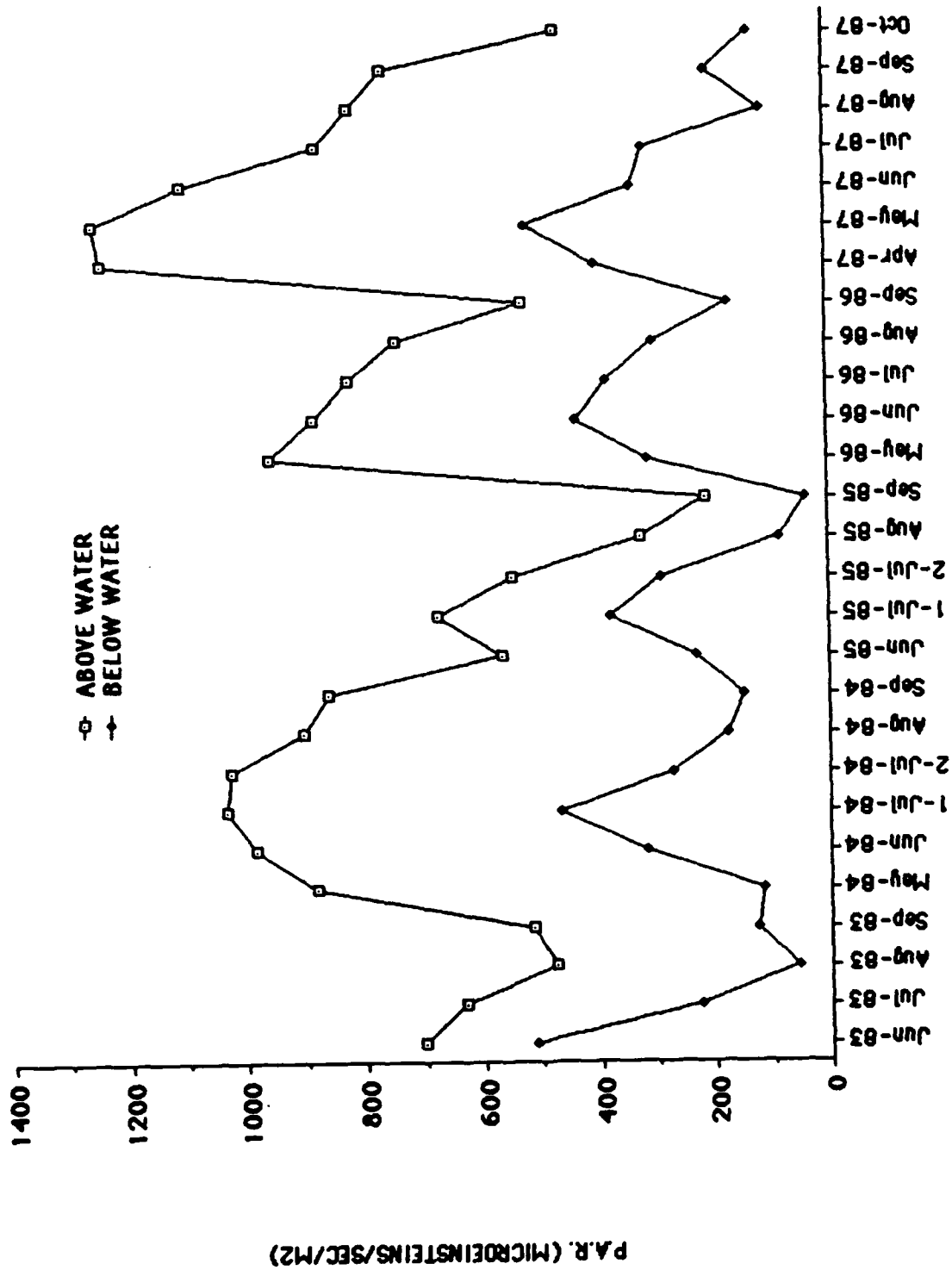
FIGURE 1.21 Average Daily Above and Below Water Solar Radiation over 28 Day Sampling Periods from the Ford River, 1983-87.

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been calculated as an average of the 30 minute PAR values for the period from 1000 to 1400 hours daily (Fig. 1.21). This approach results in comparative data for each 28 day period but may have little meaning biologically. A more appropriate measure might be cumulative solar input for each 28 day exposure period. As reported in the last annual report, we intend to calculate this cumulative solar input data for all past periods based on the 30 minute interval data. Obviously, such 30 minute based data calculations will not be very precise but will give us a comparative index of solar input as it varies seasonally. We have not yet finished this task but have a student worker assigned to finish it before the start of the next ice-free season.

Air and water temperature have been monitored since 1983 and are available as needed. The water temperature for 1987 are typical (Fig. 1.22) 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 5° C when the stations are removed from the stream. 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. 1.23. These data illustrate that average summer temperatures are usually less than 20° C and that the summer of 1983 had slightly warmer temperatures than has been true since that time.

Stream discharge data have already been presented (Fig. 1.6) for the 28 day benthic algal exposure periods. 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

FIGURE 1.22   Daily Water Temperatures for Experimental (FEX) and Control (FCD) Sites on the Ford River, 1987.
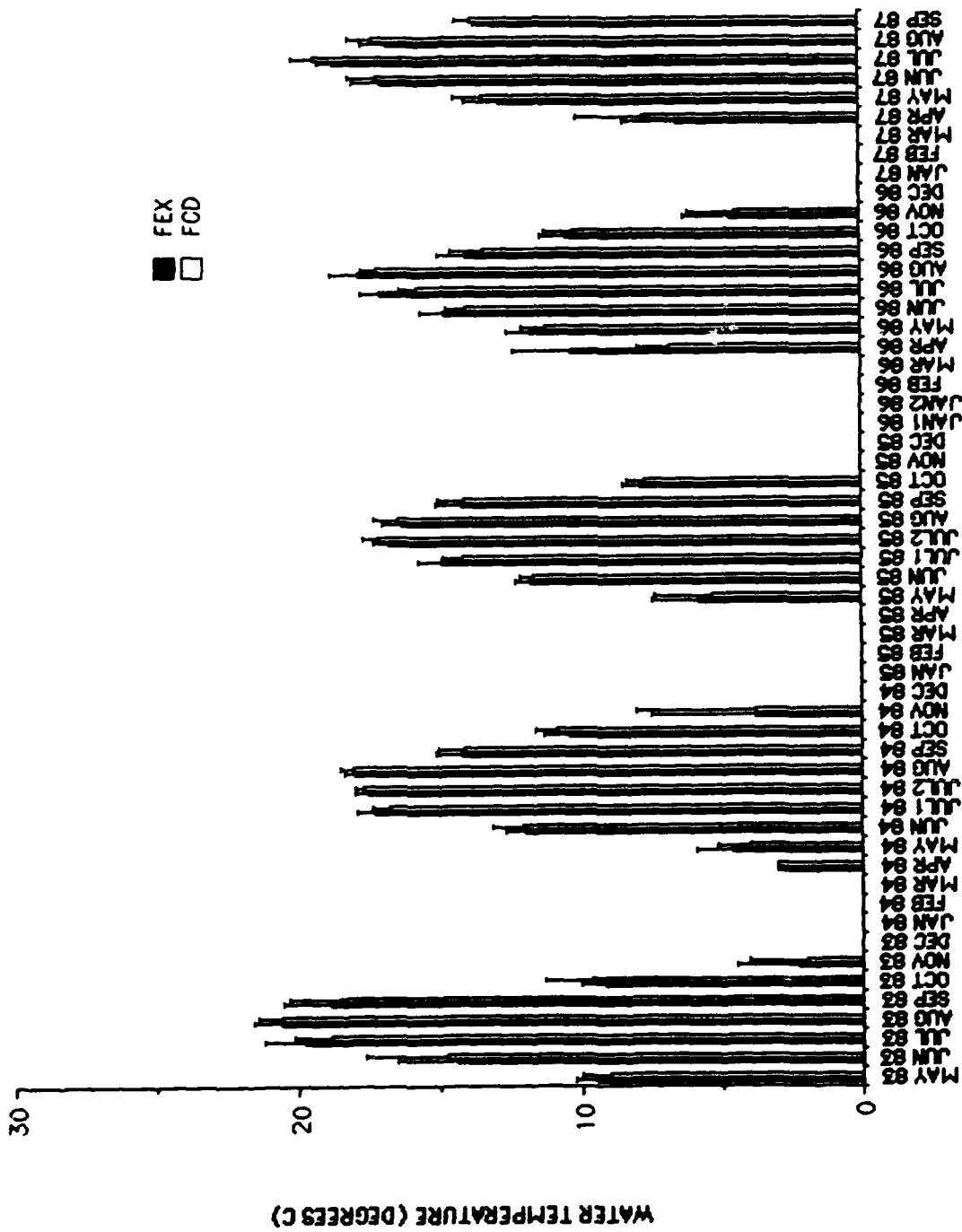
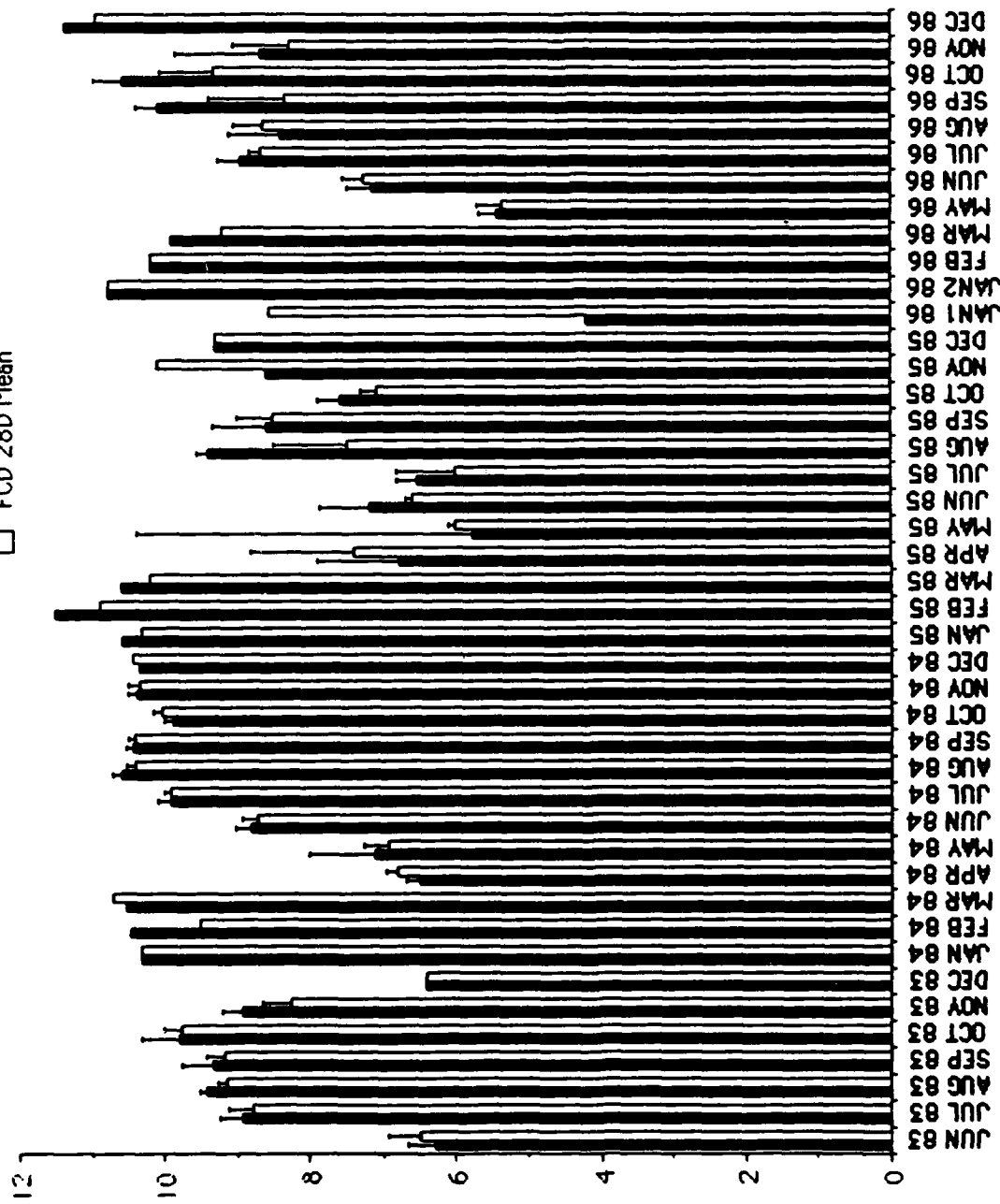FIGURE 1.23   Mean Daily Water Temperatures (± S.E.) over 28 Day Sampling Periods for Experimental (FEX) and Control (FCD) Sites from the Ford River, 1983-87.

WATER TEMPERATURE (DEGREES C)

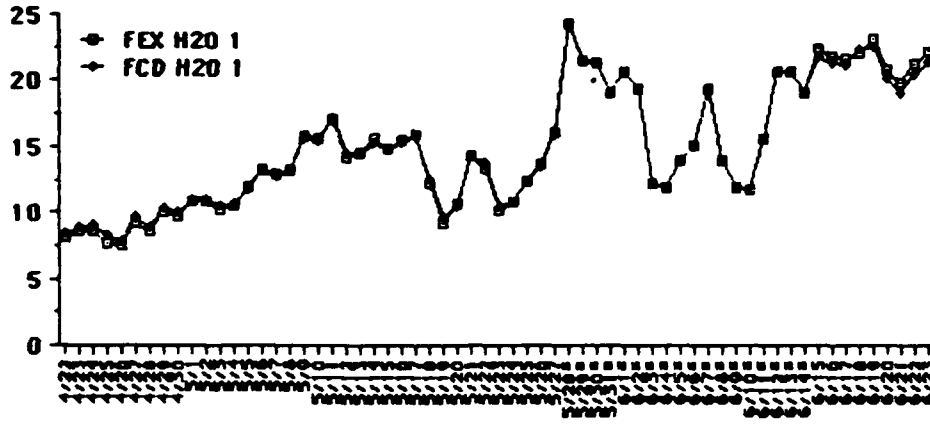59

a chore, and it has not yet been completed. In 1986, this system was abandoned and the simple but effective strip chart recorder has been used since. Data for 1986 and 1987 are currently available with mean daily flows calculated for both years. We hope to retrieve the data from the first three years and summarize it during the upcoming year. Eventually, we expect to calculate regressions of the biological parameters with mean discharge, minimum discharge, maximum discharge, peak discharge values, 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 in our data base is a priority for the rest of this winter. We have collected supplemental rainfall data for each site for the last three summers. These data for 1987 are presented in Fig. 1.24.

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 was true for hardness, nitrate, and organic nitrogen. These differences 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 intersite differences in productivity. We initiated experiments in 1987 to determine the impact of N and P inputs on the algal community and should be able to determine if the slight differences in nitrate and organic N are likely to result in increased productivity as soon as analyses of these experiments are completed.

FIGURE 1.24   Rainfall Measured at Experimental (FEX) and
Control (FCD) Sites on the Ford River, 1987.

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In addition, productivity between the two sites was not significantly different (see Element 2).

Dissolved oxygen was only slightly below saturation at both sites but was slightly but significantly higher at FEX than it was at FCD. This difference was probably related to differences in sample times between the two sites. We expected to pair dissolved oxygen data on a time basis using the automatically acquired data to test whether these differences were real or not. However, one of the two meters proved to be unreliable in 1987 making this comparison impossible.

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. Even at FEX, chloride levels were only slightly higher than typical rainfall values. Thus, cloride should have little effect on the biota at either site.

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

E. References

A.P.H.A. 1980. Standard methods for the examination of water and wastewater, 15th edition. American Public health Association. Washington, D. C. 1134 pp.

Bormann, F. H. and G. E. Likens. 1979. Pattern and process in a forested ecosystem. Springer-Verlag, N.Y., 253 pp.

Gregory, K. J. and D. E. Walling. 1973. Drainage basin form and process. A geomorphological approach. John Wiley & Sons, N.Y., 456 pp.

McKee, J. E. and H. W. Wolf. 1963. Water quality criteria, Second edition. Calif. State Water Quality Contol Bd. Publ. 3-A, Sacramento, California. 548 pp.

Omernik, J. M.   1977.   Nonpoint source - stream nutrient
level relationships: A nationwide study.   Ecol. Res.
Series EPA-600/3-77-105, Corvallis Environmental
Research Laboratory, U. S. Environmental Protection
Agency, Corvallis, OR 151 pp.

U.S. EPA.   1979a. Methods for chemical analysis of water
and wastes. EPA-600/4-79-020, Environmental Monitoring
and Support Laboratory, U. S. Environmental Protection
Agency, Cincinnati, OH.

U.S. EPA.   1979b.   Handbook for analytical quality
control in water and wastewater laboratories.
EPA-600/4-79-019,   Environmental Monitoring and
Support Laboratory, Cincinnati, OH.

Vitousek, P. M., J. R. Gosz, C. C. Grier, J. M. Melillo,
and W. A. Reiners.   1982.   A comparative analysis of
potential nitrification and nitrate mobility in forest
ecosystems.   Ecol. Monogr. 52(2):155-177.

VII. A. PERIPHYTON STUDIES

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

Changes from workplan- None.

Objectives

The objectives of the periphytic algal studies are:
(1) to quantify any changes in species diversity, species composition, species evenness, species richness and cell density that occur as a result of ELF electromagnetic fields,
(2) to quantify any changes in primary productivity that might occur as a result of ELF electromagnetic fields,
(3) to monitor any changes in chlorophyll a and organic matter accrual rates and standing crops as a result of ELF electromagnetic fields, and,
(4) to determine algal cell volumes and chlorophyll a to phaeophytin a ratios, thereby providing indices of physiological stress in periphytic algal cells 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 toxicants, 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 richness allows between site comparisons of attached algal communities which will include the subtle shifts in species composition that may potentially occur as a result of ELF radiation. The dominant 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. The potential changes in species abundance, species diversity, and species evenness of this community afford sensitive and statistically measurable parameters against which to measure seasonal variation, site variation, yearly variation and potential ELF effects.

In 1986 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 last annual report to illustrate the technique and to see if it would be useful for significance testing on single species population abundances. On the basis of our preliminary results, presented last year, we expect the BACI test to have the potential to detect the more subtle changes, particularly in single species abundance fluctuations, than we have been able to document heretofore. We will also present the results of our continued investigations into the use of the BACI analysis concerning other structural indices particularly chlorophyll a and AFDW-biomass performed this year.

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 thus reveal changes due to ELF effects. This single parameter is also a very important correlate with other

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estimates of production, such as chlorophyll a, or organic matter accrual . This labor intensive direct counting procedure is thus 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, affords 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 qualitiative physiological state of the algal community. Subtle effects of ELF electromagnetic fields on the photosynthetic pigment may result in cellular "leaking" or 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. Including the ratios of the main chlorophyll a degradation product, phaeophytin a, can also indicate the degree of physiological stress in the algal community. Site comparisons of the relative amounts of oxygen produced by the attached algae will then compare the final results of photosynthesis.

This multiple approach of methodologies couples direct determinations of quantitities of pigments present with indirect physiological measurements of pigment condition, with further direct measurements of oxygen levels produced by that pigment. These paramenters thus 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, for example measuring chlorophyll a and organic matter accrual directly to provide estimates of production when the more detailed production studies of photosynthetic rates are not feasible at all times of the year, due to weather or labor constraints.

Our rationale has thus 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 backround 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, phaeophytin a, and AFDW-biomass accrual rates and after 28 days for species composition and cell count determinations, chlorophyll a, phaeophytin a, and AFDW-biomass standing crop determinations.

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 placed in a mixture of 6 parts water, 3 parts 95% ethanol and 1 part formalin. 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 other two slides 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 additon of small amounts of potassium dichromate (Van der Weff 1955). The cleaned diatoms were then rinsed with

distilled water and settled in graduated cylinders. The
final volume of concentrate containing the cleaned diatom
frustules was then measured and 1 ml subsamples pipetted
onto 22 mm^2 coverslips, until an adequate counting
density was achieved. The coverslips were air dried and
permanently mounted on glass slides using Hyrax medium.

Counting to determine diatom density calculations,
and species determinations was done at 1250X
magnification on a Zeiss microscope equipped with phase
contrast illumination and an oil immersion 100X
Neofluar phase objective with numerical aperture of 1.30.
Transects were taken moving across the coverslip until
between 300-400 frustules were counted. Estimates of
diatom densities were then calculated from these
quantitative samples via the equation:

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

Diatom species composition was recorded for each
slide counted for determination of species richness,
diversity (H') using the
Shannon-Wiener formula (Southwood 1978; chosen for its
more universal use and acceptance than other more obscure
diversity indices), species evenness (J), 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 both chlorophyll a and phaeophytin 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.
This step was therefore eliminated. Slides were
collected, frozen for at least 24 hours to promote cell
rupture, and then pigments extracted in 90% acetone.
Chlorophyll a and phaeophytin a were then
determined following procedures outlined in Standard
Methods.

Organic matter biomass determinations were conducted following procedures 1003D for productivity estimates in <u>Standard</u> <u>Methods</u> (APHA 1980). While using the gain in ash-free dry weight per unit area as a measure of net 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). The accrual of biomass is a combination of processes involving dynamics of both colonization and production. 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. Most of these tests for prior annual reports were performed on either yearly data sets of 13 values (28 day periods = 13 per year) or a combination of two or three years data only. This report will present the results of paired t-tests of all data from June 1983 through June 1987, a five year comparison between sites. Single year data will be presented for October, 1986 through September, 1987 and results for yearly paired t-tests on all parameters measured will be presented in order to be consistent with previous reports. However, the emphasis of this report will be on presentation of statistical comparisons utilizing data collected over the full, five year period. In the future, each additional year's data will be added on to this five year data matrix so that completely up-to-date analyses for all the years of the study should be available in each future report. Biological parameters included in both the five year and single year statistical analyses include;chlorophyll a, AFDW-biomass, cell density, species diversity, species evenness, total biovolume and, average individual cell volume. Calculation of a giant correlation matrix using all

available data   (53 total variables with sites separate)
collected from biological, ambient, and nutrient
variables shows a more complete picture of potential
relationships.   Future analyses including multiple
regressions with additional variable transformations
(similar to those show in last years annual report),
particularly for variables showing significant
correlations in the large matrix, will be completed for
next year's report. Additionally, both total biovolume
and individual cell volume have been calculated for all
samples since 1983, and these parameters are now complete
and included for analyses in the five year comparisons.

In addition to the paired t-tests performed on data
collected between sites, we also analyzed the data using
a three factor ANOVA for the five year period. Factors
representing Year, Site, and Month (Date) for each of
our biological parameters were used. This year we also
repeated some of the exploratory factor analyses
reported in last year's annual report on the complete
five year data set, but interpretation is still
unfinished.

While we increase the degree of statistical analyses
performed, as well as the complexity of the analyses with
each report as more data becomes available, there still
remains a large inherent variablility 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 (samples periods when
the numbers of samples were increased to 10 slides per
sample date), AFDW-biomass had C.V.'s that averaged 40%
in 84-85, 64% in 85-86, and 45% in 86-87, diatom cell
density averages were 38% in 84-85, 39% in 85-86, and 33%
in 86-87. All three important biological parameters,
thus, 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 for species diversity and 10% in

86-87 as well, and species evenness averaging 7% in 85-86 and 6% in 86-87. 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 may 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 more than a single time period, however. We expect overall trends to be examined through the before mentioned 3-Way ANOVA, as well as BACI, and through regression analyses comparing pre-ELF exposure data with post-ELF exposure data and potentially time series analysis. We expect to contrast not only monthly but seasonally and yearly data as well. We have expanded the use of the BACI procedure this year to show the usefulness of this technique for analyses beyond the species abundance contrasts used in last year's report. These results will be presented below and appear very promising.

The abilities of both water chemistry parameters and environmental conditions to predict levels of biological variables were investigated through the use of extensive multiple regression analyses reported in the last annual report. In addition, all ambient data from the _in situ_ probes and recorders were summarized and included. The use of these multiple regressions, together with the correlation matrices often indicated potential interrelationships between the physical, chemical and biological parameters. Such regressions were calculated for the 1986 data for last year's report . This year we will emphasize the use of the entire five year data set through correlation analyses, the three way ANOVA and

paired t-tests. Eventually all these methodologies, including factor analysis will be performed on all collected data.

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-June 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, phaeophytin 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 1983-1987 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), differences between a slow flowing pool habitat, and the more rapidly flowing riffle habitat were

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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_ in 1986, and
presented as an appendix in the annual report for
1986-87.

B. Patterns for Chlorophyll a

Final site selection was completed in 1983. Data
from June 1983 through September 1987 for 28 Day
chlorophyll a standing crop showed that annual patterns
differed markedly through time (Fig. 2.1,Table 2.1).
Annual patterns do, however, indicate that each year a
peak occurs during the summer months in either July or
August. The magnitude of the peak varies from values
as large as 12-14 mg m^{-2} in 1983 to lows of 4-7 mg m^{-2} in
1984. The 1987 peak also occurred in August for both
sites (Fig. 2.1, Table 2.1) and reached levels of 9-12 mg
m^{-2}. Another consistent pattern has been that
chlorophyll a standing crop has been less than 1.0 mg m^{-2}
under the ice in winter (Fig. 2.1). However, in 1987 the
winter was characterized as being moderate in severity,
with substantially warmer temperatures resulting in less
ice cover for the Ford River. The fact that periphyton
produced substantially greater levels of chlorophyll a
for these winter months of January, February and March
is clearly visible (Fig. 2.1). The levels of pigment
observed for 1986-87 winter are much greater than those
observed in any winter for the previous years. This
period of cold water temperatures and ice covered water
has generally been less variable for the biological
samples taken during these periods. We intend to
investigate the climatic and potential hydrologic
conditions that may have resulted in the rather unusual
winter pattern observed in 1986-87 for many of our
biological variables (see discussions below). The period
of highest annual variability has generally been the
periods from late March through June. This period
sometimes contains secondary peaks in standing crop
production, e.g. May 1986, while in other years no peak
occurs (Fig. 2.1). This secondary peak seems to be
associated with dry spring seasons with low flows and

Table 2.1   Chlorophyll $\underline{a}$ (mg/m^2) from slides exposed for 28 days in the Ford River (X ± S.E., N in parentheses).

Date Out	Control Site (FCD)	Experimental Site (FEX)
10-9-86	1.82 ± 0.31 (10)	0.96 ± 0.10
11-13-86	2.65 ± 0.46 (8)	1.17 ± 0.11
12-12-86	0.79 ± 0.26 (4)	1.44 ± 0.21
1-9-87	4.00 ± 0.59 (10)	7.83 ± 1.16
2-6-87	7.01 ± 2.27 (8)	4.46 ± 1.00
3-6-87	6.64 ± 1.00 (10)	2.73 ± 0.57
5-1-87	6.19 ± 0.78 (10)	3.92 ± 0.36
5-26-87	3.71 ± 0.17 (10)	4.17 ± 0.29
6-22-87	4.92 ± 0.27 (9)	5.59 ± 0.50
7-20-87	8.01 ± 0.55 (9)	11.02 ± 0.40
8-31-87	9.85 ± 0.81 (10)	11.92 ± 0.79
9-28-87	1.90 ± 0.17 (10)	2.22 ± 0.18
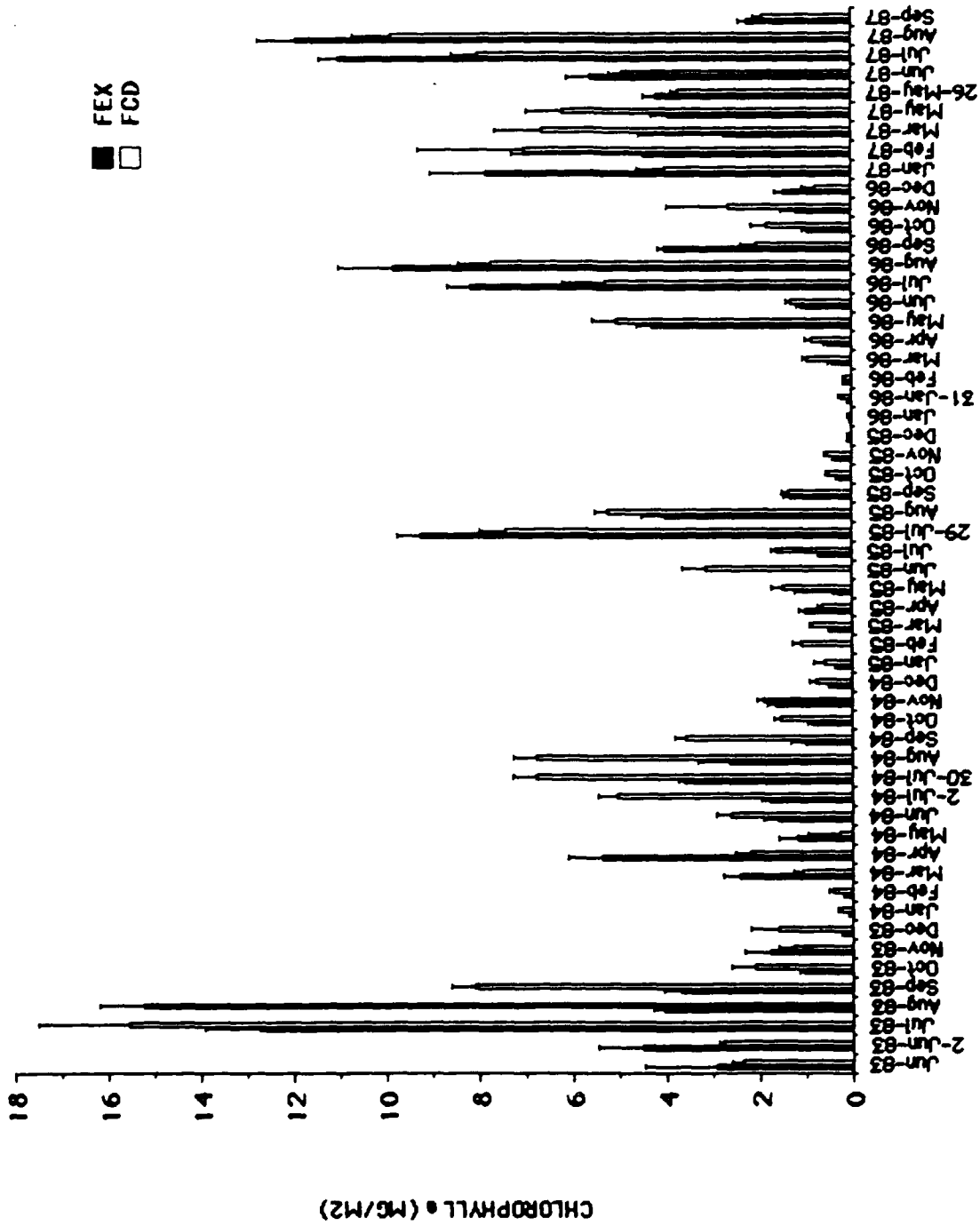
Figure 2.1   Chlorophyll-a Standing Crop for the Ford River, 1983-87.

relatively warm temperatures following snow melt runoff events. Certainly, May, 1986 was one of the driest and warmest Mays on record. The spring secondary peak for 1987 was very likely obscured by the continued high growth of the winter-time algae which continued throughout the spring months (Table 2.1). As the spring rains occurred, disrupting the established winter algae community due to increased water currents in the river, the levels of chlorophyll $\underline{a}$ showed a gradual and steady decline from the high values recorded in the winter months (Fig. 2.1, Table 2.1). Comparisons between sites showed no significant differences using a paired t-test for chlorophyll $\underline{a}$ levels (Table 2.2), and a high correlation coefficient between the sites ($r=.78$, Table 2.3). The 1986-87 data were consistent with data for the five year period. There was no significant difference between sites for the five year period (Table 2.4), and chlorophyll $\underline{a}$ at FEX was signifcantly correlated with chlorophyll $\underline{a}$ at FCD (Table 2.5).

Daily chlorophyll $\underline{a}$ accrual rates followed the same pattern as did standing crop with July-August peaks and winter lows (Fig. 2.2, Table 2.6). For 1986-87 the August peaks were roughly 0.4 mg $m^{-2}d^{-1}$ for FEX and 0.6 mg m^{-2} d^{-1} for FCD (Fig. 2.2, Table 2.6). These peak daily rates were well above those observed in previous years. Both standing crop and daily accrual rates were very similar between FEX and FCD, and there were no significant differences between the sites in 1986-87 (Table 2.2) or comparing all the 28 day sample periods for standing crop data since June 1983 (Table 2.4) 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. The following year greater care was taken to place slides in similar habitats with respect to current velocity (See Fig. 2.3 for 1987 velocities), shading, and depth. Subsequent reports have shown no significant site differences in the last three years. We may have to delete the first year's data from subsequent analyses because of the significant site differences during that year. Results from the 3 way ANOVA (Table 2.7) on the five year data set indicated a small but significant site effect exists for chlorophyll
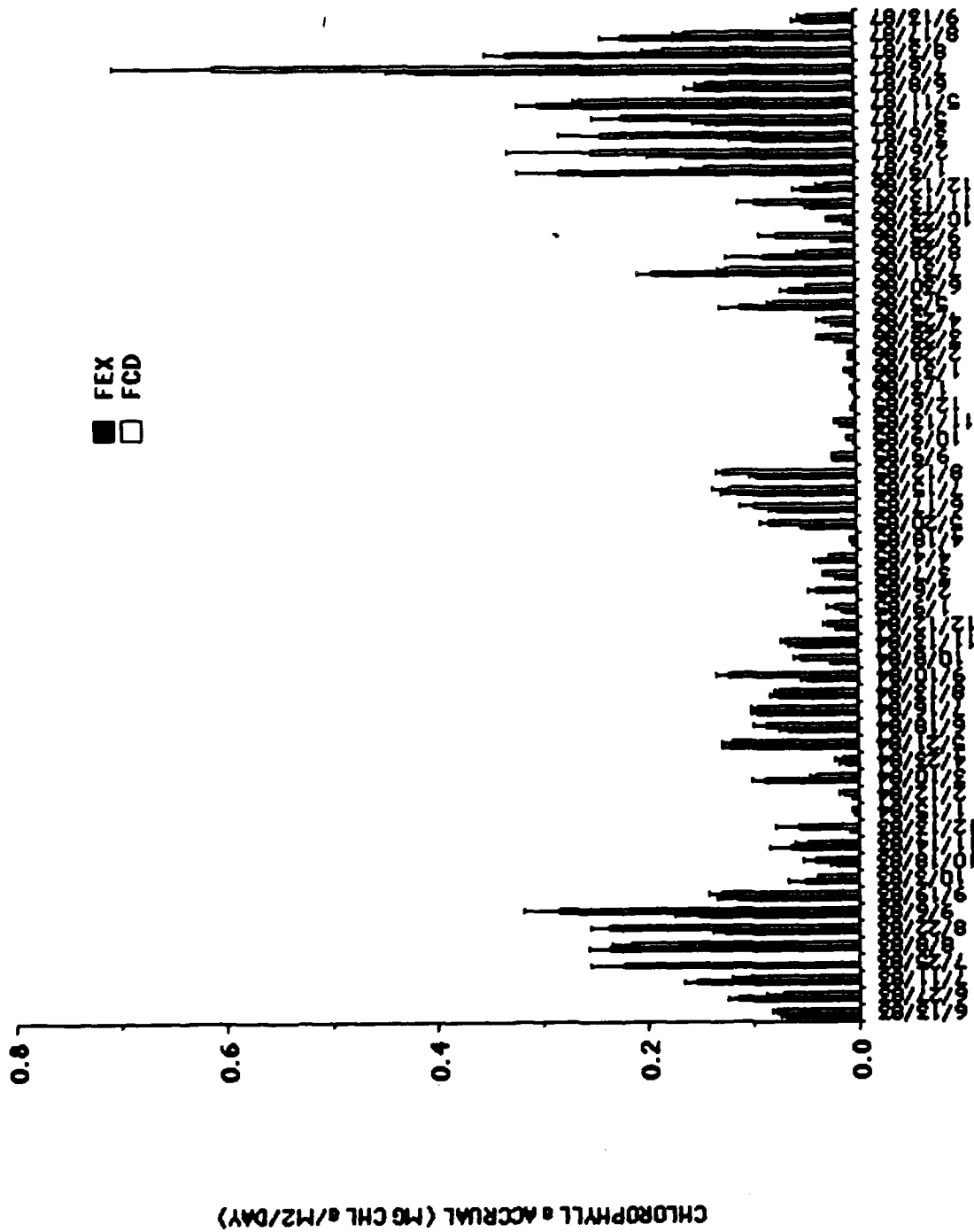
Figure 2.2 Accrual Rates of Chlorophyll-a for the Ford River.
1983-87.

CHLOROPHYLL a ACCRUAL (MG CHL a/M2/DAY)

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Table 2.2   Results of Paired t-tests of Species Diversity (H'), Species Evenness, Diatom Cell Density, Cell Volume, Biovolume, Chlorophyll a, Biomass, and Chla: Phaeophytin a Ratio between Control (FCD) and Experimental (FEX) Sites, 1986-87.

Test parameter	df	Paired t-value	Probability (two tailed)	Sig. P<.05
SPECIES DIVERSITY (H')	11	-2.615	.024	P<.05
SPECIES EVENNESS (J)	11	-2.122	.057	NS
CELL DENSITY	11	.661	.522	NS
CELL VOLUME	11	.214	.835	NS
BIOVOLUME	11	.724	.484	NS
CHLOROPHYLL a STANDING CROP	11	.009	.993	NS
ORGANIC MATTER STANDING CROP	11	-.800	.440	NS
CHLOROPHYLL a DAILY ACCRUAL	12	.417	.684	NS
ORGANIC MATTER DAILY ACCRUAL	12	.998	.338	NS
CHLOROPHYLL a: PHAEOPHYTIN a	11	-.928	.374	NS

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Table 2.3 Correlations Between Selected Biological Parameters for Control (FCD) and Experimental (FEX) Sites, 1986-87.

Parameter	Count	Correlation Coefficients	Significance
Species Diversity	12	.82	P<.01
Species Evenness	12	.82	P<.01
Density	12	.94	P<.01
Cell Volume	12	.96	P<.01
Biovolume	12	.60	P<.05
Chlorophyll a	12	.78	P<.01
Biomass	12	.79	P<.01
Phaeophytin a	12	.62	P<.05

Table 2.4   Results of Paired t-tests Comparing FCD to FEX on Monthly Ford River Biological Data from June 1983 to September 1987.

PARAMETER	DF	Mean X-Y	Probability	t-Value	Between Site Significance
Chlorophyll a	53	.478	1.504	.1384	NS
AFDW-Biomass	53	-42.044	-0.777	.4468	NS
Diatom Density	54	8.337	0.565	.5745	NS
Average Cell Volume	54	30.198	0.570	.5714	NS
Total Biovolume	54	-0.647	-0.566	.5741	NS
Diversity	53	0.087	1.224	.2265	NS
Evenness	53	.001	0.315	.7538	NS

Table 2.5   Correlations between Monthly Biological Averages for Experimental (FEX) and Control Sites on the Ford River from 1983 to 1987.

Parameter	Count	Covariance	Correlation	R^2	Sig.
Chlorophyll a	54	8.767	0.765	0.585	P<.01
AFDW-Biomass	54	170605.067	0.710	0.504	P<.01
Diatom Density	54	33952.195	0.870	0.757	P<.01
Average Cell Volume	54	1820005.735	0.963	0.927	P<.01
Total Biovolume	54	93.347	0.750	0.563	P<.01
Diversity	54	0.670	0.839	0.703	P<.01
Evenness	54	0.012	0.781	0.609	P<.01

Table 2.6 Daily Accrual Rates of Chlorophyll a (mg m^{-2} d^{-1}) and AFDW-Biomass (mg m^{-2} d^{-1}) for Control (FCD) and Experimental Sites (FEX) on the Ford River for 86-87. Means ± S.E., N in Parentheses.

Date	Chlorophyll a		AFDW-Biomass	
	FCD	FEX	FCD	FEX
10-23-86	0.024 ± .003 (10)	0.009 ± .001 (10)	4.8 ± 1.7 (9)	3.1 ± 0.6 (9)
11-13-86	0.095 ± .016 (8)	0.042 ± .004 (8)	24.8 ± 3.4 (8)	23.4 ± 14.4 (8)
12-12-86	0.028 ± .009 (4)	0.051 ± .007 (4)	13.3 ± 4.0 (7)	16.6 ± 3.4 (7)
1-9-87	0.143 ± .021 (10)	0.280 ± .041 (10)	10.9 ± 2.1 (7)	8.0 ± 1.2 (7)
2-6-87	0.250 ± .080 (8)	0.160 ± .036 (8)	19.4 ± 6.0 (9)	24.9 ± 4.7 (9)
3-6-87	0.240 ± .040 (10)	0.097 ± .021 (10)	25.9 ± 3.0 (8)	28.3 ± 5.0 (8)
5-1-87	0.221 ± .028 (10)	0.140 ± .013 (10)	29.8 ± 3.6 (10)	19.8 ± 2.1 (10)
5-11-87	0.260 ± .007 (10)	0.300 ± .021 (10)	54.1 ± 4.8 (10)	81.7 ± 4.0 (10)
6-8-87	0.140 ± .010 (10)	0.150 ± .010 (10)	51.0 ± 9.0 (9)	42.0 ± 10.0 (9)
7-6-87	0.608 ± .095 (10)	0.415 ± .029 (10)	80.0 ± 6.0 (9)	58.0 ± 12.0 (9)
8-3-87	0.180 ± .020 (9)	0.330 ± .020 (9)	30.3 ± 4.9 (9)	24.1 ± 3.9 (9)
8-17-87	0.160 ± .010 (10)	0.220 ± .020 (10)	43.0 ± 2.1 (10)	53.0 ± 9.3 (10)
9-14-87	0.045 ± .007 (10)	0.049 ± .010 (10)	22.0 ± 2.0 (7)	26.0 ± 2.0 (7)

$\underline{a}$ and that year and month show very highly significant effects. Chlorophyll $\underline{a}$ is the only biological parameter which shows this significant site difference (Table 2.7). Correlation coefficients (r) calculated between sites (Table 2.3 and 2.5) show highly significant relationships of above 0.70 for chlorophyll $\underline{a}$. Calculation of coefficients of variation for this parameter by month indicate that C.V.'s are often low (11-22%) when chlorophyll $\underline{a}$ levels are at their peak. Thus, perhaps single, monthly comparisons of peak standing crop differences and daily accrual rates will allow us to detect more subtle differences than will use of the entire year's data (but see presentation of BACI). Even so, we consider annual patterns of chlorophyll $\underline{a}$ to be important parameters in that they allow us to select time periods of low potential variability (peaks in standing crop) for single "point" comparisons and analyses.

C.   Patterns of Organic Matter Accumulation

Organic matter measured as accumulation of ash free dry weight (AFDW) on glass slides followed the same trends as did chlorophyll $\underline{a}$ (Fig. 2.1, 2.4). There were peaks in organic matter standing crop in July -August of each year of 1200 mg m^{-2} or more and winter lows of about 250 mg m^{-2} (Fig. 2.4, Table 2.8). Organic matter standing crop maintained a clearer yearly pattern than chlorophyll $\underline{a}$, particularly between 1986 and 1987 (Figure 2.4. 2.1). The pattern for the colder winter months is essentially the same for 1987 as for the previous 4 winter periods (Fig. 2.4). The milder winter in 1986-87 was reflected in the high levels of chlorophyll $\underline{a}$ measured from that time period, as well as changes in the diatom community, as discussed below. The effects of this mild winter on organic matter standing crop appeared much less noticeable compared to these other parameters (Figs. 2.1, 2.4, 2.6, 2.7, 2.8, 2.9, 2.10). Organic matter standing crop may be derived from some settling of seston on the slides despite their vertical placement in the stream, or it may be derived from a combination of bacterial, fungal, and algal production. Seston settling may be more related to the hydrologic regime than are the other sources, while bacterial and fungal
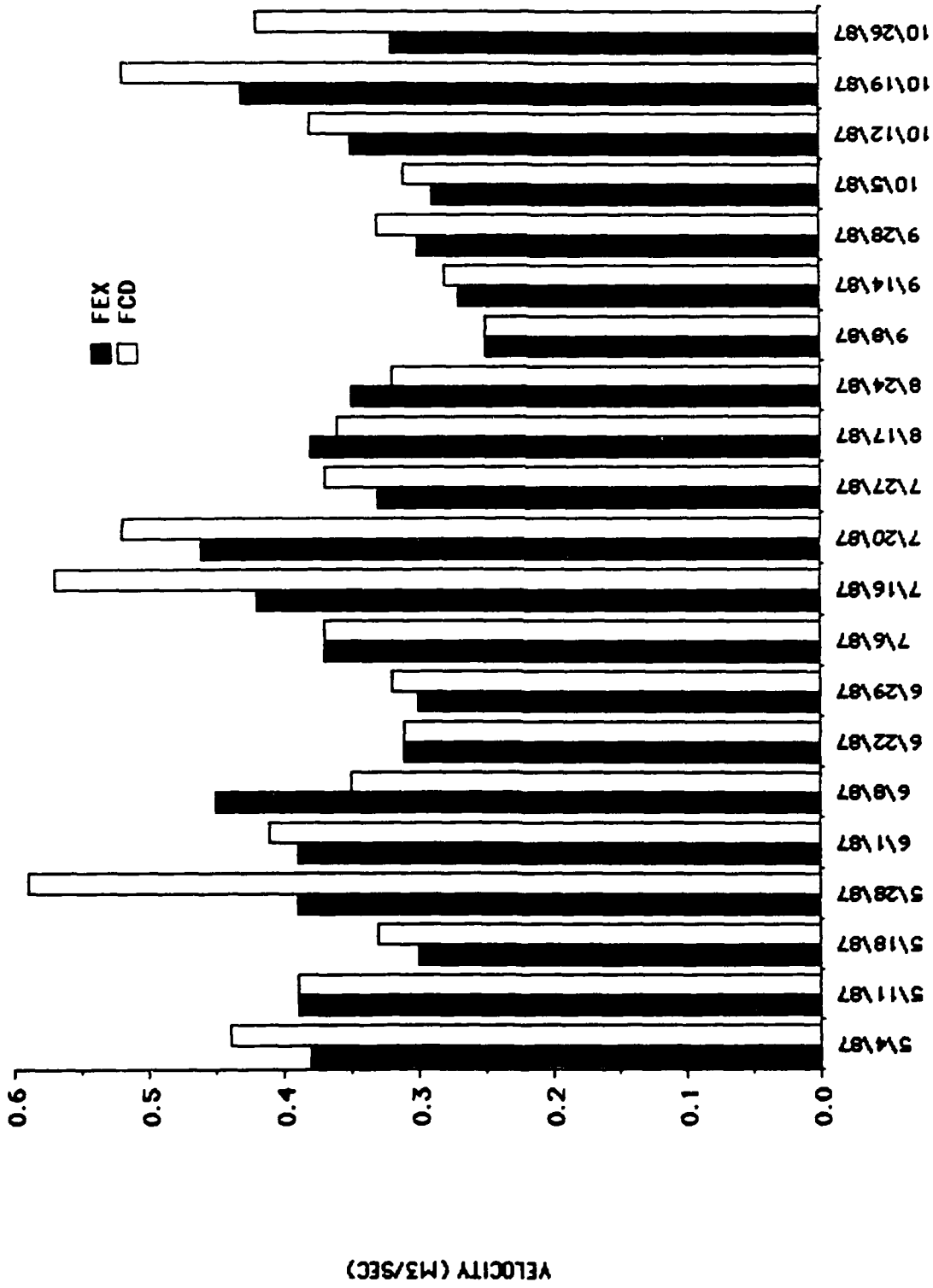
Figure 2.3 Water Velocities at Periphyton Samplers for 1987.

VELOCITY (M3/SEC)

Table 2.7 Three Way ANOVA Tables for Comparisons of Four Years, Two Sites and 52 Sample Months (28 Day Periods) for Cell Density, AFDW-Biomass, Chlorophyll-a, Total Biovolume, Individual Cell Volume, and Species Evenness (1983-87).

Anova table for a 3-factor Analysis of Variance on Y_1:FCD-FEX Cell Density

Source:	df:	Sum of Squares:	Mean Square:	F-test:
YEAR (A)	3	202776.094	67592.031	12.67***
SITE (B)	1	3929.974	3929.974	0.74
AB	3	31801.68	10600.56	1.99*
MONTH (C)	12	1709580.022	142465.002	26.71***
AC	36	2031032.003	56417.556	10.58***
BC	12	82368.255	6864.021	1.29
ABC	36	191993.89	5333.164	

Anova table for a 3-factor Analysis of Variance on Y_1:FCD-FEX AFDW-Biomass

Source:	df:	Sum of Squares:	Mean Square:	F-test:
YEAR (A)	3	2204702.544	734900.848	7.88***
SITE (B)	1	31316.751	31316.571	0.34
AB	3	509112.26	169704.087	1.82
MONTH (C)	12	11139738.874	928311.573	9.95***
AC	36	6862442.675	190623.408	2.04*
BC	12	289701.33	24141.778	0.26
ABC	36	3359218.764	93311.632	

Anova table for a 3-factor Analysis of Variance on Y_1:FCD-FEX CHL-A

Source:	df:	Sum of Squares:	Mean Square:	F-test:
YEAR (A)	3	114.318	38.106	13.89***
SITE (B)	1	11.478	11.478	4.18*
AB	3	10.176	3.392	1.24
MONTH (C)	12	524.609	43.717	15.93***
AC	36	236.215	6.562	2.39**
BC	12	25.962	2.164	0.79
ABC	36	98.78	2.744	

Table 2.7 (continued)

Anova table for a 3-factor Analysis of Variance on Y_1:FCD-FEX Biovolume

Source	df:	Sum of Squares:	Mean Square:	F-test:
YEAR (A)	3	2946.065	982.022	26.75***
SITE (B)	1	8.003	8.003	0.22
AB	3	155.276	51.759	1.41
MONTH (C)	12	1641.439	136.787	3.73**
AC	36	7175.193	199.311	5.43***
BC	12	399.807	33.317	0.91
ABC	36	1321.373	36.705	

Anova table for a 3-factor Analysis of Variance on Y_1:FCD-FEX IND. CELL VOL.

Source:	df:	Sum of Squares:	Mean Square:	F-test:
YEAR (A)	3	44240645.589	14746881.863	138.79***
SITE (B)	1	58596.019	58596.019	0.55
AB	3	117723.638	39241.213	0.37
MONTH (C)	12	58955510.893	4912959.241	46.24***
AC	36	91501708.394	2541714.122	23.92***
BC	12	580842.774	48403.564	0.46
ABC	36	3825063.669	106251.769	

Anova table for a 3-factor Analysis of Variance on Y_1:FCD-FEX SP.EVENNESS

Source:	df:	Sum of Squares:	Mean Square:	F-test:
YEAR (A)	3	.218	.073	27.08***
SITE (B)	1	4.6538E-4	4.6538E-4	0.17
AB	3	.021	7.145E-3	2.65
MONTH (C)	12	.468	.039	14.47***
AC	36	.802	.022	8.16***
BC	12	.048	3.963E-3	1.47
ABC	36	.097	2.696E-3	

$F_{.001}[3, 36] = 6.82$ $F_{.05}[1, 36] = 4.12$ $F_{.001}[12, 36] = 3.89$ $F_{.01}[36, 36] = 2.25$

$F_{.05}[3, 36] = 2.88$ $F_{.01}[12, 36] = 2.75$ $F_{.001}[36, 36] = 1.77$
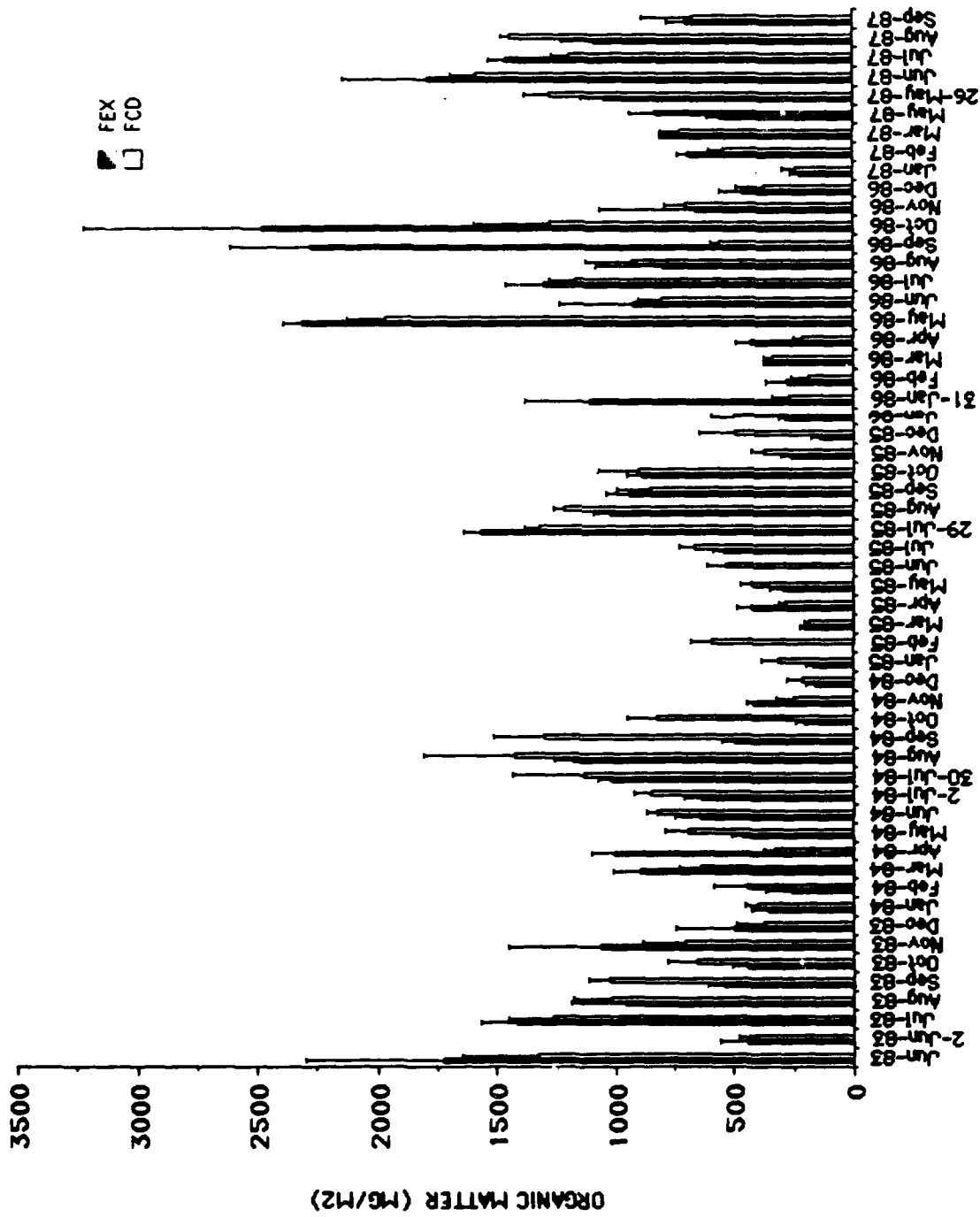
Figure 2.4   Organic Matter Standing Crop for the Ford River, 1983-87.

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

Date Out	Control Site (FCD)	Experimental Site (FEX)
10-9-86	$1,274.7 \pm 314.2$ (10)	$2,472.0 \pm 741.2$ (10)
11-13-86	695.0 ± 95.5 (8)	656.2 ± 402.2 (8)
12-12-86	372.8 ± 112.7 (7)	463.6 ± 95.2 (7)
1-9-87	236.0 ± 55.0 (7)	225.0 ± 35.0 (7)
2-6-87	542.0 ± 57.0 (9)	693.0 ± 44.0 (9)
3-6-87	723.0 ± 85.3 (8)	793.0 ± 12.0 (8)
5-1-87	835.0 ± 100.0 (10)	555.0 ± 57.0 (10)
5-26-87	$1,270.0 \pm 110.0$ (10)	$1,040.0 \pm 100.0$ (10)
6-22-87	$1,584.0 \pm 108.0$ (5)	$1,787.0 \pm 352.0$ (5)
7-20-87	$1,190.0 \pm 71.0$ (10)	$1,460.0 \pm 66.0$ (10)
8-31-8	$1,440.0 \pm 40.0$ (10)	$1,090.0 \pm 130.0$ (10)
9-28-87	670.0 ± 210.0 (7)	700.0 ± 80.0 (7)

production may be related to leaf inprts, or
decomposition of other organic materials. At any rate,
these processes are probably less coupled to solar input
than is algal production. Thus, it is not surprising
that organic matter standing crop and algal standing crop
responded differently to the mild winter conditions of
1986-87.

Organic matter levels were found to vary between
sites and often within a site (average C.V.'s 44% for
1986-87). Paired t-tests between sites, however showed
no significant differences over the five year period
(Table 2.4) or for 1987 data (Table 2.2). Correlations
between both sites (Table 2.5) also indicated a highly
significant correlation coefficient (r=.71). The results
of a three way ANOVA (Table 2.7) for AFDW-biomass showed
no significant site effect over the five year period and
a highly significant year and sample month effect
(p<.001). Thus, variability between years and between
monthly sample periods were the only significant effects
on AFDW-biomass, followed by a smaller, but significant
interaction effect between year and month.

Organic matter accrual rates (Table 2.6 and Fig.
2.5) showed high variability but overall agreement
between sites for both long term and yearly data, but
there were major differences for certain dates. Despite
the occassional, high variability there were no
significant differences between sites for 1987 (Table
2.2).

D.   Patterns of the Ratio of Chlorophyll a to
      Phaeophytin a

The ratio of chlorophyll a pigment to its primary
degradation product , phaeophytin a was determined every
28 days as part of the routine analysis of chlorophyll a
and to determine the physiological health of the algal
community (APHA 1980). This ratio continued to be highly
variable (Table 2.9) for 1986-87. Because of the
apparently random high, variability obtained with this
index, it will probably not be very useful for comparing
ELF effects between the experimental and control sites.
Paired t-tests between sites for 1986-87 showed no
significant differences   (Table 2.2).

FEX
FCD

ORGANIC MATTER ACCRUAL (MG AFDW/M2/DAY)
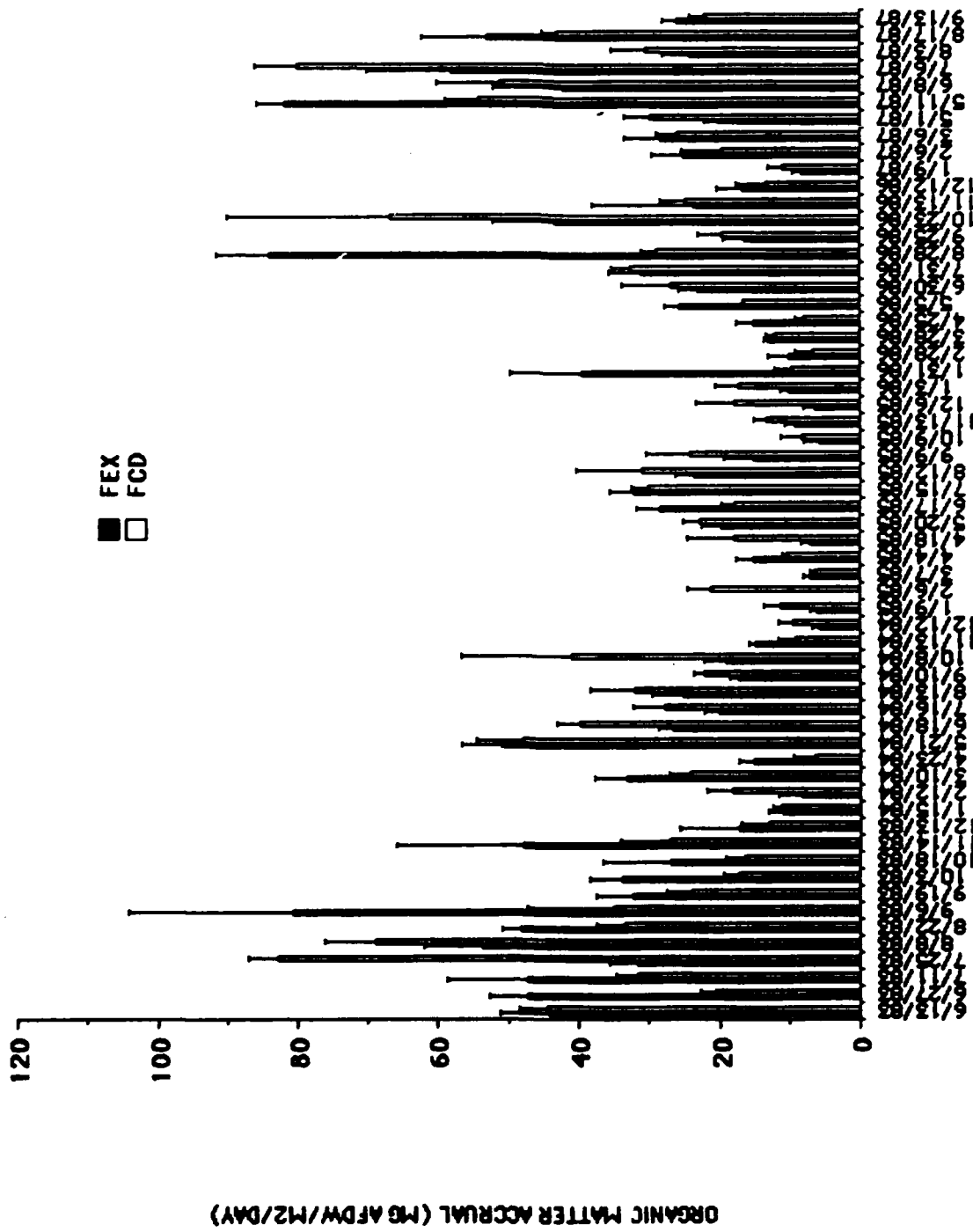
Figure 2.5   Accrual Rates of Organic Biomass for the Ford River, 1983-87.
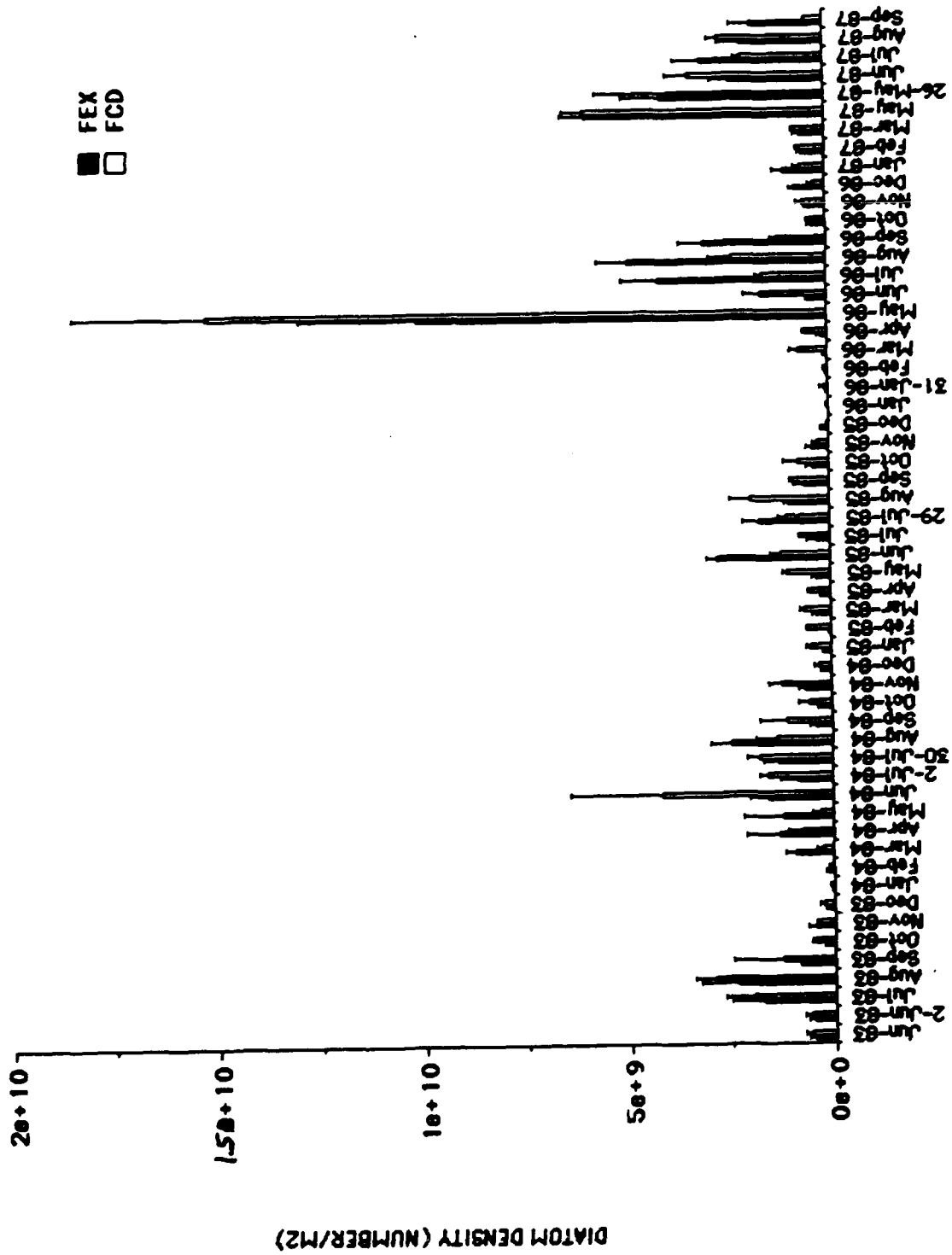
Figure 2.6   Diatom Cell Densities for the Ford River, 1983-87.

Table 2.9   Chlorophyll a to Phaeophytin a Ratios
(Means ± S.E. N in Parentheses) from Slides
Exposed 28 Days in the Ford River.

Date Out	Control Site (FCD)	Experimental Site (FEX)
10-9-86	3.31 ± 0.65 (10)	3.64 ± 0.51 (10)
11-13-86	7.69 ± 1.46 (8)	7.69 ± 4.38 (8)
12-12-86	3.85 ± 1.36 (4)	2.92 ± 0.46 (4)
1-9-87	7.50 ± 1.21 (10)	11.62 ± 3.10 (10)
2-6-87	2.86 ± 3.60 (8)	6.25 ± 1.09 (8)
3-6-87	5.80 ± 0.92 (10)	15.84 ± 7.64 (10)
5-1-87	19.43 ± 10.44 (10)	12.30 ± 0.70 (10)
5-26-87	11.67 ± 0.90 (10)	10.53 ± 1.03 (10)
6-22-87	3.95 ± 0.26 (9)	3.99 ± 0.29 (9)
7-20-87	0.77 ± 0.10 (9)	1.35 ± 0.26 (9)
8-31-87	3.22 ± 0.57 (10)	7.93 ± 2.74 (10)
9-28-87	5.00 ± 1.65 (10)	4.36 ± 0.84 (10)

Table 2.10   Cell Density (No. cells·m^{-2}·10^8) and Biovolume (cubic microns· m^{-2}·10^{11}) for Experimental (FEX) and Control (FCD) Sites for 1986-87. Means ± S.E., N=3.

Date	Experimental (FEX)		Control (FCD)	
	Biovolume	Density	Biovolume	Density
10-9-86	1.46 ± 0.63	3.59 ± 1.06	2.01 ± 0.64	3.96 ± 0.38
11-3-86	7.26 ± 2.02	4.28 ± 0.85	9.19 ± 3.21	5.29 ± 1.59
12-12-86	53.20 ± 6.55	7.48 ± 0.81	14.20 ± 3.57	2.99 ± 0.79
1-9-87	62.00 ± 14.20	10.10 ± 2.34	26.50 ± 3.54	6.17 ± 1.39
2-6-87	26.00 ± 5.12	5.29 ± 1.31	39.60 ± 4.42	6.51 ± 0.64
3-6-87	23.90 ± 2.41	6.11 ± 1.32	33.70 ± 4.11	7.26 ± 0.81
5-1-87	8.02 ± 1.81	58.70 ± 5.77	10.10 ± 0.38	58.80 ± 5.22
5-26-87	4.45 ± 0.81	39.80 ± 9.68	7.48 ± 4.46	38.30 ± 17.70
6-22-87	4.32 ± 0.47	23.00 ± 4.37	9.24 ± 1.71	32.80 ± 5.77
7-20-87	6.28 ± 1.52	30.10 ± 6.19	3.22 ± 0.47	19.80 ± 1.85
8-31-87	4.03 ± 1.62	20.10 ± 5.18	6.06 ± 0.64	25.40 ± 2.46
9-28-87	3.59 ± 0.54	17.50 ± 4.77	1.87 ± 0.31	4.42 ± 0.16

E.   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, Table 2.10). Typically the lowest
values occurred in January or February when the Ford
River was ice covered and 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 the
most affected by the vagaries 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, and May
1987 (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 1987, this peak density
was for early May (> 5 x 10^9 cells per square meter,
Table 2.10), and was followed by a continued steady
decline in diatom densities thereafter throughout the
summer and fall (Fig. 2.6).   Thus, 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. The least predictable variable is
determining the precise magnitude of these density
differences. The peak is generally a period when cell
growth can be very fast and resulting densities
correspondingly large (Fig. 2.6, May 1986).

In spite of these problems in predicting variability
between years, within years both sites appeared to show
corresponding periods of high or low diatom densities.
Results of paired t-tests from cell density data

collected from June 1983 through June 1987 (Table 2.2
and 2.4) indicated that between site differences in cell
density were not significant . The two sites also
appeared to be affected similarly in the timing of the
observed cell density fluctuations as determined from
correlation analyses (Table 2.3 and 2.5) . Results of
the three way ANOVA (Table 2.7) for cell density over
the five year period showed highly significant effects
(p<.001) for yearly and monthly differences in diatom
density. Two interaction effects are also significant;
the most significant interaction between year and month,
followed by a smaller, but significant year and site
interaction. We will have to evaluate our data in
greater detail to determine the exact nature of these
interactions, particularly the one between site and year.

F. Patterns in Individual Cell Volume and Total Biovolume

Major diatom species were measured individually for
volume calculations. Length, width, and thickness
measurements were used from light microscope
determinations along with electron photomicrograph
measurements. This allowed calculation of each species
cell volume by fitting the closest geometric figure or
set of figures to each single species morphology. Volume
estimates for each species counted per sample were
multiplied by the density of that species in the sample
and summed over all the species present to provide an
accurate picture of total biovolume and average
individual cell volume. Paired t-tests on both average
cell volume and total biovolume between sites were not
significantly different (Tables 2.2 and 2.4) for the
five year study period. Correlation coefficients (r) of
.96 for individual cell volume and .75 for total
biovolume for the five year period were highly
significant (p<.01, Table 2.3 and 2.5), indicating that a
fairly close pattern of fluctuations for each parameter
occurred at both sites.

Generally, the total biovolume of diatom cells was
low (Fig. 2.7). Notable exceptions occurred in May 1986
when a large peak was observed which corresponded with a
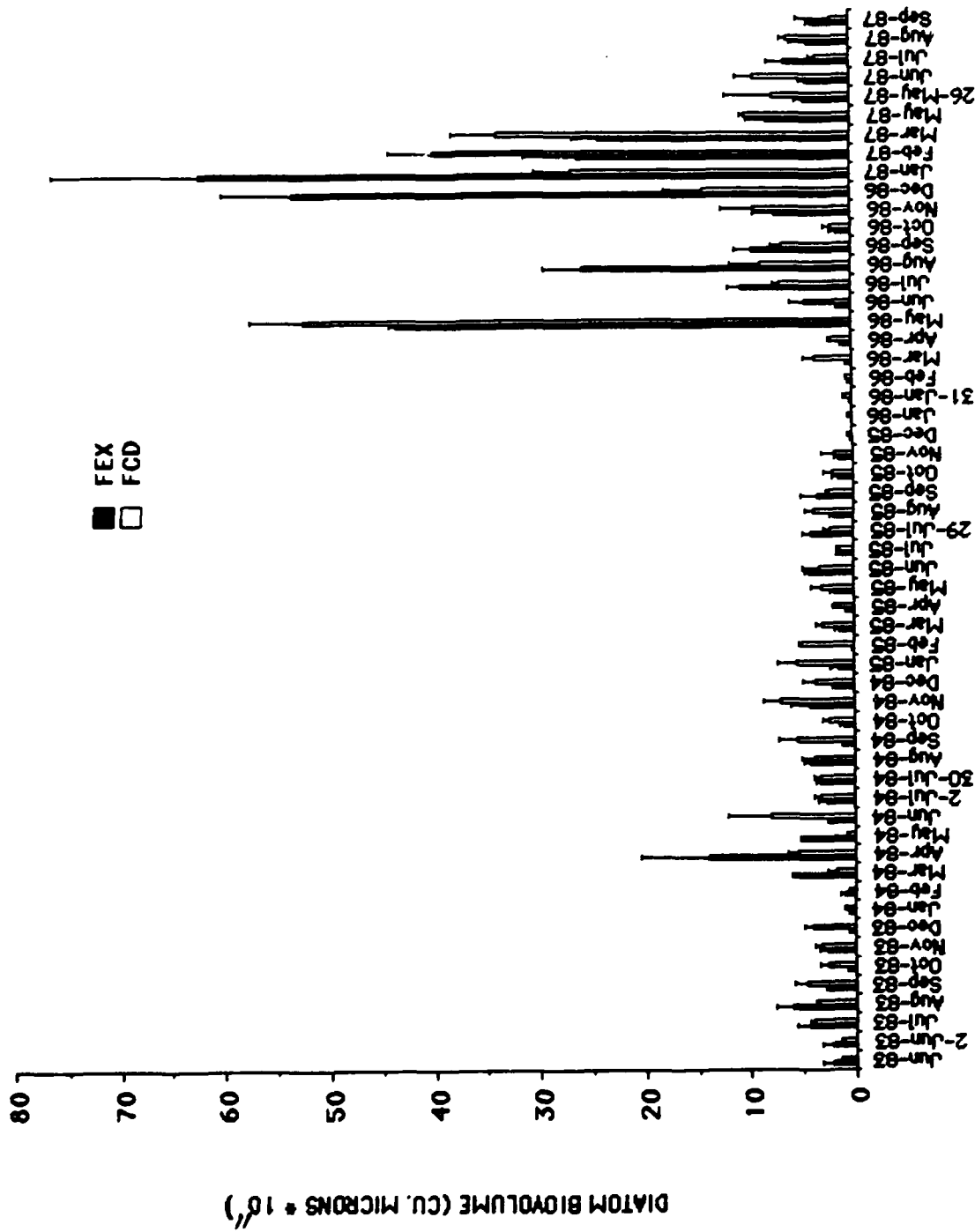
Figure 2.7   Diatom Biovolume for the Ford River, 1983-87.

DIATOM BIOVOLUME (CU. MICRONS * 10^7)

FEX
FCD
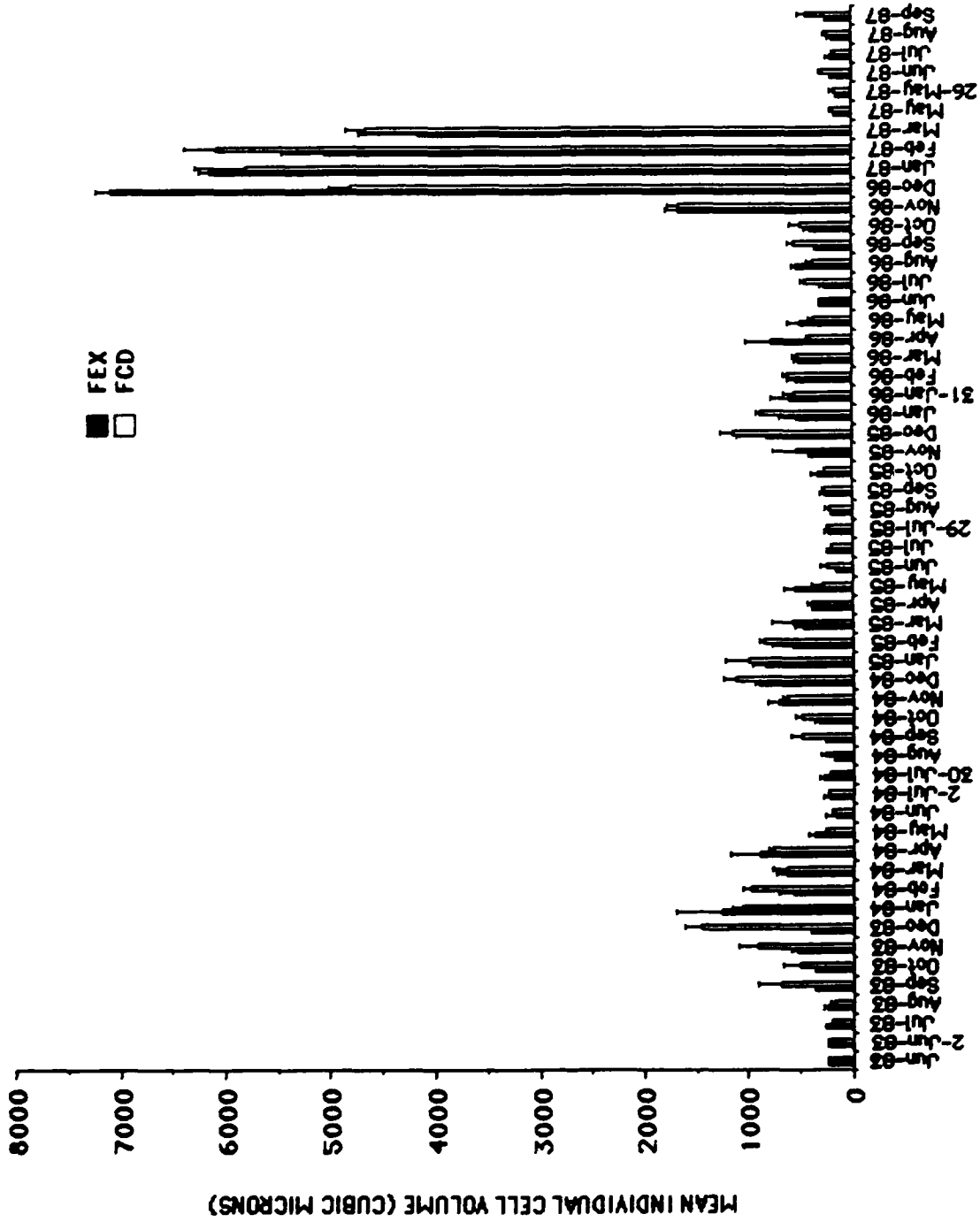
Figure 2.8 Individual Cell Sizes for the Ford River, 1983-87.

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similar peak recorded in diatom density for the same period (Fig. 2.6). The large peaks in biovolume recorded from Dec., Jan, Feb., and March 1987, occurred without a similar rise in diatom density (Figs. 2.6, 2.7). This was due to the presence of the very large diatom _Synedra ulna_, which has an individual cell volume of about 1800 cubic microns compared to the more average volume of about 225 cubic microns for other diatom species (see also discussion under species diversity and evenness). Thus, the presence of a small number of these extremely large forms resulted in an overall large estimate of total biovolume.

Individual cell volumes for the five year period (Fig. 2.8) 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, a pattern also characteristic of the 1987 data (Table 2.11). The three way ANOVA on the five year data set indicated the same significant factor effects for biovolume and individual cell volume (Table 2.7), i.e. year and month and a strong, year x month interaction. No significant site effect or interaction term appeared which included the site factor.

G. 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 subtly 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 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

Table 2.11 Average Individual Diatom Cell Volume (cubic microns) for Experimental (FEX) and Control (FCD) Sites for 1986-87. Means $\pm$ S.E., N=3.

Date	FEX	FCD
10-9-86	384.73 $\pm$ 58.71	485.17 $\pm$ 108.21
11-3-86	1,648.67 $\pm$ 123.75	1,657.33 $\pm$ 103.38
12-12-86	7,080.67 $\pm$ 127.71	4,797.33 $\pm$ 193.28
1-9-87	6,127.67 $\pm$ 101.72	5,785.33 $\pm$ 473.10
2-6-87	5,036.99 $\pm$ 394.92	6,070.00 $\pm$ 288.00
3-6-87	4,145.00 $\pm$ 570.59	4,645.33 $\pm$ 175.58
5-1-87	133.59 $\pm$ 22.56	174.95 $\pm$ 19.05
5-26-87	116.08 $\pm$ 17.98	171.70 $\pm$ 25.67
6-22-87	193.63 $\pm$ 16.62	282.91 $\pm$ 15.27
7-20-87	211.17 $\pm$ 32.21	167.76 $\pm$ 18.26
8-31-87	186.97 $\pm$ 26.65	241.13 $\pm$ 29.52
9-28-87	219.20 $\pm$ 25.90	427.29 $\pm$ 81.60
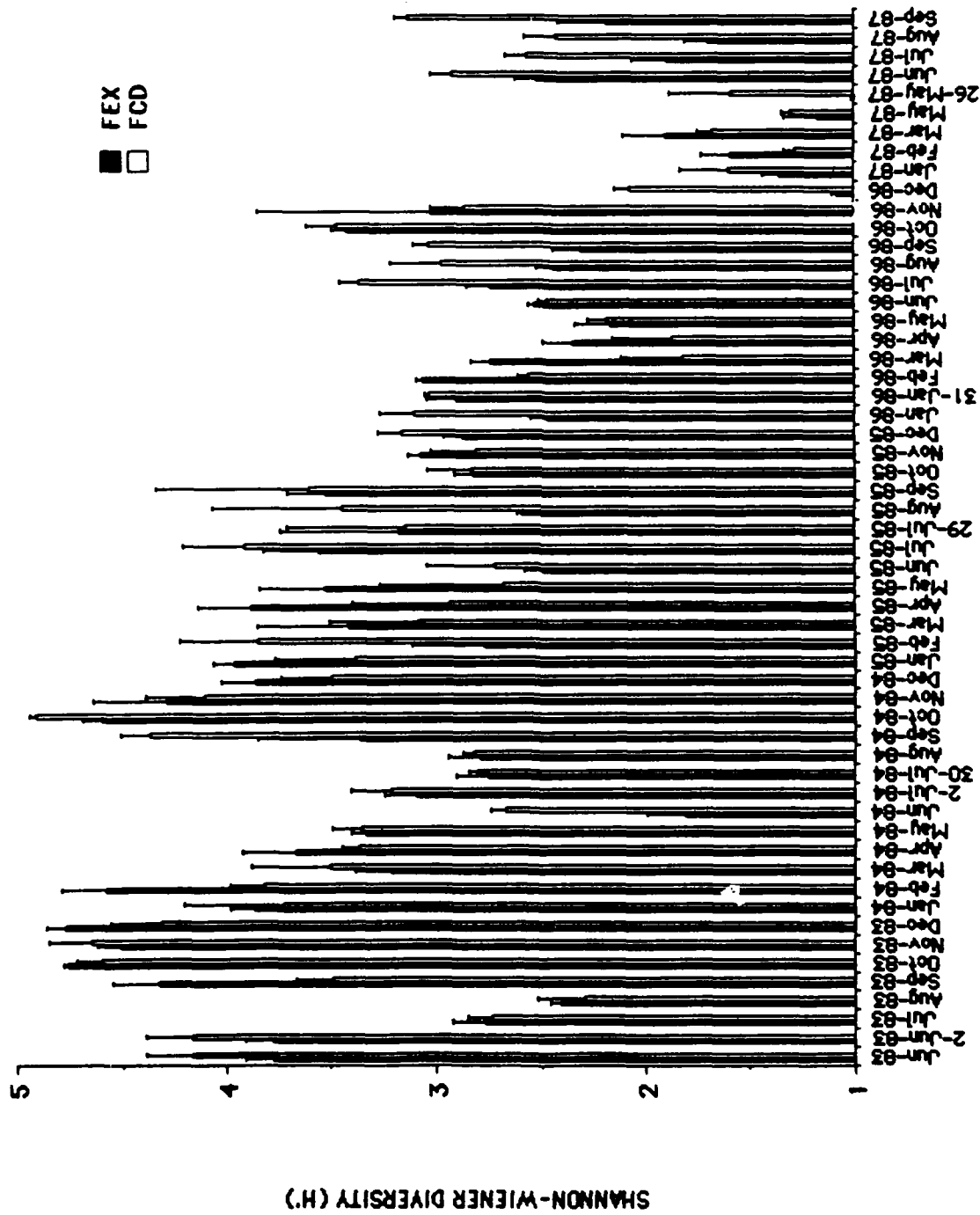
Figure 2.9   Diatom Species Diversity for the Ford River, 1983-87.

SHANNON-WIENER DIVERSITY (H')
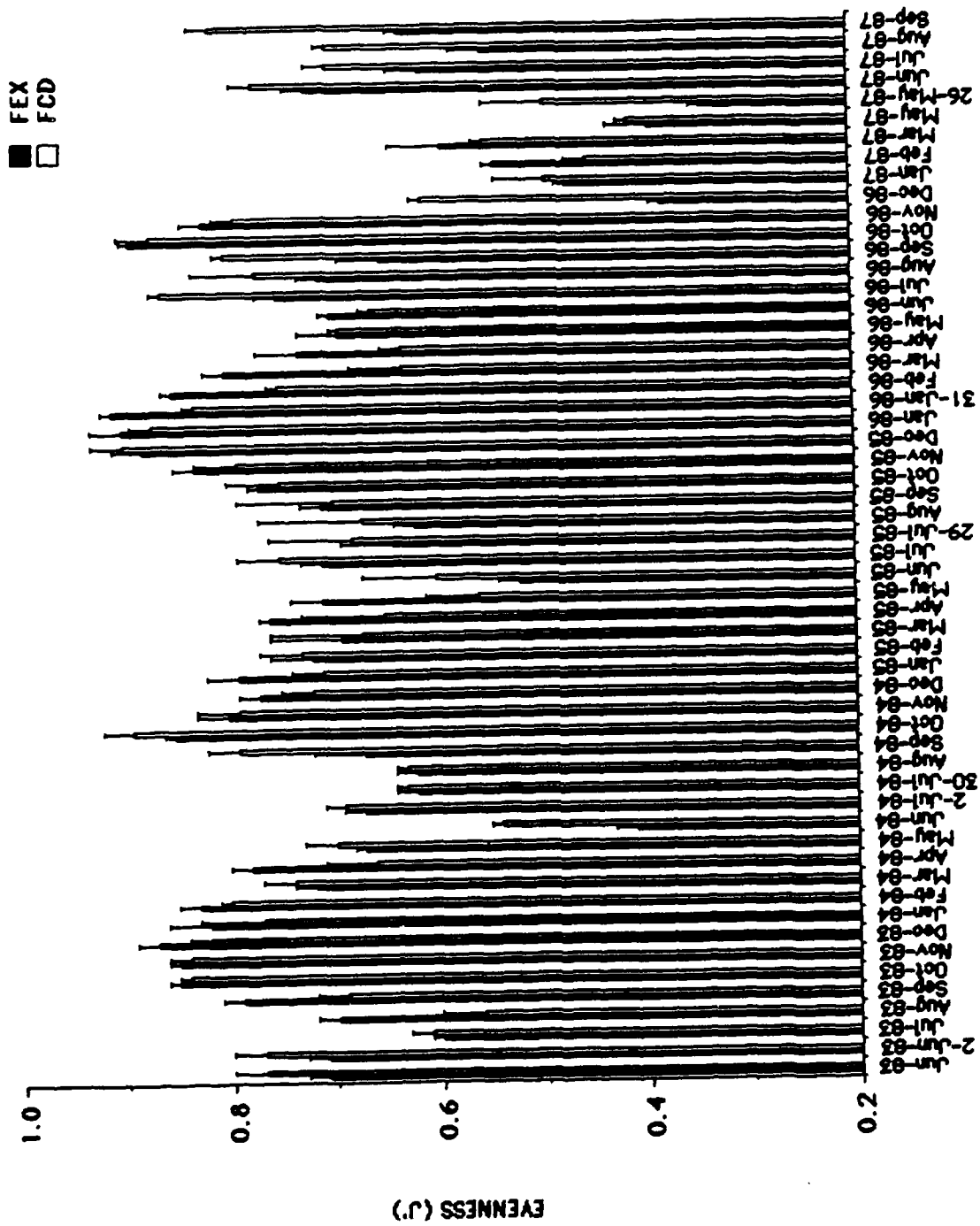
Figure 2.10   Diatom Species Evenness for the Ford River,
1983-87.

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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 Simpson's Evenness index (J) over the entire period from 1983 to 1987 (Figs. 2.9, 2.10) were similar with evenness and diversity appearing to track each other during most seasons. An exception to this pattern of similarity was the winter of 1985-86 when declines in diversity were accompanied by increases in species evenness. In general, however, the pattern for both indices was that greatest values occurred in the winter months and lowest values in the summer. These periods corresponded with predictable increases observed for certain diatom species each year in the wintertime, like Meridion circulare, Gomphonema olivaceum, and Synedra ulna. In addition, decreases in dominance by the genera Achnanthes or Cocconeis from summer time highs of 40-60 % to relatively rare numbers in winter made it more likely that less dramatic increases by otherwise rare or seldom encountered diatom species would be detected in the counts of 300 valves per slide. In winter, no single diatom species reached the dominance levels found for periphyton communities in the summer. This reduction in dominance expla .ns, in part, why the community indices of diversity ᴺᵈ ᵉvenness are generally larger in winter months. one exception to this argument was observed in the winter of 1987 (Figs.2.9, 2.10, Table 2.12) when both indices were lower in the winter than in the summer when dominance should have affected both indices to reduce their magnitude. The large, spindle-like diatom Synedra ulna var. ulna became dominant during the winter and maintained this dominance until the first floods of spring. December to May of 1987 was particularly warm for the region resulting in little ice-cover on the river. These unique conditions may have favored the growth of this large diatom. We expect to correlate snow depth and snow fall measurements with winter diatom dominance to perhaps explain the abundance of this diatom species. While the total cell density measurements made at this time were not unusually high (Fig. 2.6, Table 2.10), calculations of total biovolume and individual cell volume which were based on cell size rather than cell number showed very large peaks, the largest recorded in the last five years (Figs. 2.7, 2.8; Tables 2.10, 2.11)

Comparisons of diversity and evenness between sites through paired t-tests (Table 2.2, 2.4) indicated no significant differences in diversity or evenness between sites. Correlation coefficients of .84 for diversity and .78 for evenness indicated the close relationship of these parameters between the two sites over the five year period (Table 2.5) . The three way ANOVA (Table 2.7) for species evenness corroborated the significance of the previously discussed ANOVA's on the other biological parameters, with year, month, and year x month interaction being significant.

H. Before and After, Control and Impact (BACI) Analysis

Our current methods for analysis of "before" and "after" ELF effects as reported in previous annual reports, include a traditional 3-way analysis of variance. The variables include a year, site, and month effect for each of the biological parameters. The 3-factor ANOVA results were presented in Table 2.7 and discussed under each biological parameter's sub-heading. While this analysis may prove to be the most statistically robust of several analyses available, they all may suffer from a lack of true replication or "pseudoreplication" (Hurlbert 1984). Thus, to consider the validity of such questions, and to remove ourselves from dependancy on a single methodology, we have analyzed our data according to the new techniques presented by Stewart-Oaten et al. (1986). The methods discussed and presented by Stewart-Oaten et al. (1986) are intended to meet Hurlbert's objections (Hurlbert 1984) concerning the appropriate design of sampling programs to assess biological impact at a single point. The design requires replicated sampling in time; Before and After the antenna is operating at both Control and Impact sites (the BACI design).

In the BACI test, Impact (FEX) and Control (FCD) sites are sampled simultaneously with each sampling time acting as a replicate. Only a single point is used to represent a sampling time regardless of the number of samples taken at that time, and that point is the

Table 2.12   Species Diversity (H') and Evenness (J) for Experimental (FEX) and Control (FCD) Sites for 1986-87. Means $\pm$ S.E., N=3.

Date	FEX		FCD	
	Diversity	Evenness	Diversity	Evenness
10-9-86	3.42 $\pm$ .07	0.89 $\pm$ .01	3.47 $\pm$ .15	0.88 $\pm$ .02
11-8-86	3.02 $\pm$ .08	0.82 $\pm$ .02	2.86 $\pm$ .16	0.79 $\pm$ .02
12-12-86	1.08 $\pm$ .03	0.38 $\pm$ .01	2.07 $\pm$ .07	0.61 $\pm$ .01
1-9-87	1.35 $\pm$ .07	0.47 $\pm$ .01	1.60 $\pm$ .23	0.49 $\pm$ .06
2-6-87	1.59 $\pm$ .14	0.54 $\pm$ .01	1.28 $\pm$ .09	0.45 $\pm$ .02
3-6-87	1.90 $\pm$ .02	0.59 $\pm$ .05	1.68 $\pm$ .06	0.55 $\pm$ .01
5-1-87	1.17 $\pm$ .16	0.39 $\pm$ .04	1.30 $\pm$ .04	0.42 $\pm$ .01
5-26-87	0.96 $\pm$ .05	0.34 $\pm$ .01	1.59 $\pm$ .29	0.49 $\pm$ .06
6-22-87	2.52 $\pm$ .10	0.72 $\pm$ .02	2.92 $\pm$ .10	0.77 $\pm$ .02
7-20-87	1.89 $\pm$ .17	0.61 $\pm$ .03	2.57 $\pm$ .10	0.70 $\pm$ .02
8-31-87	1.70 $\pm$ .11	0.55 $\pm$ .02	2.42 $\pm$ .16	0.70 $\pm$ .01
9-28-87	2.18 $\pm$ .23	0.63 $\pm$ .06	3.13 $\pm$ .06	0.81 $\pm$ .01

difference between the Impact and Control sites for that time. By plotting this difference between sites for each sampling time throughout a year, a curve of differences can be determined. The analysis is then used to detect whether the variability about this curve of differences for the two sites changes significantly after the antenna is switched on, or the impact begins from the curve of differences established before the impact started.

Last year, in order to illustrate the use of the BACI analysis (Stewart-Oaten et al.1986), we compared abundances of the diatom species, Cocconeis placentula between our control (FCD) and impact (FEX) sites from 1983 to 1985, using 1985 as a hypothetical "impact" year. This year, to further illustrate the applicability of this technique to test other parameters, we have used it to analyze our "community level" parameters of chlorophyll a and ash free dry weight-biomass data for the years 1984-1987, using 1984-85 as our "before" period and 1986-87 as our "after" period. In fact, the site at FEX received from 2-6 amps (usually 4 amps) ELF exposure for variable time periods during the daylight hours on a total of 31 days during the period from July 22 through October 30, 1986. During 1987, the site at FEX received 15 amps for variable time periods during the daylight hours on a total of 53 days from May 22 through August 31, 1987. These exposures are one tenth or less of the expected exposures when the system becomes fully operational at 150 amps. Nevertheless, the BACI tecnique allows us to compare these two years of minimum exposure to previous years of no exposure.

The BACI procedure examines the difference between the means of any parameter measured simultaneously at both the control and impact sites. The differences recorded before impact are compared to the differences after impact, by either a t-test or the Mann-Whitney U test, in order to determine the effect of the impact. If the magnitude of the difference between the control and impact sites for any given parameter changes significantly after impact, there is a significant effect due to the impact. This procedure assumes that the following conditions 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 are additive. This second condition implies that the difference between the two sites is relatively constant regardless of the actual magnitude of the parameter. The first condition is easily met by a proper study design. In our example, the parameters were measured from glass slides that had been exposed in the river for 28 days prior to sampling. As new slides were used for each 28 day period, the parameters measured on the slides are independent of the value of those parameters for any other 28 day period. The second condition was usually met by log transforming the original data (if necessary) befcre calculating the differences. If regression of the differences versus the averages of the parameter at both sites (for either the actual or the transformed data) produced a slope that was not significantly different from zero, the differences were additive and significance testing proceeded.

Neither the differences between the control and impact sites for chlorophyll a or AFDW-biomass untransformed data were additive. The original values were therefore log transformed for both parameters and both time periods; 1984-85 and 1986-87. The differences between the log transformed values were plotted (Figs. 2.11, 2.12). Regressions of the differences in the logs between each parameter and the average value of the logs all produced slopes that were not significantly different from zero (chlorophyll a before; p=0.28, after; p=0.20: AFDW-biomass before; p=0.38, after; p=0.28). As the log transformed data met the conditions of independence and additivity, the differences in the logs for both parameters were compared between the "before" and "after" periods with a two-tailed t-test. The differences between the control and impact sites for the log of chlorophyll a were not significantly different (t=1.46,p=0.23), nor were the differences for the log of AFDW-biomass (t=1.46,p=0.15).

We feel that this type of analysis is very promising for testing ELF effects. The results from the two types
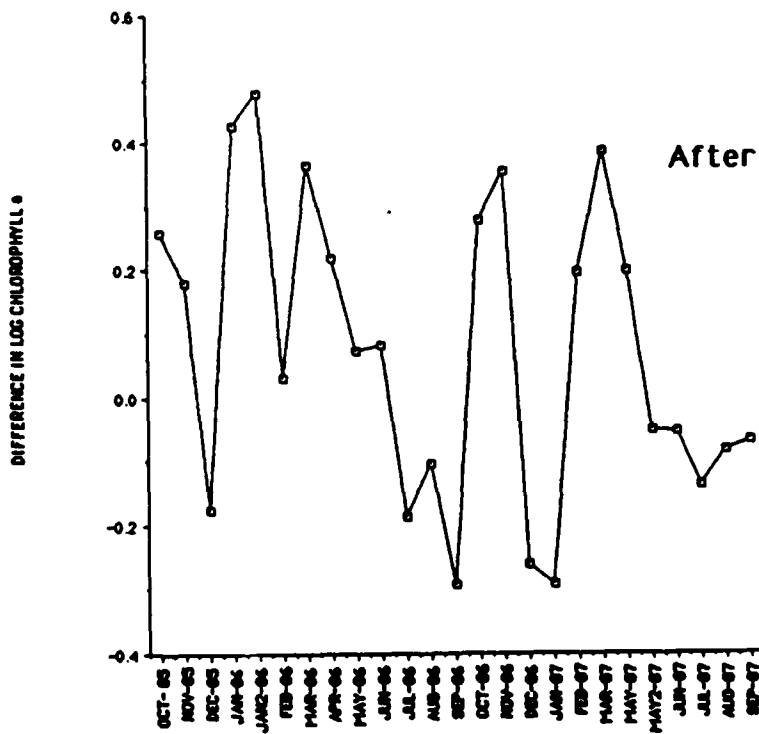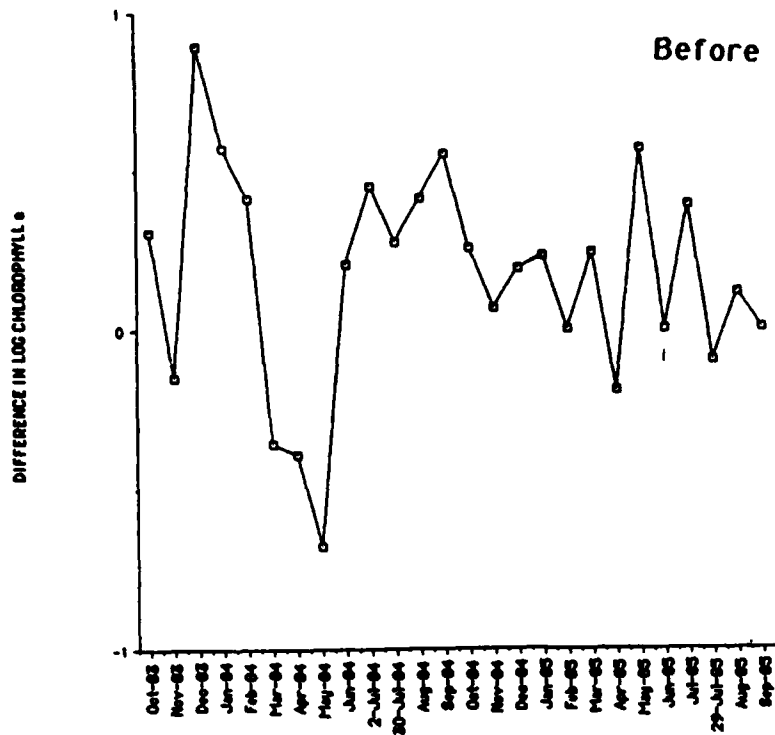
Figure 2.11   Chlorophyll-a Differences Between Sites for the
Before Period and the After Period.

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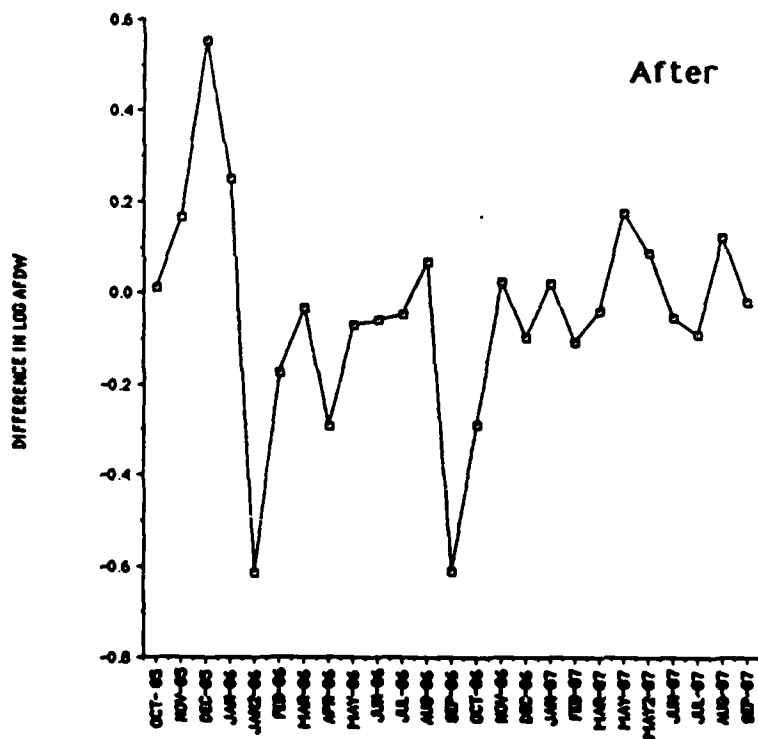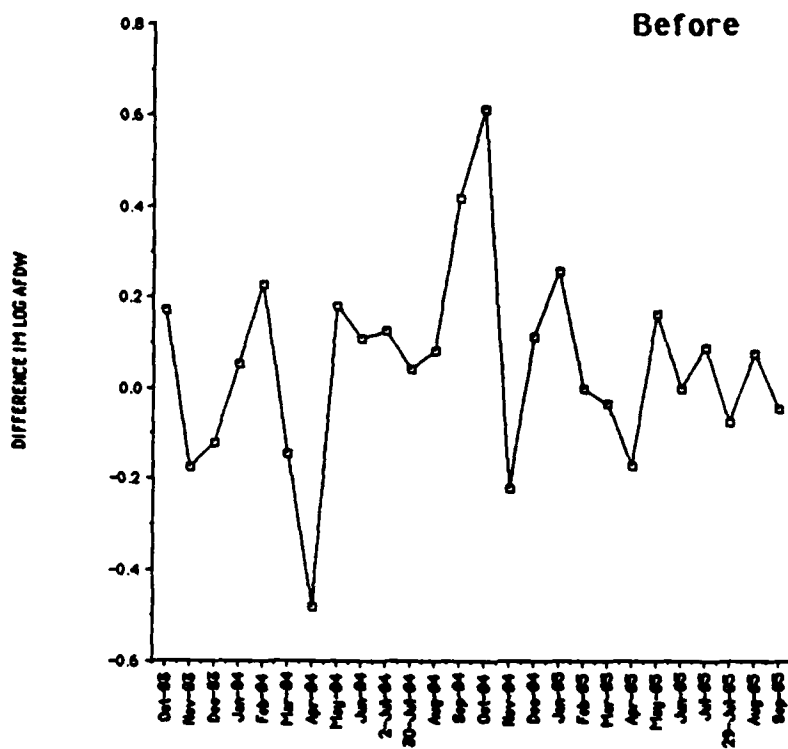
Figure 2.12   Organic Matter Biomass (AFDW) Differences
               Between Sites for the Before and After Period.

of parameters tested indicated that the BACI test provided the ability to detect significant changes in both single species population changes (as reported in last year's annual report) as well as the community level parameters like chlorophyll a and AFDW-biomass (reported here). Thus, we expect to use the BACI analysis in combination with our other statistical methodologies.

I. Effects of Environmental Variables on the Periphyton Community

The entire set of five year data was separated by site and entered for calculation of correlation coefficients. All nutrient chemistry data were used to determine the relationships between the biological parameters and the nutrient resources available in the water. Field chemistry data on pH, alkalinity, hardness, dissolved oxygen, conductivity, suspended and dissolved solids were also correlated to the biological parameters. Additionally, the ambient environmental data were correlated with biological data and included photosynthetically active radiation (PAR) determined below and above the water surface, stream discharge, and water temperature. In addition to these correlation coefficient calculations, exploratory factor analyses were performed on the resulting correlation matrices. These factor analyses will not be reported in detail here but represent an approach that we expect to explore more fully in the future.

The multiple regressions calculated for the June 1983 to June 1985 data sets for each site were presented in the last two annual reports and were not repeated for 1986-87. Likewise, variable transformations were performed last year 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 throughly investigated. Our conclusion from last year's 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 1987. We will present small

segments of this analysis as the entire correlation matrix was over twelve pages in length, and the factor analysis ran over seventy five pages.

Stepwise regressions in 1986 for chlorophyll a and the ambient monitoring parameters indicated that water temperature alone explained 61% of the variance followed by conductivity of the water (33%). Water temperature was the only significantly important factor for organic matter standing crop and accounted for only 36% of the variability. Between the biological variables, organic matter biomass explained 55% of the variance in diatom cell density. Only water temperature of the physical and chemical variables was even weakly correlated with density.

Comparisons of the five year data set between sites indicated some differences in the correlations of the biological parameters with the water chemistry constituents (Table 2.13). Chlorophyll a correlated significantly with pH at FEX but not at FCD (Table 2.13). AFDW-biomass correlated significantly with conductivity at FCD but not FEX (r=.50 and .09), while cell density showed a significant negative correlation with hardness at FCD but not at FEX. While most variable relationships appeared generally constant in their magnitude and effect on both sites (Table 2.13), the contradictions as noted may deserve further investigation. Chlorophyll a again appeared to be largely temperature influenced, and negatively correlated to discharge. Thus, temperature, a physiological constraint, and discharge, a physical constraint, were closely correlated with chlorophyll a levels. These relationships are not surprising in that low flow periods in mid-summer are often the times of highest temperatures and benthic algal production.

AFDW-biomass levels (Table 2.13) were correlated strongly with temperature and dissolved oxygen, although not as strongly as chlorophyll a. Cell density appeared to be most influenced by the amount of sunlight or PAR (Table 2.13), since high levels of PAR above the water surface significantly correlated with high cell densities. Cell volume showed inconsistent relationships

Table 2.13   Significant Correlations Between Water Chemistry Parameters and Biological Parameters by Sites for 1983-87.   (N=54).

Biological Parameter	Water Chemistry Parameter	Correlation Coefficient (r)	
		FCD	FEX
Chlorophyll-A	conductivity	.42**	.36**
	dissolved oxygen	-.61**	-.54**
	hardness	.34*	.33*
	pH	.09	.32*
	water temperature	.67**	.48**
	alkalinity	.34*	.38**
	discharge	-.31*	-.28
AFDW-Biomass	conductivity	.50**	.09
	dissolved oxygen	-.32*	-.33*
	water temperature	.34*	.23
Cell Density	hardness	-.31*	-.17
	surface solar radiation	.35**	.35**
Cell Volume	hardness	.46**	.14
	alkalinity	.41**	.18
Species Diversity	suspended solids	.07	.34*
	surface solar radiation	-.51**	-.53**
	below water solar	-.39**	-.38**
Species Evenness	conductivity	.25	.46**
	dissolved oxygen	-.34*	-.40**
	hardness	.30*	.36**
	water temp.	.18	.42**
	alkalinity	.37**	.43**
	dissolved solids	.35**	.07
	surface solar radiation	.35**	-.46**
	below water solar	.24	-.32*

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 diffference (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, P/R 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. Alternate sites were tested first in alternate weeks.

The assumptions made for the purposes of production calculations considered algal periphyton to occupy only the upper surface half of each rock. Surface area was, therefore, determined by wrapping each rock in aluminum foil, straightening the foil, and determining the area of foil using a leaf area meter (LI-COR). Production estimates; mg O_2 /mg Chl a and mg O_2/m^2 were calculated after subjecting the rocks with attached periphyton to chlorophyll a extraction. We discovered errors in the calculations from past annual reports. Thus, corrected data are presented in this annual report since the start of this procedure in 1984.

We agree with reviewers from past years that P/R studies should be done for as many seasons of the year as possible. However, these procedures are labor intensive 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.

Gross and net primary production and respiration were very similar between the control (FCD) and experimental (FEX) sites for 85-87 (Tables 2.15 and 2.16). The modified procedures used in 1985-86-87 resulted in lower standard deviations for each parameter and in

that did not hold between sites (Table 2.13). Species diversity and species evenness were negatively correlated with the amounts of sunlight (except species evenness for FCD) (Table 2.13), This and the positive correlation of PAR and cell density suggested that optimum growing conditions for diatoms during the summer might result in dominance by only a few species. In fact, Achnanthes and Cocconeis become very dominant in the summer during low flow and warm temperature conditions, and this dominance decreases as temperatures cool and flows increase during the autumn (Oemke and Burton 1986).

The correlations between the biological and nutrient parameters (Table 2.14), indicated that chlorophyll a, AFDW-biomass, and cell density were significantly, negatively correlated to levels of nitrate and inorganic nitrogen in the water at both sites. Species diversity also showed a negative correlation with chloride levels. These correlations appear to show patterns generally reverse from expected. However, the low r values coupled with preliminary experiments on nutrient additions suggest that these results are misleading. Additions of N and P stimulated chlorophyll a and AFDW-biomass production under low flow, mid-summer conditions in experiments conducted in 1987. We will finish the analysis of density and changes in species composition for this experiment during the upcoming year and will better be able to predict the effects of nutrient additions on these parameters at that time.

J. Photosynthesis-respiration ratio studies (P/R)

A separate study was undertaken to evaluate primary production using short term changes in dissolved oxygen gas 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.

Table 2.14 Significant Correlations between Biological Parameters and Nutrient Water Chemistry Parameters by Sites for 1983-87 (N = 45).

Biological Parameter	Water Chemistry Parameter	Correlation Coefficient (r)	
		FCD	FEX
Chlorophyll a	Nitrate-N	-.35*	-.31*
	Inorganic-N	-.34*	-.30*
AFDW-Biomass	Nitrate-N	-.35*	-.39*
	Inorganic-N	-.32*	-.40**
	Reactive-P	.22	.41**
	Chloride	-.005	.33*
Cell Density	Inorganic-N	-.21	-.30*
Diversity	Nitrite-N	.08	-.37*
	Total-P	-.02	-.33*
	Chloride	-.35*	-.39*
Total Biovolume	Organic-N	.06	.30*

*, P < .05
**, P < .01

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additional convergence of mean values between sites compared to 1984. Differences between years were not very great for these parameters (Tables 2.15, 2.16) suggesting that this community based comparison offers a robust means for detection of possible ELF effects once the antenna goes operational.

K.   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 1986-87 data showed no site differences, although the five year three way ANOVA indicated a small but significant difference between sites. Combining all sample periods in a single paired t-test, however, showed no significant differences existed between sites. Likewise in 1986 and in 1985 no between site differences were detected (yearly paired t-tests). Differences between sites occurred in 1983 and 1984 only. This parameter may be better used to test single point, or single sample period differences between sites when production is high and the coefficients of variation for chlorophyll a also low. Additionally this parameter seems suitable for testing with the new BACI technique to detect differences between sites once ELF exposure begins.

2.   Organic Matter

Organic matter (AFDW-biomass) standing crop and accrual rates showed considerable year to year variability similar to chlorophyll a. These parameters have been consistently characterized by showing no significatnt differences between sites since 1983. The combined paired t-test and three way ANOVA showed very close agreement, analyzing all the data available, to indicate no between site differences. The only trend has been for a July-August peak in standing crop and accrual

Table 2.15 Hourly Production and Respiration Rates for Rock Substrates at the Ford Control Site (FCD) for 1984-87.

Date	NET PRIMARY PRODUCTION			RESPIRATION*			GROSS PRIMARY PRODUCTION**	
	mgO_2/m^2	mg Chl a/m²	$\dfrac{mgO_2}{mgChl\ a}$	mgO_2/m^2	mgChl a/m²	$\dfrac{mgO_2}{mgChl\ a}$	mgO_2/m^2	$mgO_2/mgChl\ a$
7/26/84	40.79 ± 9.77	15.44 ± 1.85	2.69 ± 0.82	88.57 ± 3.30	21.01 ± 2.18	4.26 ± 0.54	129.36	6.95
8/16/84	71.17 ± 10.33	23.59 ± 2.50	3.22 ± 0.83	123.05 ± 13.49	19.43 ± 3.07	6.05 ± 1.22	194.22	9.27
9/13/84	82.82 ± 25.73	18.79 ± 1.31	4.00 ± 0.99	48.11 ± 25.93	20.88 ± 2.19	2.25 ± 1.33	139.93	6.25
10/04/84	28.90 ± 27.51	24.33 ± 3.33	1.53 ± 1.55	41.90 ± 40.10	22.60 ± 3.53	1.37 ± 1.20	70.80	2.90
Avg ± S.D.	55.92 ± 25.27	20.54 ± 4.19	2.86 ± 1.04	75.41 ± 37.91	20.98 ± 1.30	3.48 ± 2.10	131.33 ± 50.41	6.34 ± 2.63
6/25/85	66.21 ± 17.39	21.32 ± 6.76	2.99 ± 0.38	55.31 ± 10.55	24.19 ± 3.50	2.37 ± 0.86	121.52	5.36
7/02/85	80.48 ± 9.88	36.61 ± 2.49	2.19 ± 0.13	56.36 ± 14.49	38.06 ± 5.13	1.51 ± 0.23	136.84	3.70
7/10/85	85.87 ± 50.15	31.54 ± 1.65	2.68 ± 1.45	9.37 ± 8.84	22.99 ± 4.90	0.50 ± 0.45	95.24	3.18
7/23/88	70.92 ± 21.14	16.58 ± 7.64	3.55 ± 1.09	22.64 ± 6.61	16.21 ± 6.92	1.62 ± 0.38	93.56	5.17
8/1/85	22.21 ± 12.66	12.88 ± 5.50	1.70 ± 0.37	60.76 ± 53.09	15.86 ± 3.34	4.45 ± 4.69	89.97	6.15
8/18/85	78.04 ± 18.68	17.53 ± 6.81	4.79 ± 1.41	26.83 ± 9.15	16.76 ± 7.98	1.72 ± 0.42	104.87	6.51
8/14/85	89.06 ± 1.40	18.48 ± 9.14	5.39 ± 1.88	28.06 ± 1.40	11.74 ± 3.38	2.52 ± 0.65	117.12	7.91
Avg ± S.D.	70.39 ± 22.68	22.13 ± 8.66	3.33 ± 1.35	37.05 ± 20.11	20.83 ± 8.74	2.10 ± 1.23	107.87 ± 19.13	5.43 ± 1.63
6/18/86	84.57 ± 8.41	14.50 ± 6.77	6.49 ± 1.99	27.91 ± 12.06	25.86 ± 8.64	1.06 ± 0.17	112.78	7.55
6/25/86	89.58 ± 10.13	16.69 ± 7.72	5.97 ± 2.13	12.19 ± 4.44	17.67 ± 7.22	0.70 ± 0.04	101.77	6.67
7/2/86	32.00 ± 11.18	13.94 ± 3.90	2.28 ± 0.16	40.47 ± 8.99	17.76 ± 2.03	2.33 ± 0.51	72.47	4.61
7/9/86	77.26 ± 36.27	16.91 ± 1.47	4.54 ± 2.05	47.50 ± 5.47	19.88 ± 4.86	2.44 ± 0.40	124.76	6.98
7/22/86	20.89 ± 5.22	12.37 ± 5.32	1.98 ± 1.19	38.78 ± 11.57	10.43 ± 1.66	3.92 ± 1.90	59.67	5.90
7/24/86	48.34 ± 10.72	11.91 ± 0.33	3.92 ± 0.99	23.46 ± 6.44	12.45 ± 0.64	1.87 ± 0.45	71.80	5.79
7/30/86	46.63 ± 43.92	22.51 ± 4.69	1.73 ± 1.10	34.10 ± 4.05	26.27 ± 4.51	1.41 ± 0.67	80.73	3.14
8/12/86	36.90 ± 35.93	16.51 ± 3.89	2.50 ± 2.30	34.65 ± 9.78	18.92 ± 6.49	2.01 ± 1.07	71.54	4.51
8/21/86	23.84 ± 11.65	20.74 ± 12.44	5.45 ± 3.54	38.71 ± 14.95	18.08 ± 14.03	2.41 ± 1.69	62.55	7.86
Avg ± S.D.	51.15 ± 26.35	16.23 ± 3.57	3.87 ± 1.83	33.09 ± 10.52	18.59 ± 5.24	2.02 ± 0.94	84.23 ± 23.20	5.89 ± 1.56
6/10/87	34.50 ± 12.40	21.90 ± 14.37	2.19 ± 1.51	20.13 ± 10.61	21.74 ± 24.64	1.51 ± 0.78	54.63	3.70
6/24/87	107.48 ± 30.10	***		45.32 ± 12.37			152.80	
7/1/87	65.25 ± 20.81			11.02 ± 6.13			76.27	
7/8/87	97.21 ± 71.65			47.09 ± 17.45			168.86	
7/22/87	109.91 ± 67.95			34.66 ± 18.65			114.57	
7/29/87	87.62 ± 13.84	29.49 ± 11.29	3.61 ± 1.09	38.67 ± 7.67	25.40 ± 6.30	1.67 ± 0.27	126.29	5.28
8/12/87	63.44 ± 27.14	20.13 ± 3.11	3.28 ± 1.57	36.56 ± 9.20	35.30 ± 8.37	1.05 ± 0.25	98.74	4.33
8/19/87	61.75 ± 5.24	24.24 ± 2.35	3.39 ± 0.39	37.84 ± 6.84	24.33 ± 5.91	1.59 ± 0.36	119.59	4.98
8/26/87	47.78 ± 5.83	16.08 ± 7.11	3.49 ± 1.80	32.85 ± 1.95	21.73 ± 8.04	1.72 ± 0.60	80.63	5.21
9/2/87	37.67 ± 15.74	19.52 ± 4.14	1.88 ± 0.40	41.90 ± 7.37	26.04 ± 6.98	1.74 ± 0.72	79.57	3.62
Avg ± S.D.	73.26 ± 27.78	21.89 ± 4.60	2.97 ± 0.74	34.60 ± 11.17	25.76 ± 5.01	1.55 ± 0.26	107.20 ± 36.08	4.52 ± 0.74

* = Gross Respiration of Entire Microbial Community/Bacteria and Algae
** = Total Metabolism = Respiration + Net Primary Production
*** = Chlorophyll a data missing for 6/24 - 7/22/1987

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Table 2.16 Hourly Production and Respiration Rates for Rock Substrates at the Ford Experimental Site (FES) for 1984-1987.

Date	NET PRIMARY PRODUCTION			RESPIRATION			GROSS PRIMARY PRODUCTION	
	mgO$_2$/m^2	mg Chl a/m^2	mgO$_2$/mgChl a	mgO$_2$/m^2	mgChl a/m^2	mgO$_2$/mgChl a	mgO$_2$ m^2	mgO$_2$/mgChl a
8/9/84	6.46 ± 5.89	8.23 ± 1.29	0.85 ± 0.86	60.30 ± 48.85	13.73 ± 7.17	5.08 ± 4.88	66.76	5.93
8/23/84	205.41 ± 57.78	18.94 ± 3.51	11.28 ± 5.11	86.28 ± 35.33	19.27 ± 3.35	4.35 ± 2.83	291.69	15.63
9/6/84	40.88 ± 45.44	15.32 ± 6.03	3.78 ± 1.37	24.38 ± 11.56	16.40 ± 4.12	1.68 ± 0.83	65.26	5.46
9/20/84	69.75 ± 69.29	21.62 ± 1.45	4.14 ± 1.56	54.29 ± 43.75	17.20 ± 3.50	4.44 ± 1.09	124.04	8.58
Avg ± SD	80.63 ± 87.12	16.03 ± 5.80	5.01 ± 4.43	56.31 ± 25.41	16.65 ± 2.29	3.89 ± 1.51	136.94 ± 106.74	8.90 ± 4.69
6/25/85	38.83 ± 12.42	11.14 ± 3.04	3.78 ± 2.19	24.38 ± 10.30	7.78 ± 3.01	3.15 ± 0.90	63.21	6.93
7/02/85	78.07 ± 28.01	26.32 ± 8.16	2.94 ± 0.49	47.94 ± 13.18	32.04 ± 7.05	1.97 ± 0.62	126.01	4.91
7/10/85	57.45 ± 8.44	13.97 ± 4.55	4.26 ± 0.71	22.94 ± 5.39	20.23 ± 7.84	1.28 ± 0.59	80.39	5.54
7/23/85	67.47 ± 13.53	18.31 ± 3.95	3.73 ± 0.56	46.36 ± 1.95	21.45 ± 6.52	2.27 ± 0.53	113.78	6.00
8/1/85	64.43 ± 25.79	13.54 ± 3.80	5.22 ± 3.23	62.75 ± 3.67	15.14 ± 6.33	4.56 ± 1.53	127.18	9.78
8/8/85	11.27 ± 10.26	15.67 ± 1.16	0.68 ± 0.59	34.95 ± 11.40	20.23 ± 6.09	1.91 ± 1.12	46.22	2.59
8/14/85	86.77 ± 10.75	17.00 ± 2.48	5.11 ± 0.11	28.64 ± 9.33	21.80 ± 9.56	1.38 ± 0.21	115.41	6.49
Avg ± SD	57.75 ± 25.53	16.56 ± 4.91	3.67 ± 1.54	38.28 ± 14.66	19.81 ± 7.34	2.36 ± 1.15	96.03 ± 32.56	6.03 ± 2.18
6/18/86	55.86 ± 23.21	16.67 ± 7.02	3.98 ± 2.57	47.22 ± 17.19	14.42 ± 7.24	4.45 ± 3.76	103.68	8.43
6/25/86	73.63 ± 46.67	13.42 ± 3.02	4.52 ± 1.05	9.57 ± 8.18	11.65 ± 0.22	0.82 ± 0.69	83.20	5.34
7/2/86	53.46 ± 4.97	12.15 ± 2.89	4.59 ± 1.64	21.05 ± 8.06	11.85 ± 3.42	1.77 ± 0.33	74.51	6.36
7/9/86	52.53 ± 52.21	18.51 ± 15.15	2.46 ± 0.90	43.00 ± 12.14	13.24 ± 4.79	3.60 ± 0.43	95.53	6.06
7/22/86	68.25 ± 36.09	19.31 ± 8.33	3.40 ± 0.84	43.13 ± 10.47	8.92 ± 2.41	4.23 ± 2.39	111.38	7.63
7/23/86	68.16 ± 47.50	18.75 ± 15.74	4.16 ± 0.54	46.67 ± 11.10	11.91 ± 0.33	3.92 ± 0.99	114.83	8.08
7/30/86	30.75 ± 1.06	18.53 ± 0.30	1.67 ± 0.07	51.01 ± 13.11	23.00 ± 10.46	2.59 ± 1.44	81.76	4.26
8/12/86	68.76 ± 30.86	15.85 ± 1.83	4.23 ± 1.59	28.77 ± 13.92	21.29 ± 5.07	1.38 ± 0.67	97.53	5.61
8/21/86	86.30 ± 13.23	17.84 ± 9.47	10.37 ± 9.21	36.51 ± 1.72	14.09 ± 13.88	2.30 ± 1.04	116.81	12.67
Avg ± SD	61.29 ± 14.85	16.78 ± 2.53	4.37 ± 2.45	36.33 ± 13.87	14.37 ± 4.70	2.78 ± 1.32	97.63 ± 15.34	7.16 ± 2.48
6/10/87	39.63 ± 21.19	16.25 ± 4.17	2.33 ± 0.89	31.86 ± 8.60	5.33 ± 1.71	6.34 ± 2.66	71.84	8.67
6/24/87	90.19 ± 16.68	***		42.00 ± 8.94			132.19	
7/1/87	88.69 ± 4.36			38.96 ± 7.51			127.85	
7/8/87	92.13 ± 74.39			51.79 ± 20.32			143.92	
7/22/87	130.70 ± 8.51			16.63 ± 3.59			147.22	
7/29/87	108.43 ± 26.69	18.41 ± 2.60	5.46 ± 0.13	33.70 ± 3.30	25.92 ± 3.84	1.44 ± 0.36	142.13	6.90
8/12/87	106.84 ± 3.26	31.29 ± 3.00	3.43 ± 0.22	35.28 ± 9.31	30.56 ± 7.11	1.16 ± 0.25	142.12	4.59
8/19/87	38.36 ± 20.54	22.38 ± 7.71	1.73 ± 0.98	17.22 ± 0.12	18.12 ± 1.34	0.96 ± 0.06	55.58	2.69
8/26/87	74.99 ± 16.23	15.73 ± 4.78	3.84 ± 0.73	19.36 ± 2.18	18.13 ± 2.15	1.42 ± 0.53	94.35	5.26
9/21/87	44.60 ± 6.57	17.86 ± 7.09	2.76 ± 0.97	17.52 ± 18.13	20.05 ± 11.17	1.13 ± 1.31	62.12	3.89
Avg S.D.	81.48 ± 31.71	20.32 ± 5.86	3.26 ± 1.32	30.43 ± 12.26	19.69 ± 8.58	2.08 ± 2.10	111.94 ± 37.02	5.33 ± 2.15

rates and winter time lows for both standing crop and accrual.

3.   Chlorophyll a to Phaeophytin a Ratios

This ratio continued to vary widely throughout the year in 1986-87. The random nature of the fluctuations appear to indicate that this parameter will not be useful for detection of ELF effects.

4.   Diatom Cell Density

Diatom cell density continued to be characterized by no statistical difference between sites, regardless of length of data set compared or type of analyses performed. Density appears to be high throughout the summer periods with some tendency towards a June peak. Density was always lowest during the winter periods.

5.   Species Diversity and Evenness

Diatom species diversity and evenness were not significantly different in 1987. This continues the trend seen in 1983, 1984, 1985 and, 1986. Annual trends show a high diversity and evenness during winter (except winter of 1987) and lower values during the summer periods.

6.   Total Biovolume and Individual Cell Volume

Individual cell volume comparisons of diatoms between sites, showed no significant differences. Total biovolume was also not significantly different between sites for 1987. Combined data from 83-87 used in both paired t-tests and three way ANOVA's showed no between site differences for these two parameters. Individual cell volume generally is larger during the winter periods and smallest in the summer periods.

7.   Before and After, Control and Impact (BACI) Analyses

Stewart-Oaten et al. (1986) developed this procedure

for just the type of comparison we wish to conduct. We
further illustrate the applicability of this procedure by
comparing our AFDW-biomass and Chlorophyll a data between
hypothetical 'before and after' years. No significant
differences were observed between the years examined.
This procedure will likely be used to examine both
species changes, as well as community level changes in
our final report.

8. Correlation with Environmental Variables

A correlation matrix was generated using all the
available data collected from each individual site over
the past five year period. Although some water
chemistry parameters appeared to influence the biological
parameters at one site more than another, there was
generally amazing agreement between sites regarding the
influences of either environmental factors, or water
chemistry constituents. The results of the correlations
also agreed with our previously reported analyses using
multiple regression analyses.

9. Photosynthesis-Respiration Studies

Net production, respiration, and gross produciton
of the community on rock surfaces did not differ greatly
between sites. The lack of significance reported in last
year's report between sites for 1984, 1985, and 1986,
plus the data from 1987, indicate that this parameter may
offer a precise means of detecting ELF effects on
community metabolism.

L. References

APHA. 1980. Standard methods for the examination of
       water and wastewater, 15th edition. American
       Public Health Association,Washington, D.C. 1134 pp.

Bott, T. L., J. T. Brock, C. E. Cushing, S. V. Gregory,
       D. King, and R. C. Petersen. 1978. A comparison
       of methods for measuring primary productivity and
       community respiration in streams.Hydrobiol.
       60(1):3-12.

Burton, T. M. and D. L. King. 1983. Alterations in the
        biodynamics of the Red Cedar River associated with
        human impacts during the past 20 years, p. 181-197.
        In: T. D. Fontaine III and S. M. Bartell (eds.)
        Dynamics of lotic ecosystems. Ann Arbor Science,
        Ann Arbor, MI, 494 pp.

Cummings, K. W. 1975. Macroinvertebrates, p. 170-198.
        In: B. A. Whitton (ed.) River ecology, Univ.
        Calif. Press, Berkeley, CA 725 pp.

Hurlbert, S. H. 1984. Pseudoreplication and the design
        of ecological field experiments. Ecol. Monogr.
        54:187-211.

Oemke, M. P. and T. M. Burton. Diatom colonization
        dynamics in a lotic system. Hydrobiol.
        139:153-166.

Patrick, R. 1966. The effect of varying amounts and
        ratios of nitrogen and phosphate on algal blooms.
        Proc. Ind. Waste Conf. 21:41-51.

Sokal, R. R. and F. J. Rohlf. 1969. Biometry. W. H.
        Freeman, San Francisco, 776 pp.

Southwood, T. R. E. 1978. Ecological methods, 2nd
        edition. Chapman and Hall, London, 524 pp.

Stewart-Oaten, A., W. W. Murdoch, and K. R. parker.
        1986. Environmental impact assessment:
        "Pseudoreplication" in time? Ecology
        67(4):929-940.

Van der Werff, A. 1955. A new method of concentrating
        and cleaning diatoms and other organisms. Int.
        Ver. Theor. Angew. Limnol. Verh. 12:276-277.

Wetzel, R. G. 1975. Limnology. W. B. Saunders Co.,
        Philadelphia, Pa. 743 pp.

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

Changes from workplan - None.

Rationale

Small E.L.F. 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. 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.

Little is currently known about interactions between stream herbivores (grazers) and the attached algal community in freshwater systems. Most research on freshwater herbivore-algal interactions has been conducted in either ponds (Kesler 1981, Hunter 1980) or in laboratory streams (Kehde and Wilhm 1972, 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 comunity 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 $\underline{a}$ or biomass in the algal comunity. 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 $\underline{a}$ 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. 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 geeen algae to blue-green algae. These studies have demonstrated that grazers can alter the succession of algal species on substrates. Dickman and Gochnauer (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. To our knowledge, no detailed study of the effects of grazing on periphytic algal species occurrence and abundance in lotic systems other than that by Hill and Knight (1987) or Colletti et al (1987) has been conducted.

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) 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
(see Appendix A for a copy of this paper; it represents
initial attempts to study grazer communities in the Ford
River as part of this project). Our hypothesis is that
grazer abundance is an important determinant in
structuring the attached algal community, and that the
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 concommitant 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 will be determined
to provide the data necessary for linking invertebrate
herbivores to the periphyton community based on trophic
level analyses. This objective includes the
determination of the effects of various levels of
herbivory on periphyton community dynamics. The ultimate

objective is 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

In 1985 we designed and built small, microcosm streamside flow-through artificial streams 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 had to be 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 duplicates use of 12 separate chambers placed in the Ford River and avoids 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. 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).

In 1986 and 1987 simultaneous experiments were conducted. Preliminary results from the most recent experiments conducted this past summer (1987) will be presented along with the final detailed species analyses results from the 1986 studies. The details of the 1985 study were included in the final draft of last year's annual report as recommended by the reviewers.

Ceramic tiles (3.6cm ^{2}) 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). Thus, each replicate treatment had 4 or 8 subsamples taken from it depending upon the treatment. Each level of grazing was always replicated at least three times (3 chambers with no grazers, 3 with "average" density of grazers, and 3 with double the "average" density of grazers). The colonized tiles were exposed to grazing for a total of 6 or 7 days (usually 7 but 6 in 1986 when a storm event caused the experiment to be terminated one day earlier than planned).

In 1986, the studies at FEX contrasted the effects of grazing by limpets with the effects of grazing by the insect larva, Glossosoma. In 1987, only the contrasts utilizing the trichopteran larvae were repeated for both sites.

Results and Discussion

A. The 1987 Study

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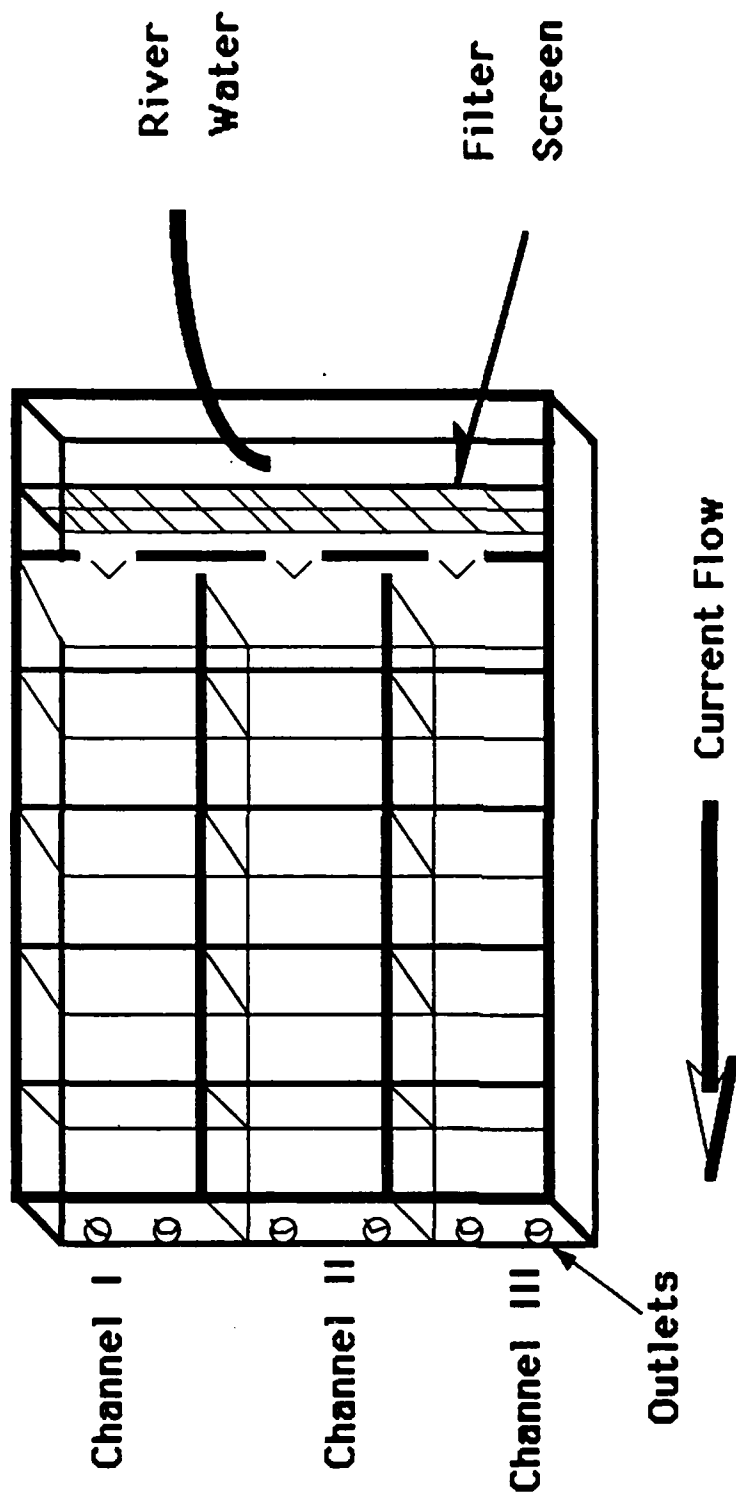
FIGURE 3.1 Experimental stream used in grazer studies from 1985–87.

While the final detailed analyses of diatom species counts remain to be completed for these experiments, the data are relatively complete for the comparisons of AFDW-biomass between the two sites (Table 3.1). One factor ANOVA using results from both sites showed significant differences between FEX control tile AFDW-biomass and FCD control tile AFDW-biomass ($p<.05$) as well as significant differences for AFDW-biomass between FEX _Glossosoma_ grazed tiles and FCD grazed tiles ($p<.05$). Within a site however, comparing treatments at FEX separately from treatments at FCD, no significant differences were detected between AFDW- biomass levels 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 any combination of FEX and FCD treatments nor between control and grazed tiles within a site (Table 3.1). Thus, no overall clear evidence for grazing significantly altering either chlorophyll _a_ or AFDW biomass levels was evident for the 1987 experiments, although grazed tiles showed small declines in both parameters in three of the four comparisons after grazing (Table 3.1).

Chlorophyll _a_ and AFDW-biomass 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. This pattern of ambiguous results for significant and consistent changes in either chlorophyll _a_ or AFDW biomass as a result of grazing, is precisely the pattern observed in all previously run experiments (see Annual Report 1986 and 1987). More precise examination of species composition changes due to grazing for the 1987 experiments (similar to what follows for the final analysis of the 1986 experiments and to what was reported previously for the 1985 experiments) may ultimately show a pattern of predictable and significant change.

Table 3.1   Results of 1987 Grazer Experiment at Experimental (FEX) and Control Sites (FCD) for Chlorophyll a (mg/m^2) and AFDW-Biomass (mg/m^2). Means ± S E., N in Parentheses.

Site	Treatment	Chlorophyll a	AFDW-Biomass
FEX	control	7.48 ± .51 (24)	3,706.9 ± 481.0 (16)
	grazed	6.48 ± .25 (24)	3,408.7 ± 203.7 (23)
FCD	control	5.91 ± .41 (24)	2,263.5 ± 294.0 (23)
	grazed	6.13 ± .56 (24)	1,902.5 ± 175.8 (24)

B. The 1986 Study

These experiments were conducted at the same time period in August at both FEX and FCD for no grazer versus 30 Glossosoma per chamber comparisons (0 versus double the "average" grazer levels in the Ford River). In addition, two potential new grazers, limpets and a grazing species of Chironomidae, that were causing obvious visual differences in the algal communities on rocks in the river, were investigated to see if they would represent better test animals than Glossosoma. Chlorophyll a levels and AFDW biomass (organic matter standing crop) were not significantly different between any Glossosoma and control treatments within a site (Figures 3.2 and 3.3 in the last annual report). At FEX, a limpet was used and was found to reduce chlorophyll a levels significantly below ($p<.05$) levels from control tiles or Glossosoma grazed tiles. At FCD a grazing chironomid was tested and, like Glossosoma, caused no significant reduction in either chlorophyll a or AFDW biomass.

Examination of the diatom community structure on both grazed and ungrazed control tiles through calculation of community indices of species diversity and evenness (Shannon-Wiener H' and Simpson's J), as well as determinations of cell density, individual average cell volume, and total biovolume of the complete diatom community, indicated general corroboration of previous experimental results presented for 1985 in last year's annual report (no significant changes occurred in most of these parameters as a result of grazing even though species composition was significantly altered). Species evenness, however, was significantly different (Table 3.2) between control and grazed tiles. This difference was significant primarily because of the strong differences between evenness means of FEX control tiles and the FCD Glossosoma grazed tiles (see Table 3.3). This across site comparison was difficult to evaluate since it contrasted treatments exposed to potentially different variables rather than a within site contrasts, which control for such variables. No other contrasts of

Table 3.2   Results of 1986 Experiments with Single Factor ANOVA Tests on Biological Parameters Comparing Ungrazed to Grazed Tiles with Sites Separate.

Comparison	Significance
Species Evenness	*, P < .05
Species Diversity	N.S., P > .06
Individual Cell Volume	N.S., P > .80
Total Biovolume	N.S., P > .56
Diatom Cell Density	N.S., P > .17

the biological parameters was found to be significantly
different (Table 3.2), whether contrasting treatment
means within a site or between sites contrasting all
treatment means. Grazing activity thus appeared to show
only a generalized pattern of lowering species evenness
as well as diversity (Table 3.3) but not significantly
within a site. No consistent pattern was thus determined
for the 1986 series of experiments analyzing these
particular biological parameters.

Examination of species abundances, however, revealed
some patterns identical to those revealed in the 1985
Glossosoma experiments (see last year's annual report for
details). Arcsine transformations of the proportions of
the major diatom species populations determined on grazed
and control tiles for 1986 showed nearly identical trends
to those reported previously for 1985.   The diatom,
Achnanthes affinis increased in abundance as a direct
result of grazing activity (Table 3.4 and 3.5). Although
these results show probability values slightly larger
than the .05 level (i.e. .06 for FCD and .10 for FEX),
the pattern of increasing abundances observed for this
diatom species in 1986 was the same as discovered in both
1985 series of grazing experiments, where the abundances
of the same diatom species showed significantly higher
increases as a result of grazing activity. Given the
vagaries inherent in field experiments with the
influences of natural environmental variability making
precisely predictable outcomes rare, the data appear to
be strong evidence for a fairly consistent conclusion;
that grazing by the larvae of the trichopteran Glossosoma
results in increases in abundance by certain diatom
species above levels of abundance for the same diatom
species in ungrazed periphyton. The tiles used in the
1986 experiments were exposed for the same period as the
1985 experimental studies as well as the 1987
experiments, yet these 1986 tiles showed considerably
more visible accumulation of detrital material which may
have affected the overall accuracy of measuring the
individual species changes due to grazing.   Larger
accumulations of organic matter are much more
likely to be affected by physical forces from water
currents, resulting in the phenomenon of 'sloughing'.

Table 3.3   Mean Values (± S.E.) of Biological Parameters for 1986
Grazer Experiments.

Site	Treatment	Cell Density (x109)	Species Diversity	Species Evenness	Individual Cell Volume	Total Biovolume (x10^{12})
FEX	Control	9.18 ± 1.78	2.96 ± .17	0.78 ± .03	392.7 ± 58.0	3.66 ± 0.88
	30 Glossosoma	6.31 ± 0.60	2.83 ± .08	0.73 ± .02	359.3 ± 89.3	2.20 ± 0.42
	20 Limpets	4.84 ± 2.49	2.68 ± .05	0.71 ± .02	443.7 ± 110.5	2.67 ± 1.90
FCD	Control	12.4 ± 1.97	2.70 ± .13	0.72 ± .03	353.3 ± 98.8	4.43 ± 1.30
	30 Glossosoma	16.2 ± 6.33	2.46 ± .05	0.63 ± .01	324.0 ± 54.0	4.90 ± 1.50

Table 3.4   Results of Single Factor ANOVA Performed on
Arcsine transformed Proportions of the Diatom
Achnanthes affinis on Grazed and Ungrazed
Tiles at FEX and FCD for 1986 Grazer
Experiments.

Sites	Contrast	P-Value	F-test
FEX	Grazed vs Ungrazed	.056	7.145
FCD	Grazed vs Ungrazed	.099	4.582

Table 3.5   Mean Abundances of <u>A. affinis</u> on Grazed and
             Ungrazed Tiles for 1986 Grazer Experiments.
             (Arcsine transformed, X ± S. E., N=3).

<u>Site</u>	<u>Grazed Tile</u>	<u>Ungrazed Tile</u>
FEX	38.25 ± 0.86	30.74 ± 2.70
FCD	44.42 ± 0.57	37.38 ± 3.20

Sloughing effects may have had more dramatic effects on species changes in 1986 than in 1985 or 1987 because of the larger detrital layer at the start of the experiment. Earlier work on colonization dynamics in the Ford River indicated that sloughing probably results in larger losses as the algal layer increases in thickness (Oemke and Burton 1986). Closer attention to avoiding such large accumulation on the tiles will hopefully provide clearer, more consistent between year comparisons.

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 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 but was not as significant as in 1985. This difference between years may be related to different amounts of organic matter on the colonized tiles at the start of the experiment. Nevertheless, results are consistent enough to suggest that this pattern of response is typical of the pre-E.L.F. exposure period and offer a baseline for comparison of results after the E.L.F. antenna becomes fully operational.

References

Cummins, K. W. 1973. Trophic relations of aquatic insects. Ann. Rev. Entomol. 68:183-206.

Dickman, M. C. and M. B. Gochn0auer. 1978. A scanning electron microscopic study of periphyton colonization in a small stream subjected to sodium chloride additions. Verh. Internat. Verein. Limnol. 20:1738-1743.

Eichenberger, E. and A. Schlatter. 1978. Effect of herbivorous insects on the production of benthic algal vegetation in outdoor channels. Verh. Internat. Verein. Limnol. 20:1806-1810.

Hart, D. D. 1983. The importance of competitive interactions within stream populations and communities, p 99-136. In: J. R. Barnes and J. W. Minshall (eds.) Stream ecology. Plenum Press, N. Y., 399 pp.

Hill, W. R. and A. W. Knight. 1987. Experimental analysis of the grazing interaction between a mayfly and stream algae. Ecology68(6):1955-1965.

Hunter, R. D. 1980. Effects of grazing on the quantity and quality of freshwater aufwuchs . Hydrobiol. 69:251-259.

Kehde, P. M. and J. L. Wilhm. 1972. The effects of grazing by snails on community structure of periphyton in laboratory streams. Amer. Midl. Natur. 87:8-24.

Kesler, D. H. 1981. Periphyton grazing by Amnicola limosa: An enclosure-exclosure experiment. J. Freshwater Ecol. 1:51-59.

Lamberti, G. A. and V. H. Resh. 1983. Stream periphyton and insect herbivores: An experimental study of grazing by a caddisfly population. Ecology 64(5):1124-1135.

McAuliffe, J. R. 1983. Competition, colonization patterns and disturbance in stream benthic communities, p. 137-156. In:J. R. Barnes and G. W. Minshall (eds.) Stream ecology. Plenum Press, N. Y., 399 pp.

McAuliffe, J. R. 1984. Resource depression by a stream herbivore: effects on distributions and abundances of other grazers. Oikos 42:327-333.

Oemke, M. P. 1983. Diatom utilization by the stream grazer, Glossosoma nigrior (Banks) (Trichoptera: Glossomatidae) in two southern Michigan streams. Ph.D. Dissertation, Michigan State Univ., East Lansing, MI., 162 pp.

Oemke, M. P. 1984. Diatom feeding preferences of Glossosoma nigrior [Banks] larvae, stream grazers in two southern Michigan streams, p. 285-290. In: J. C. Morse (ed.) Fourth Int. Symp. on Trichoptera. Series Entomologica 30, Dr. W. Junk Publ., The Hague.

Oemke, M. P. and T. M. Burton. 1986. Diatom colonization dynamics in a lotic system. Hydrobiol. 139:153-166.

Sumner, W. T. and C. D. McIntire. 1982.Grazer-periphyton interactions in laboratory streams. Arch.. Hydrobiol. 93(2):135-157.

Webb, K. M. and R. W. Merritt. 1987. The influence of diet on the growth of Stenonema vicarium (Walker) (Ephemoroptera: Heptogeniidae). Hydrobiol. 153:253-259.

Wiley, M. J. and S. L. Kohler. 1984. Behavioral adaptations of aquatic insects, p. 101-133. In: V. H. Resh and D. M. Rosenberg (eds.) The ecology of aquatic insects. Praeger Scientific, N. Y., 625 pp.

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

Changes from the Original Synopsis - None.

Objectives

1) To monitor structural (diversity, evenness, richness, numbers of individuals) and functional community parameters (total biomass, biomass according to functional feeding groups) for benthic insect fauna from August 1986 to June, 1987 at FEX and FCD sites; 2) to monitor changes in size classes of selected insects over that period at FEX and FCD, and 3) to compare 1983 through 1987 data.

Rationale

Extremely low frequency waves may alter structural and functional community parameters (A.I.B.S. 1985, Greenebaum et al. 1979, Halberg et al. 1975) as well as life histories of insects (Walters and Carstensen 1986, Greenberg and Bindokas 1981). The phenomenon that may be most sensitive to ELF influence could be life history patterns as changes in growth rates, age at sexual maturity and fecundity are reflected in alterations in life history patterns. Toward this end, numbers of individuals are being monitored, seasonal changes in numbers and biomass of functional feeding groups are determined (after Merritt and Cummins 1984), and changes in size classes of selected aquatic insects are being followed to look for changes in life history patterns of aquatic insects as related to ELF effects. Size classes as determined by the ratio, mean dry weight per individual (MDW/IND) are being followed for selected aquatic insects, as not all species can be monitoried. We selected species based on the following criteria: 1) large population sizes, 2) discrete generation times, and 3) members of functional feeding groups hypothesized as responding to ELF effects on food resources such as periphyton levels.

Materials and Methods

From 1983 through 1987 60 µm mesh-lined half cylinder 18 x 28 x 10 cm substrate sample baskets were filled with benthic substrata and buried flush with the stream bottom at FEX and FCD. Seven replicates for each site were collected monthly, with replacement, from May through September of each year. Meier et al. (1979) showed that in southern Michigan 30 to 39 days's incubation of samplers in substrates gave the maximum numbers of individuals colonizing substrates, owing to emergence of adult insects. In September, sufficient samplers were placed at the sites to allow for collections from October through April, without replacement. After 1986, January and February collections were excluded, owing to past sampling difficulties.

Samples were processed by placing samplers in separate buckets, washing substrata thoroughly and retaining the

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suspended animals in a 60 µm mesh soil sieve. Animals were preserved in 80% ethyl alcohol. In the laboratory, insects were picked from detritus and then separated to order level. Specimens were identified to the lowest taxon possible and then were measured to the nearest mm. for biomass estimates (after Smock, 1980). Numbers of individuals, taxon diversity (H'), taxon richness (S), evenness (J') and percent numerical dominance for selected species were determined for each replicate. Total sample biomass, biomass for functional feeding groups (after Merritt and Cummins, 1984) and mean dry weight per individual (MDW/IND) values were computed. Statistical analyses included power tests, coefficient of variation values, Student-t tests, linear regression analyses, 2-Way ANOVA tests for differences between sites over time, correlation coefficient values, and percent dominance of chironomids. MDW/IND values were computed for insects that had high numerical abundances. Those were: Chironomidae, Paraleptophlebia mollis, Ephemerella invaria,, E. subvaria, Optioservus sp., Glossosoma nigrior and Protoptila sp.

Overall Philosophy Regarding Power Analysis and Environmental Testing

The issue of sample size and power analysis is very complex. The sample variances have several components. Some of the sums of squared deviations are due to sample methodology, some are due to fluctuations in environmental conditions (light levels, flow rates, water temperatures), and some are biological (growth stage). All of these varied effects may change rapidly and dramatically between seasons, months, and even several days' sample collections. This is further complicated when one compares two sites that are not exactly equal, given the fact that we are dealing with a unidirectional (a river) system. The selection of sample size is a trade-off between precision, number of community parameters sampled, and budgetary limitations. Since there are few existing hypotheses identifying specific processes that are affected by ELF fields, the decision was made to include a variety of ecological processes. We have chosen a variety of parameters for robustness rather than focusing on detection of subtle effects on one or two ecological processes. The risk of not including an adequate array is more important than missing subtle shifts with only a few processes requiring large investments of sample analyses.

The data gathered before the antenna becomes operational represent the baseline pattern of seasonal and annual variation. These data will then be contrasted with patterns observed at the control site after the antenna is functioning. One is not going to be testing ecological differences on a short-term single point basis. The important ecological patterns are the temporal patterns occurring between seasons and between years. A description of statistical methods for the seasonal data (before and after the antenna is operational) appears in the Future Plans section of this element.

TAXON DIVERSITY, FEX AND FCD

MONTHS, 1986–1987

□ FEX H'   +   FCD H'

TAXON RICHNESS, FEX AND FCD

MONTHS, 1986–1987

□ FEX S'   +   FCD S'
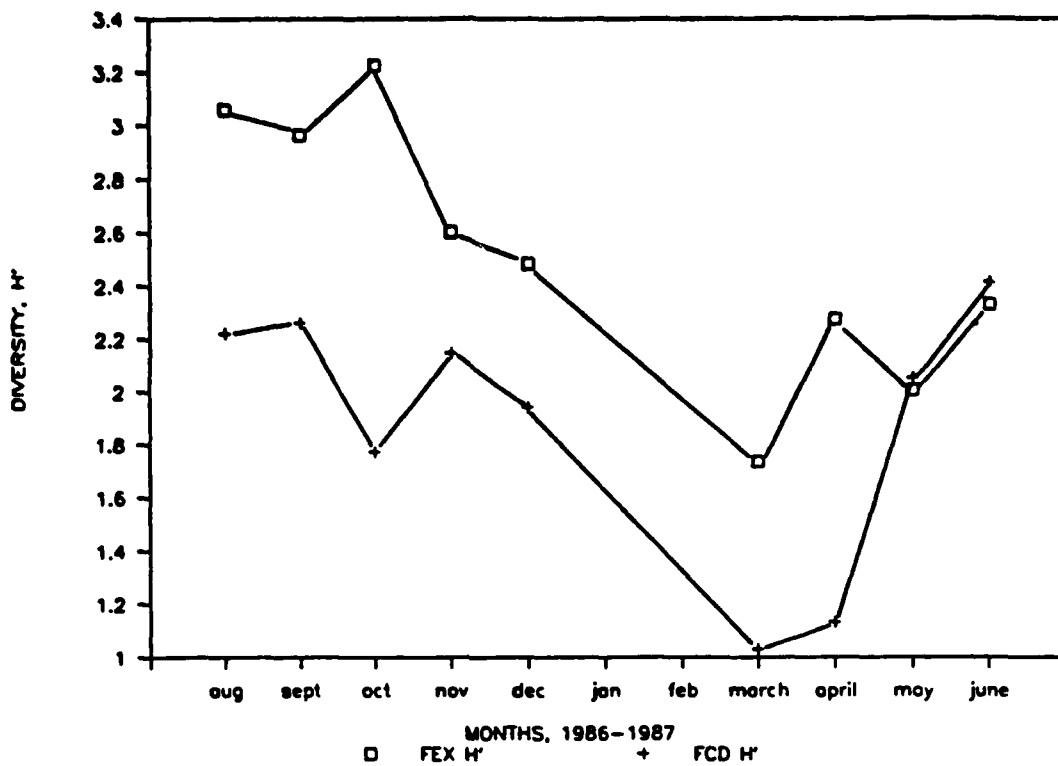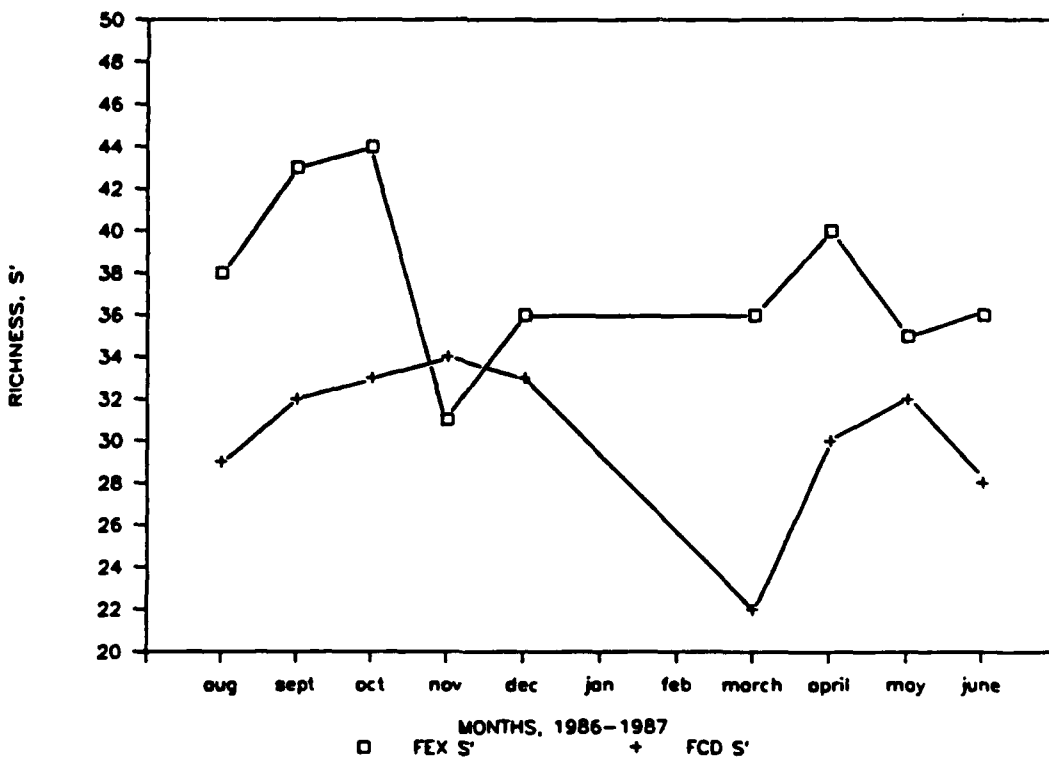
Figure 4.1A. Mean Diversity (H') per sampler at FEX and FCD, August, 1986 to June 1987.

Figure 4.1B. Mean Taxon Richness (S) per sampler at FEX and FCD, August, 1986 to June, 1987.

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TAXON EVENNESS, FEX AND FCD
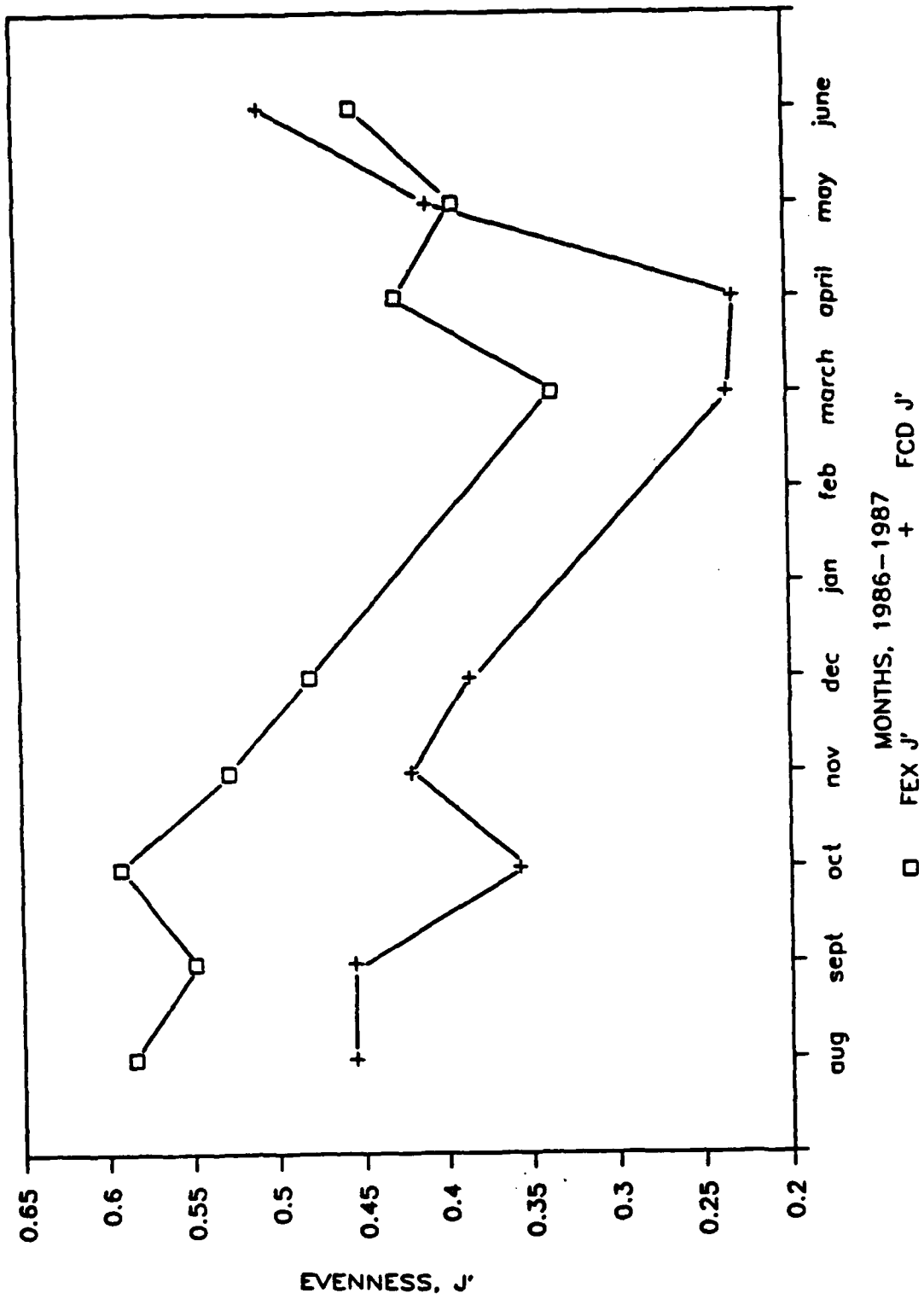
Figure 4.2. Mean Evenness (J') per sampler at FEX and FCD, August, 1986 to June, 1987.

Results and Discussion

Structural Community Indices

<u>1986 - 1987</u> <u>Results</u>:

Taxon diversity (H',Shannon-Weiner) fell from November until April, Figure 4.1A. H' was significantly higher at FEX than at FCD from July 1986 through June 1987, Table 4.1.

Taxon richness (S') also fell in November, but it remained rather stable throughout the winter, Figure 4.1B. In April of 1978 it rose again. As with H', richness values were significantly higher at FEX than at FCD (Table 4.1).

Taxon evenness (J') patterns were similar to H' and S' patterns, Figure 4.2, and evenness was significantly higher at FEX than at FCD throughout the period (Table 4.1).

TABLE 4.1
Diversity (H'), Richness (S), and Evenness (J') of Insects
in Substrates at FEX and FCD
(Students' T-Test; ArcSine Transform for J')

Parameter	July-Oct.86		Nov.86-April 87		April-June 87	
	FEX	FCD	FEX	FCD	FEX	FCD
Diversity						
Mean	2.889	2.179	2.274	1.707	2.209	1.820
T	5.090		2.598		2.176	
d.f.	38		28		30	
p value	<.00001		.007		.019	
Richness						
Mean	42.2	33.2	34.1	29.6	36.9	30.1
T	4.803		1.831		4.426	
d.f.	38		28		30	
p value	<.00001		.039		<.0001	
Evenness						
Mean	47.13	41.11	41.94	35.85	40.86	37.26
T	4.138		2.634		1.682	
d.f.	38		28		30	
p value	<.0001		.007		.052	

Levels of significance for the above parameters over the entire period were very high; H'= <.00001, S'=<.0000001 and J'=<.00001.

Coefficient of variation mean values for above parameters for each month at each site from July of 1985 through June of 1987 averaged below 20% (n = 21), indicating that sufficient samples (5) had been analyzed to have 95% confidence that the mean was ± 40% of its estimated value at the .05 alpha level (Table 4.2). Although seven samples were collected for each

date, time and money constraints allowed processing of only five samples.

Table 4.2 presents mean values for the above parameters as well as for numbers of individuals for the two sites combined. Only numbers of individuals had high coefficient of variation values.

TABLE 4.2
Coefficient of Variation Values for Monthly Samples From July, 1985 through June, 1987; FEX and FCD Combined

Statistic	Diversity	Richness	Evenness	Number Individ.
Grand Mean	16.33%	15.53%	14.56%	31.31%
S.Deviation	9.42	7.62	7.23	17.86
N = 42				

Numbers of individuals peaked at FEX in March and again in May, 1987 (Fig. 4.3A). This was also true for numbers of chironomids (Fig. 4.3B). FCD samples were less variable than FEX samples with respect to numbers of individuals and chironomids. At FCD, a peak for both values occurred in April, followed by decreases in numbers. In past years, numbers of all individuals and numbers of chironomids have been low during autumn, winter and early spring and have been highest during the early summer and summer months. The winter of 1986 - 1987 was very mild, relatively speaking in Dickinson County. It appears as though the benthic insects responded to the milder winter in a number of parameters. Total numbers of individuals were higher than in the past. Functional community parameters, including biomass and mean dry weight per individual values were also higher during the winter and spring months than in the past. Those data are presented in the next section.

Summary of 1983 through 1987 Results:

Diversity and Evenness values showed consistent depressions during winters and early springs with consistent peaks in summer months (Figure 4.4A, 4.4B). In the summer of 1986 the peak lasted longer than in previous years. This may be related to the unusually mild winter of 1986 - 1987. Taxon richness, Figure 4.4C, followed the same pattern in 1986 - 1987 as did H' and J'. The intensity of the summer peak of 1986 was even higher and lasted longer than for H' and J' over this period. (Compare Figures 4.4A, B and C). Further, the winter-spring depression was much less pronounced as compared with previous winter-spring depressions for this parameter. One interpretation of the results for the three parameters is that the mild winter allowed the maintenance of taxa in surficial sediments that might otherwise move deeper or go to stream banks during colder winters.

MEAN NO INDIVIDUALS
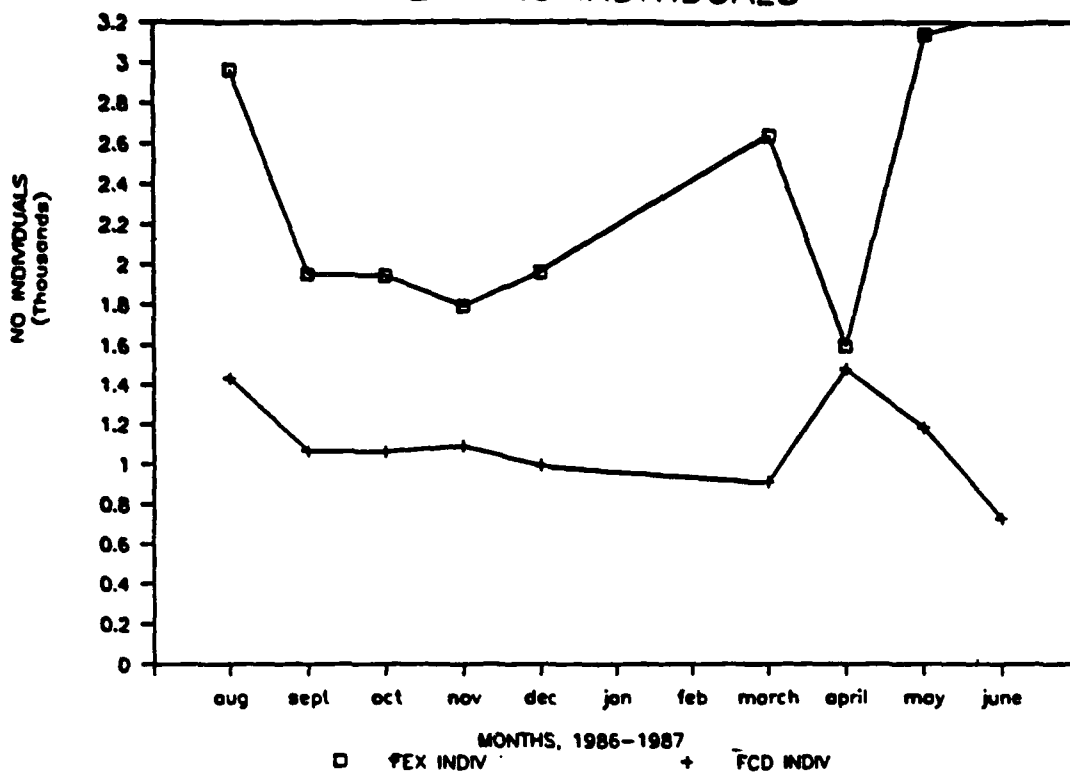
MEAN NO CHIRONOMIDS
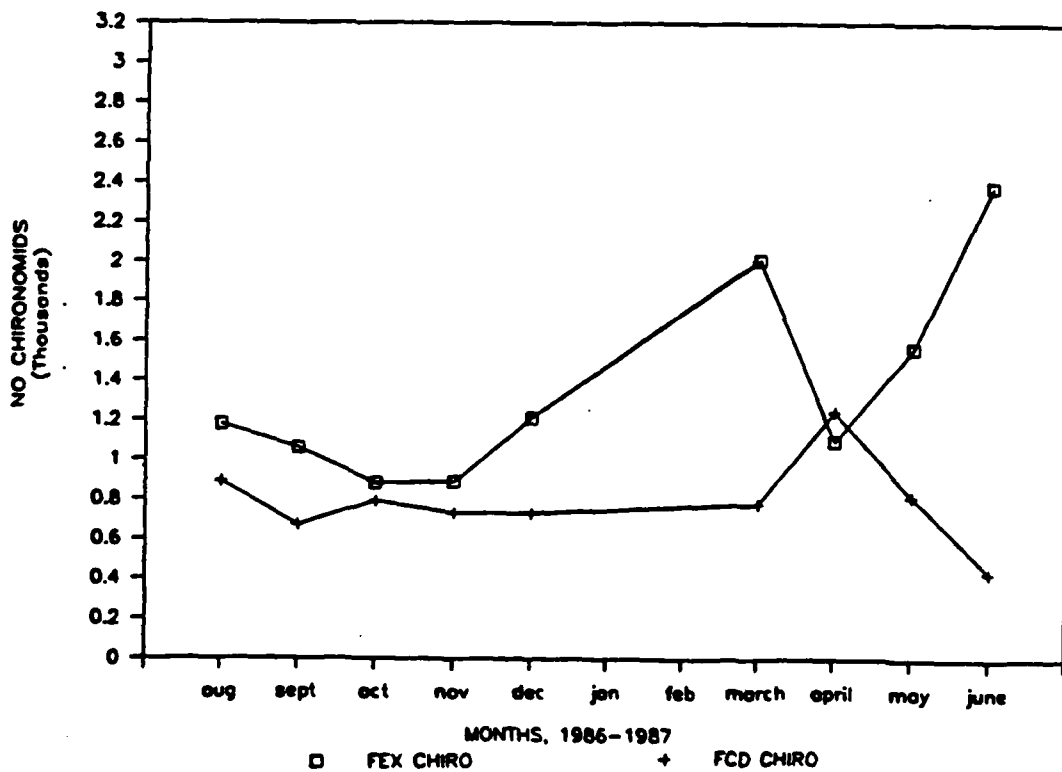
Figure 4.3A.   Mean Number of Individuals per sampler at FEX and FCD,
     August, 1986 to June, 1987.
Figure 4.3B.   Mean Number of Chironomids per sampler at FEX and FCD,
     August, 1986 to June, 1987.

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DIVERSITY, FEX AND FCD 1983-1987
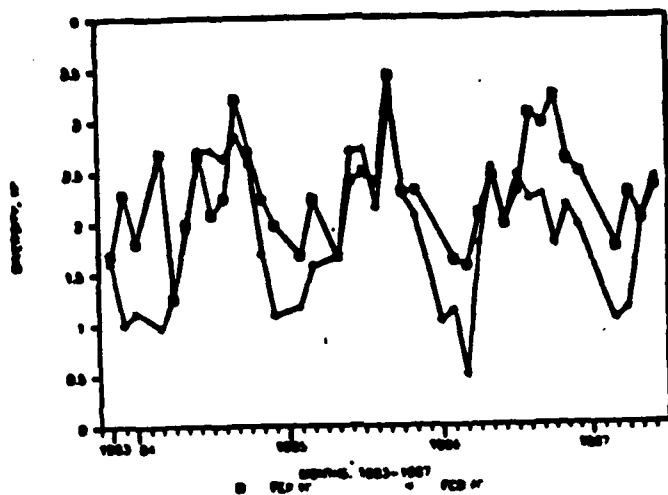
EVENNESS, FEX AND FCD 1983-1987
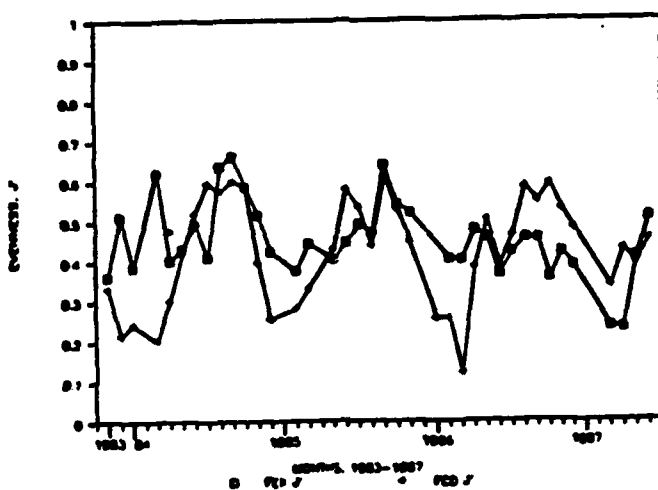
RICHNESS, FEX AND FCD 1983-1987
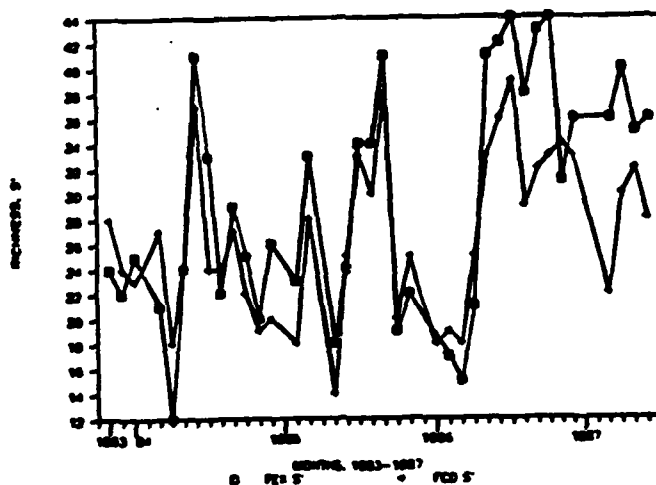
Figure 4.4A. Mean Taxon Diversity per sampler at FEX and FCD, June, 1983 to June, 1987.

Figure 4.4B. Mean Taxon Evenness per sampler at FEX and FCD, June, 1983 to June, 1987.

Figure 4.4C. Mean Taxon Richness per sampler at FEX and FCD, June, 1983 to June, 1987

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J' and H' values are affected by changes in numerical
dominance of the family Chironomidae in our analyses (See
figures 4.4 and 4.3.). We identify chironomids in substrates
to family level, owing to the time necessary to identify large
numbers of chironomids even to genus. When percent dominance
of chironomids increases, evenness and diversity go down. In
order to determine the affect that chironomids have on
structural community parameters, parameters were computed
with and then without chironomids. Differences in means and
standard deviations for the two parameters with and without
chironomids appear in Table 4.3.

TABLE 4.3

Descriptive Statistics for H' and J', With and Without
Chironomids in Substrates from July, 1983 through June, 1987.
(ArcSine transformation for J')

Site and Parameter	Descriptive Statistics			
	Mean	S.D.	Minimum	Maximum
FEX				
H', with chironomids	2.284	0.507	1.246	3.413
without chironomids	3.086	0.674	1.308	4.324
J', with chironomids	43.64	5.02	35.43	54.39
without chironomids	53.49	7.28	32.71	67.49
FCD				
H', with chironomids	1.915	0.663	0.497	3.226
without chironomids	3.281	0.512	1.503	4.075
J', with chironomids	39.06	7.83	20.27	51.38
without chironomids	57.51	5.46	34.14	64.38
Percent Chironomid Dominance				
FEX	48.33	8.32	28.52	62.94
FCD	57.51	5.46	34.14	64.38

The impact of chironomids on H' and J' means was dramatic.
The greatest affect was on substrates from FCD, owing to higher
numbers of chironomids relative to other taxa at that site.

In order to see whether the differences in mean values for
H' and J' affected correlation coefficient values (C.C.) among
the structural community parameters, C.C. values were computed
with and without chironomids. Table 4.4 presents those results.

TABLE 4.4

Correlation Matrix for Structural Community Parameters. Insects in Substrates from July, 1983 through June, 1987 (ArcSine transformation for J' and % Chironomids)

With Chironomids

	FEX S	FCD S	FEX H'	FCD H'	FEX J'	FCD J'	FEX % Chironomid Dominance	FCD
FEX,S	1.00							
FCD,S	.84	1.00						
FEX,H'	.54	.59	1.00					
FCD,H'	.46	.54	.62	1.00				
FEX,J'	.09	.24	.88	.47	1.00			
FCD,J'	.30	.34	.53	.96	.46	1.00		
FEX, %Chironomids			-.61	-.62	-.65	-.59	1.00	
FCD, %Chironomids			-.43	-.85	-.35	-.88	-.64	1.00

Without Chironomids

	FEX S	FCD S	FEX H'	FCD H'	FEX J'	FCD J'
FEX,S	1.00					
FCD,S	.85	1.00				
FEX,H'	.56	.40	1.00			
FCD,H'	.57	.62	.58	1.00		
FEX,J'	.06	-.01	.82	.39	1.00	
FCD,J'	.13	.11	.46	.83	.51	1.00

Critical value (1-tail, .05) = + or - .275
Critical value (2-tail, .05) = + or - .324

In general, correlation coefficients for H' versus J' and for S versus J for each site were only slightly higher when chironomids were included in the analysis. Thus, although means for each parameter differed dramatically depending on whether or not chironomids were included, correlation coefficients showed no dramatic differences. This was also true when sites were compared with each other for each parameter. There was a large impact on H' and J' at FCD by high numbers of chironomids relative to the other taxa (C.C. = -0.85, -0.88, respectively). Although C.C. values were significant at FEX for H' and for J' as related to numbers of chironomids (-0.61 and -0.65 respectively) they were not as highly correlated at that site. As chironomids usually include many individuals for each sample, those numbers of individuals depress the H' and J' values. The C.C. for H' versus J' at FCD was high whether or not chironomids were included (0.96 with chironomids and 0.83 without chironomids). The same pattern held for C.C. values for the FEX site.

Functional Community Indices

1983 Through 1987 Results.

Biomass and Functional Feeding Groups:

Seasonal trends for total insect biomass from June 1983 through June 1987 are apparent (Figure 4.5A) However, coefficient of variation values for total biomass have been consistently high. In the spring and summer of 1986, the total biomass at FEX was the highest recorded since we chose those sites in June of 1983. The high biomass is likely related to the high early spring water temperatures in 1986. That fall-winter and following spring, the expected reduction in total insect biomass did not occur as in previous years. Coefficient of variation values were the highest in the spring when total biomass was lowest. The C.V. values in in Figure 4.5B contain black bars below the time axis. The bars denote periods of low total biomass. Changes in species assemblages and fast growth rates for five of the seven species intensively studied occur in the spring. Higher variance relative to mean biomass values appear to occur during periods of transition for the insects.

We suspect that the extremely mild winter and spring affected insect biomass in a positive way. We are now speculating as to what the total biomass will be for July and August of 1987. Those samples are currently being processed. We hypothesize that the summer peak will not be as high as in previous years, owing to possible early emergences as a result of the mild winter and spring months.

Total biomass values were separated into functional feeding groups (F.F.G., after Merritt and Cummins, 1984). Predators contributed more to total biomass than the other three F.F.G. (figures 4.6A, B, 4.7A, B). One major predator, the dragonfly Ophiogomphus colubrinus contributed the most biomass to that functional feeding group (F.F.G.). Three F.F.G. showed seasonal patterns similar to the total biomass patterns: Collector-filter feeders, collector-gatherers (Figure 4.7A, B) and predators (Figure 4.6A). Shredders had many peaks (Figure 4.6B). Collector-filter feeders and collector-gatherers were the functional feeding groups (F.F.G.) that inflated total biomass at FEX for 1986-87. Warmer weather and fewer days of snow cover in the river appeared to influence these groups more than others. The fact that increases occurred only at FEX is difficult to interpret. There is more cobble and less sand at FEX. Possibly, the site is more conducive to collector-filter feeders and collector-gatherers under mild winter conditions than the FCD site. Shredders showed no consistent pattern, but one would have expected them to be more abundant in the fall and winter, as they consume leaf and wood debris. Detection of seasonal patterns for this group are best served by sampling leafpacks, Element 6, rather than substrates.

TOTAL BIOMASS, FEX AND FCD

COEFFICIENT OF VARIATION
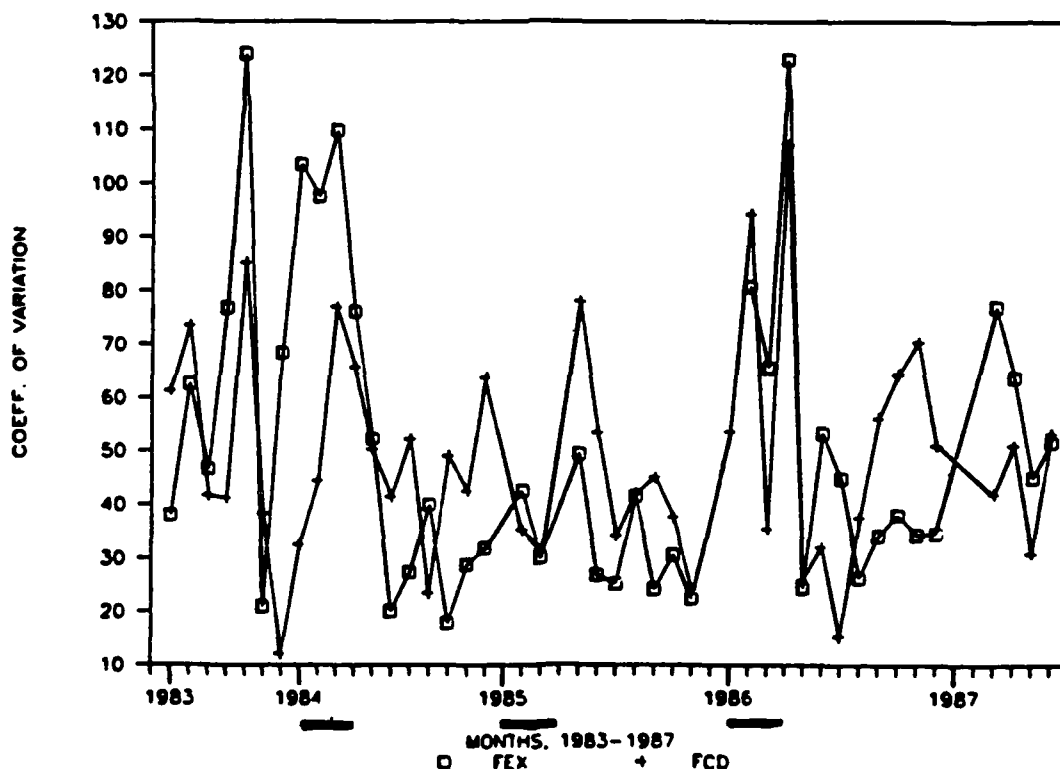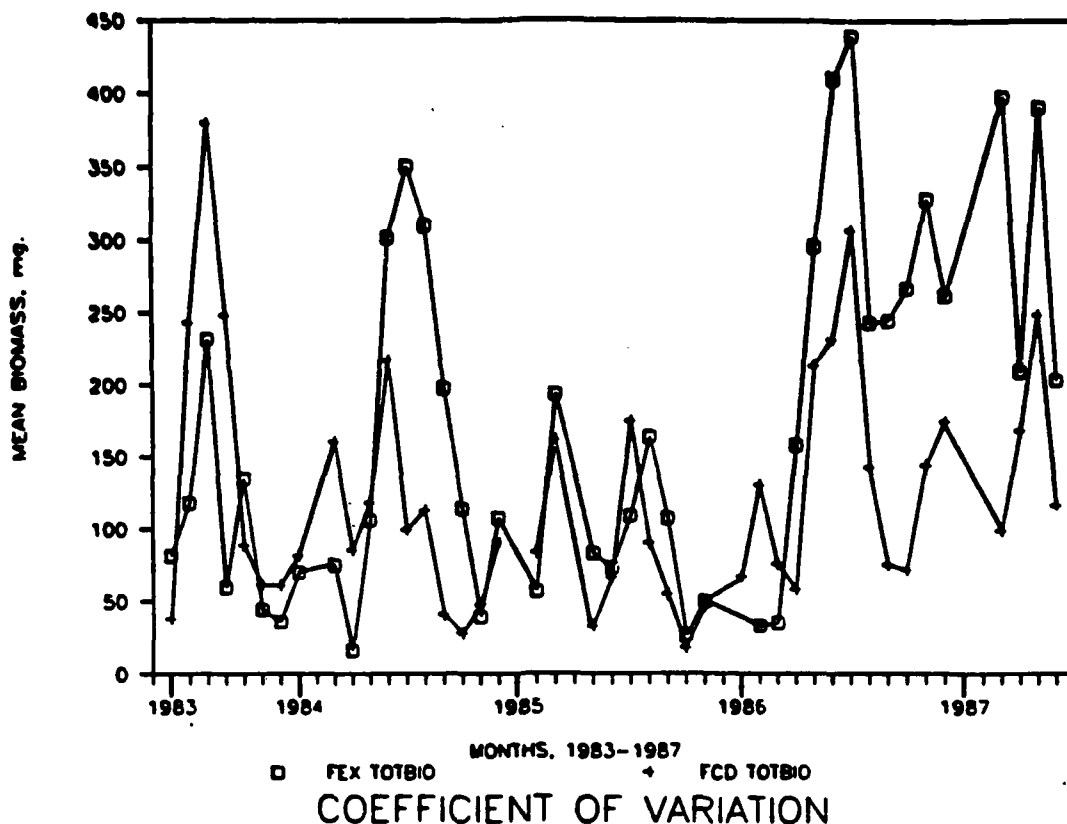
Figure 4.5A. Changes in Insect Mean Total Biomass (mg.) at FEX and FCD
from June 1983 to June 1987.

Figure 4.5B. Changes in Coefficient of Variation (C.V.) Values at FEX
and FCD from June 1983 to June 1987. Black bars indicate periods of
high C.V. values relative to total biomass values, Jan. through April.

PREDATOR BIOMASS
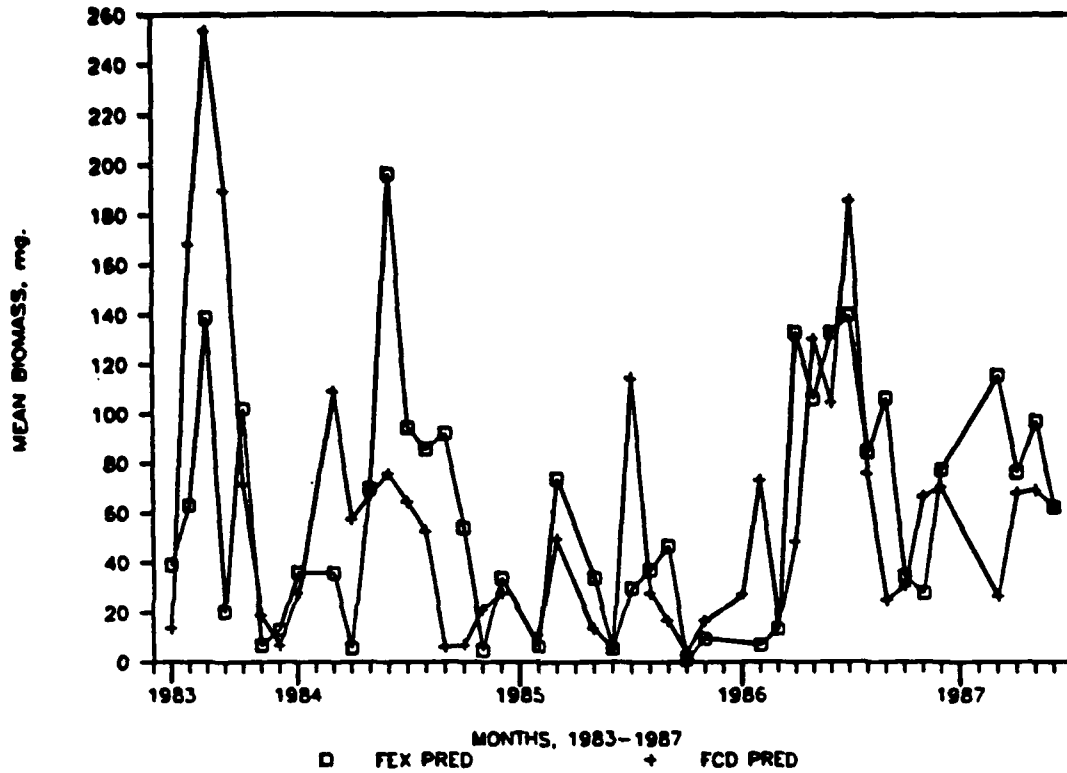
SHREDDER BIOMASS, FEX AND FCD
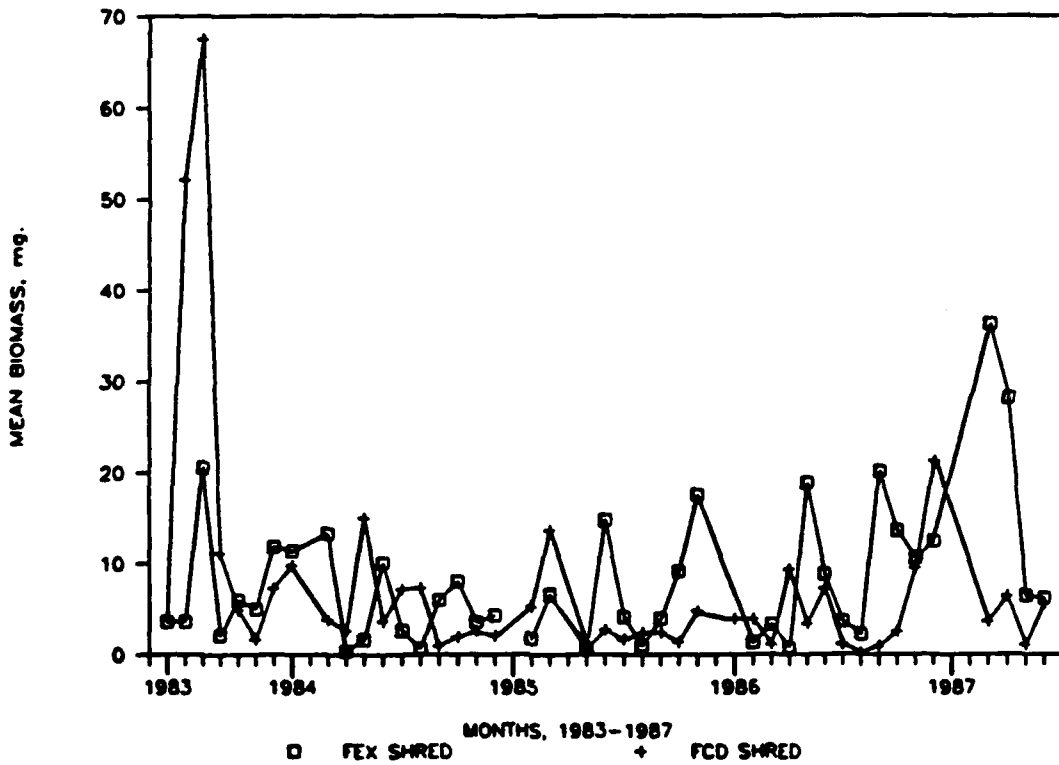
Figure 4.6A.   Changes in Predator Biomass (mg.) at FEX and FCD from June 1983 to June 1987.

Figure 4.6B.   Changes in Shredder Biomass (mg.) at FEX and FCD from June 1983 to June 1987.

COLLECTOR-FILTER FEEDERS
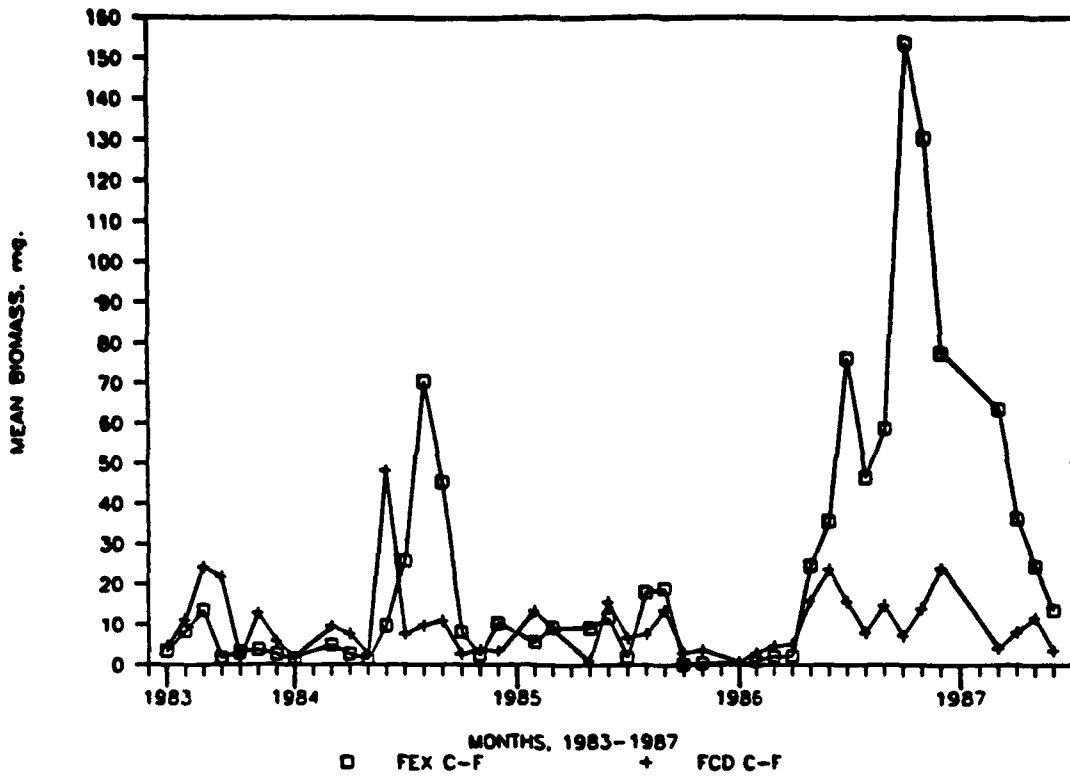
COLLECTOR-GATHERERS
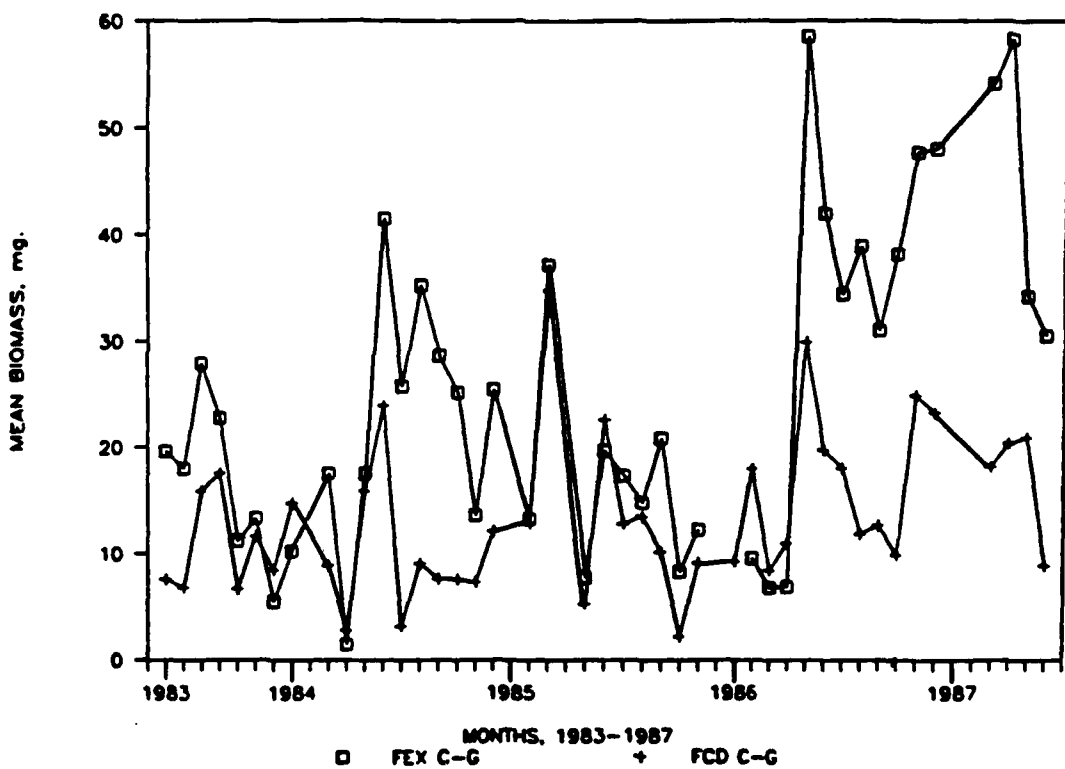
Figure 4.7A.   Changes in Collector-Filter Feeder Biomass (mg.) at FEX
and FCD from June 1983 to June 1987.

Figure 4.7B.   Changes in Collector-Gatherer Biomass (mg.) at FEX and FCD
from June 1983 to June 1987.

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Table 4.5A presents the correlation coefficients for the functional feeding groups with respect to total biomass within and and between sites. Table 4.5B presents C.C. values for functional feeding groups between sites. Table abbreviations are:

TB = Total Biomass   CF = Collector-Filterers
CG = Collector-Gatherers   S = Shredders
 P = Predators

TABLE 4.5A

Correlation Coefficients for Insect Functional Feeding Groups
Related to Total Insect Biomass at FEX and FCD

| | F E X | | | | F C D | | | |
	TB	CF	CG	S	TB	CF	CG	S
TB	1.00				1.00			
CF	.63	1.00			.59	1.00		
CG	.78	.62	1.00		.52	.49	1.00	
S	.30	.29	.56	1.00	.57	.26	.10	1.00
P	.76	.22	.56	.25	.92	.43	.28	.64

Critical value (1-tailed, .05) = + or - .26
Critical value (2-tailed, .05) = = or - .30

TABLE 4.5B
Correlation Coefficients Between FEX and FCD for Insect
Total Biomass and Functional Feeding Groups

| | F E X | | | | |
	TB	CF	CG	S	P
FCD					
TB	.49				
CF	.40	.16			
CG	.41	.23	.64		
S	.05	-.05	.05	.14	
P	.33	.04	.26	.05	.43

Critical Value (1-tailed, .05) = + or -.26
Critical Value (2-tailed, .05) = - or -.30

Correlation coefficients were higher for parameters when compared within sites (Table 4.5A) than when compared between sites (Table 4.5B). Predators and Shredders were more highly correlated with total biomass at FCD than at FEX; whereas, the collector-filter feeders and collector-gatherers were more highly correlated at FEX than at FCD. FEX contains more cobbles of intermediate size (> 2.5cm). It could be that since collector-filter feeders often use substrates for holdfasts and collector-gatherers collect periphyton from stable substrates, those functional feeding groups are more common at FEX.

The biomass of collector-gatherers at FEX was highly
correlated collector-gatherer biomass at FCD (Table 4.5B).
Collector-filter feeders and shredders showed the least
similarity between the two sites. Each of those F.F.G.
had higher mean biomass values over time at FEX than at FCD.
(See figs.4.6A,B, 4.7A,B). Different values for F.F.G. biomass
likely reflect differing environmental conditions between the
two sites. Again, FCD is not a true control for FEX for E.L.F.
studies. As we are studying unidirectional flows in a river
system, FCD is considered as a reference station rather than a
control station for FEX. Thus, seasonal trends within each site
will be studied more than direct comparisons between sites. If,
when the E.L.F. antenna is turned on and a change in seasonal
patterns occurs at FEX but not at FCD for any parameter, the
parameter(s) will become suspect as being altered by E.L.F.

Comparisons of Biomass Data with Periphyton and
Ambient Monitoring Data, 1983 - 1987

Figure 4.8 shows changes in total insect biomass, diatom
density and water temperature from June of 1983 through June
of 1987. The values are grand means for the two sites combined.
Until July 1986, the three variables were highly correlated with
one another (Table 4.6). This year's data for the Annual Report
shows a strong deviation from previous years.

TABLE 4.6
Regression Coefficients for Insect Biomass, Diatom
Density and Water Temperature, 1983 - 1987

A. June 1983 - July 1987	r2	Significance
Insect Biomass vs. Diatom Density	.384	p<.00007
Insect Biomass vs. Water Temperature	.342	p<.00004
Diatom Density vs. Water Temperature	.339	p<.00004
B. June 1983 - May 1984		
Insect Biomass vs. Diatom Density	.610	p<.005
Insect Biomass vs. Water Temperature	.678	p<.002
Diatom Density vs. Water Temperature	.723	p<.009
C. May 1984 - June 1985		
Insect Biomass vs. Diatom Density	.548	p<.01*
Insect Biomass vs. Water Temperature	.678	p<.03*
Diatom Density vs. Water Temperature	.389	p<.05*
D. July 1985 - July 1986		
Insect Biomass vs. Diatom Density	.595	p<.003
Insect Biomass vs. Water Temperature	.594	p<.003
Diatom Density vs. Water Temperature	.544	p<.006
E. July 1986 - June 1987		
Insect Biomass vs. Diatom Density	.012	p =.765
Insect Biomass vs. Water Temperature	.018	p =.716
Diatom Density vs. Water Temperature	.217	p =.174
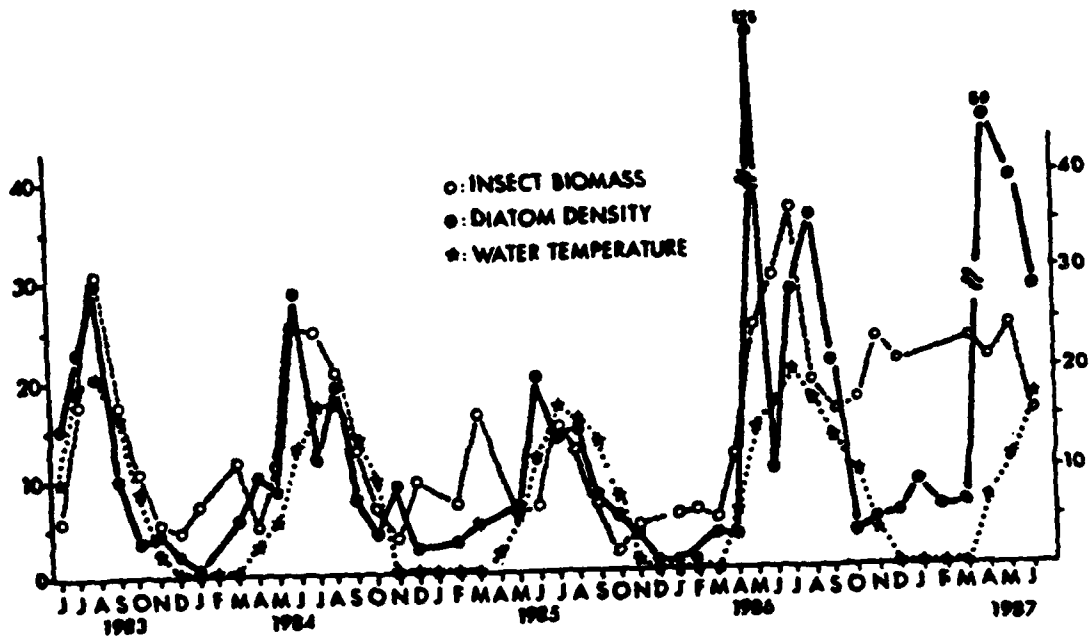
Figure 4.8. Changes in Insect Mean Total Biomass (mg./sample X 10^{-1}), Diatom Density (number per m^2 X 10^8), and Water Temperature (C^0) for FEX and FCD Combined. June 1983 to June 1987.

CHIRONOMID AT FEX AND FCD

MONTHS, 1983-1987

□   FEX CHIRO   +   FCD CHIRO

P. MOLLIS AT FEX AND FCD

MONTHS, 1983-1987

□   FEX PMOL   +   FCD PMOL
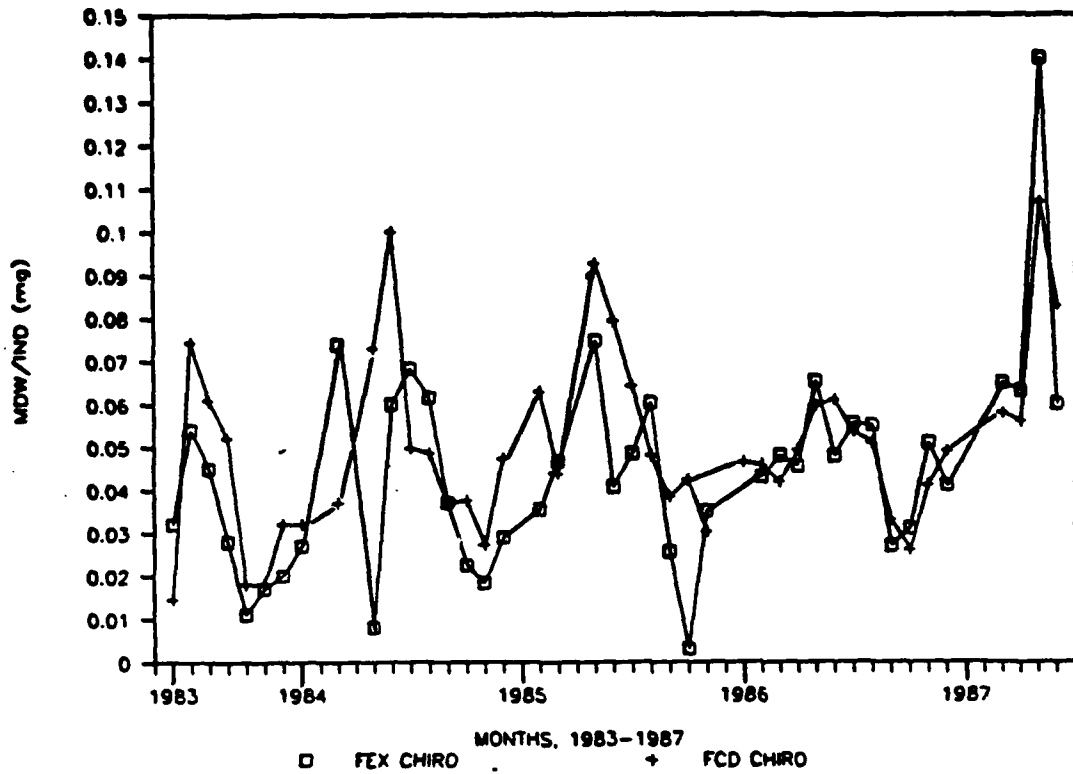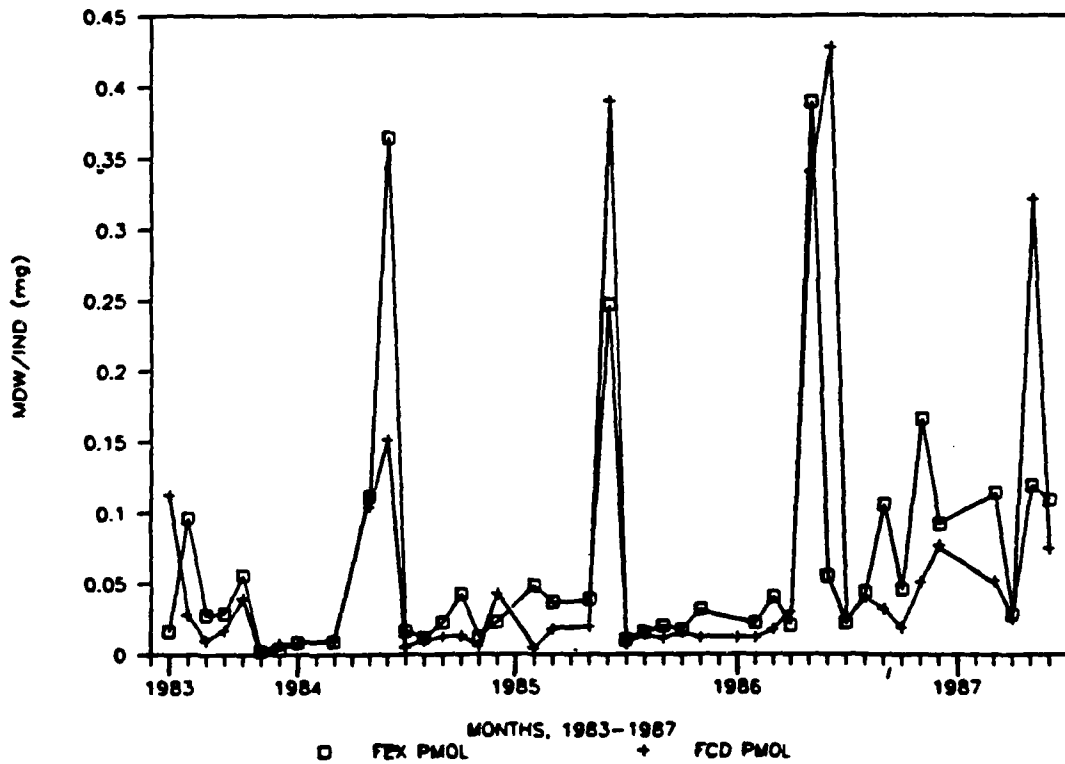
Figure 4.9A.   Mean Dry Weight per Individual (MDW/IND) for Chironomidae
at FEX and FCD, June 1983 to June 1987.
Figure 4.9B.   Mean Dry Weight per Individual (MDW/IND) for Paraleptophlebia
mollis at FEX and FCD from June 1983 to June 1987.

we the time and finances to select one or two species for more detailed analysis, a more distinct pattern might emerge.

b. <u>Paraleptophlebia</u> <u>mollis</u> (Eaton). A very distinctive size-class pattern emerges for this mayfly collector-gatherer (Fig.4.9B). It appears to be univoltine, with its emergence being between late May and June in 1986. Number of individuals for this species was highest in August when the MDW/IND values are low. Apparently, eggs hatch slowly over the summer, as no mature nymphs were taken after June. Also, nymphs remained small throughout the winter and early spring. In the fall of 1986 and spring of 1987 strong growth spurts appeared, unlike previous years over those seasons. The mild winter and spring may have triggered early development for some individuals at FEX and FCD. Accelerated growth appears to usually occur over a one to two-month period in the late spring. This species has the most consistent MDW/IND seasonal patterns of all the species we are following. It has a very low growth rate for most of the year and then increase in size quickly in May and June prior to transformation. If ELF seriously affects this species, either in numerical abundance or seasonal growth patterns, we should be able to detect it.

c. <u>Ephemerella</u> <u>invaria</u> (Walker) and <u>Ephemerella</u> <u>subvaria</u> McDunnough. There are distinctive size class patterns for each species (Figure 4.10A and 4.10B). <u>Ephemerella</u> <u>invaria</u> is most abundant in the early fall when its MDW/IND value is low. It appears to be univoltine, with its major emergence being in late spring. A comparison with data for this species from Element 6 (leaf processing) shows that the size classes are similar, an expected result.

<u>Ephemerella</u> <u>subvaria</u>'s growth as inferred from size class data, occurs from October through late spring. Emergences may be staggered in late spring and early summer, as some mature nymphs are found after the major peak has passed. For both <u>E. invaria</u> and <u>E.subvaria</u>, their maximum MDW values were in the spring of 1987 at both sites. It is possible that the mild winter facilitated the development of a larger individual prior to spring emergence.

c. <u>Optioservus</u> sp. No distinctive pattern emerges for this collector-gatherer elmid. One major problem lies in the fact that this genus is not univoltine. Even though this genus does not meet the criteria of having discrete generations, we will continue to use it, as it has high numbers and we can gather considerable information as to larval and adult numbers as the genus is holobiotic. There is a tendency for larger larvae to occur in the winter (Fig. 4.11A). Certainly, from April through October the MDW/IND values were lower.

Adults are most common in the late spring and summer months (Figure 4.11B). Nymphal maximum abundances tend to lag slightly behind maximum adult abundances (Figure 4.11C). After the 1986 summer adult peak, adult numbers did not approach zero as for

E INVARIA AT FEX AND FCD

MONTHS, 1984-1987

□ FEX INV   + FCD INV

E. SUBVARIA AT FEX AND FCD

MONTHS, 1984-1987

□ FEX SUB   + FCD SUB
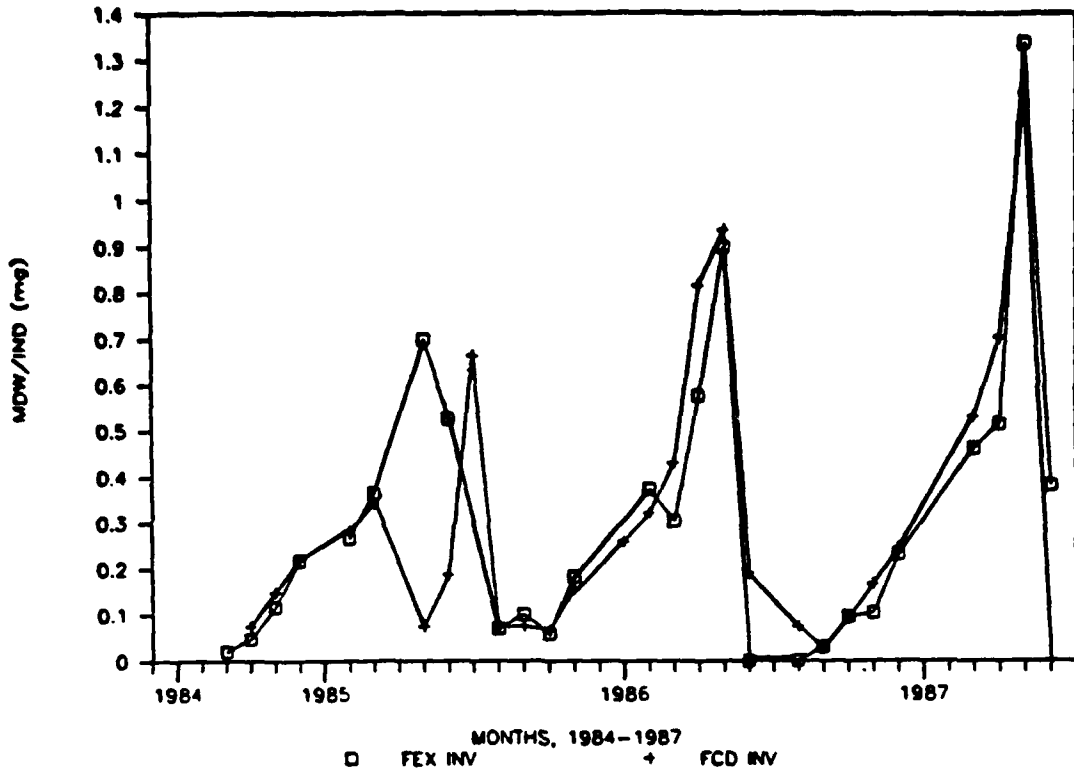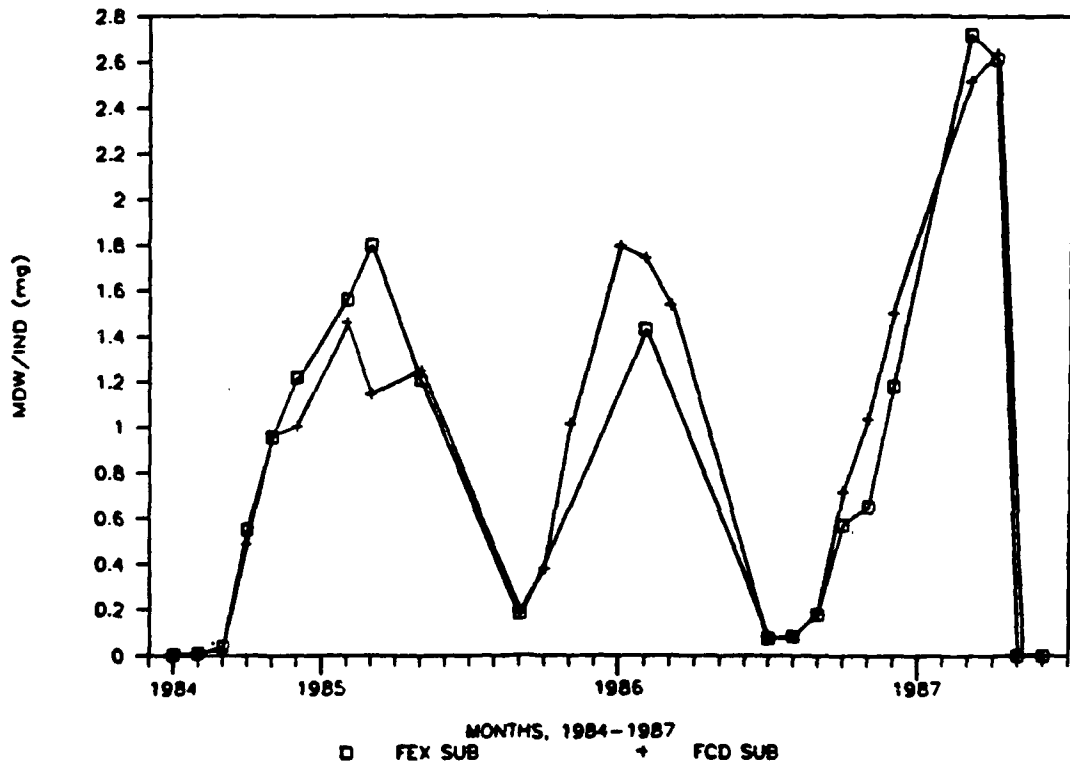
Figure 4.10A. Mean Dry Weight per Individual (MDW/IND) for _Ephemerella invaria_ at FEX and FCD, July 1984 to June 1987.

Figure 4.10B. Mean Dry Weight per Individual (MDW/IND) for _Ephemerella subvaria_ at FEX and FCD, July 1984 to June 1987.

OPTIOSERVUS AT FEX AND FCD
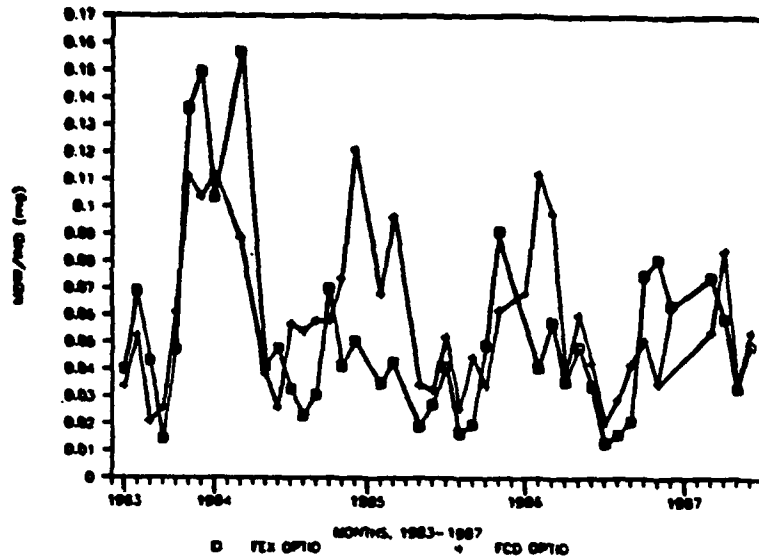
OPTIOSERVUS ADULTS, FEX AND FCD
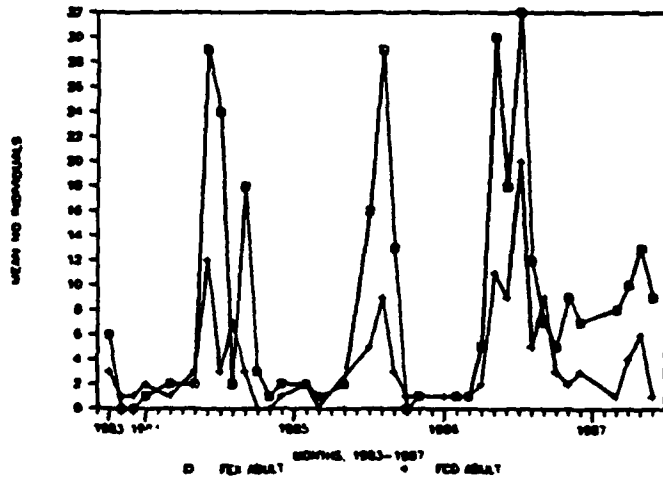
OPTIOSERVUS LARVA, FEX AND FCD
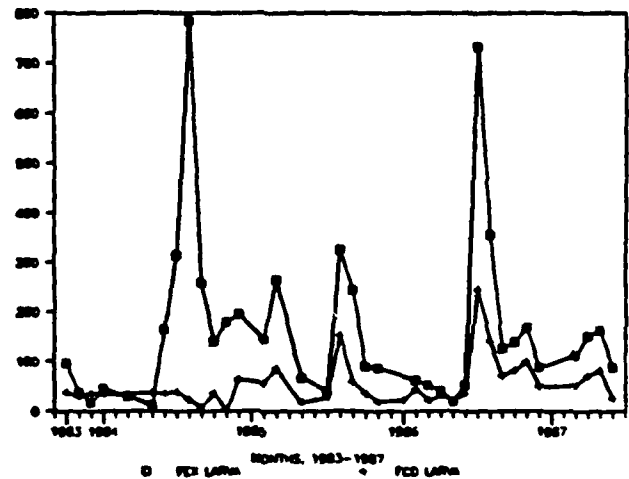
Figure 4.11A. Mean Dry Weight per Individual (MDW/IND) for Optioservus
     sp. at FEX and FCD, June 1983 to June 1987.
Figure 4.11B. Mean Number of Adults of Optioservus sp. at FEX and FCD,
     June 1983 to June 1987.
Figure 4.11C. Mean Number of Larvae of Optioservus sp. at FEX and FCD,
     June 1983 to June 1987.

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other years. Their higher numbers during the winter and spring of 1987 adults may be a function of habitat preference differences during warm versus cold water periods. Again the mild winter may have affected the distribution of the adults. This pattern was not reflected by larvae of _Optioservus_.

d. _Glossosoma nigrior_ and _Protoptila_ sp. are members of the trichopteran family, Glossosomatidae. In the previous annual report, individuals in the family and not genera were followed over time. We now have sufficient data at the genus level to track both MDW/IND values and mean number of individuals over time. The MDW/IND values for _Glossosoma nigrior_ indicate that this species is univoltine, with its major emergence being between May and June (Figure 4.12A). The highest numbers of individuals occur just after the MDW/IND peak has passed, indicating that the high numbers are young of the year (Figure 4.12B). This species is more common at FCD than at FEX, indicating that the habitat at FCD is more conducive to these collector-gatherers than habitats at FEX.

e. _Protoptila_ sp. The MDW/IND peak values indicate that this genus is univoltine, with its major emergence being in April and May (Figure 4.13A). The maximum number of individuals occurs just after the MDW/IND peak, indicating the the high numerical abundances represent the young of the year, Figure 4.13B). As for _Glossosoma nigrior_, _Protoptila_ is also more common at FCD than at FEX, indicating that the habitat at FCD is also more conducive to both these collector-gatherers.

Future Plans for This Element

The same design and accumulation of data will continue as in the past. We have added more replicates for our collection dates (seven as opposed to five in the past). However, we have processed more than five only for the late fall and winter samples thus far. The late spring and summer samples are so large that one sample takes at least three times as long as samples taken at other times of the year. In the winter of 1986 and spring of 1987 the samples were also very large, and we could only process five of the seven samples. If time permits, we will process the remaining two samples for each site.

The principle change for next year will be in the form of more sophisticated analyses. We have requested that ambient monitoring data be made available on a monthly basis in the future so that some of these analyses can commence this coming summer rather in the fall. By the end of the 1988 summer season, we will have five year's worth of pre-operation data (i.e., without the lines being fully operational) and one year's worth of operational data. We will take the most consistent data sets and regress integrated degree days against them. This will be done for the means and for the variances for the integrated degree days. There are many times when the variances "give more information" than the

GLOSSOSOMA NIGRIOR AT FEX AND FCD

FEX GLOSS   FCD GLOSS

GLOSSOSOMA NIGRIOR AT FEX AND FCD

FEX GLOSS   FCD GLOSS
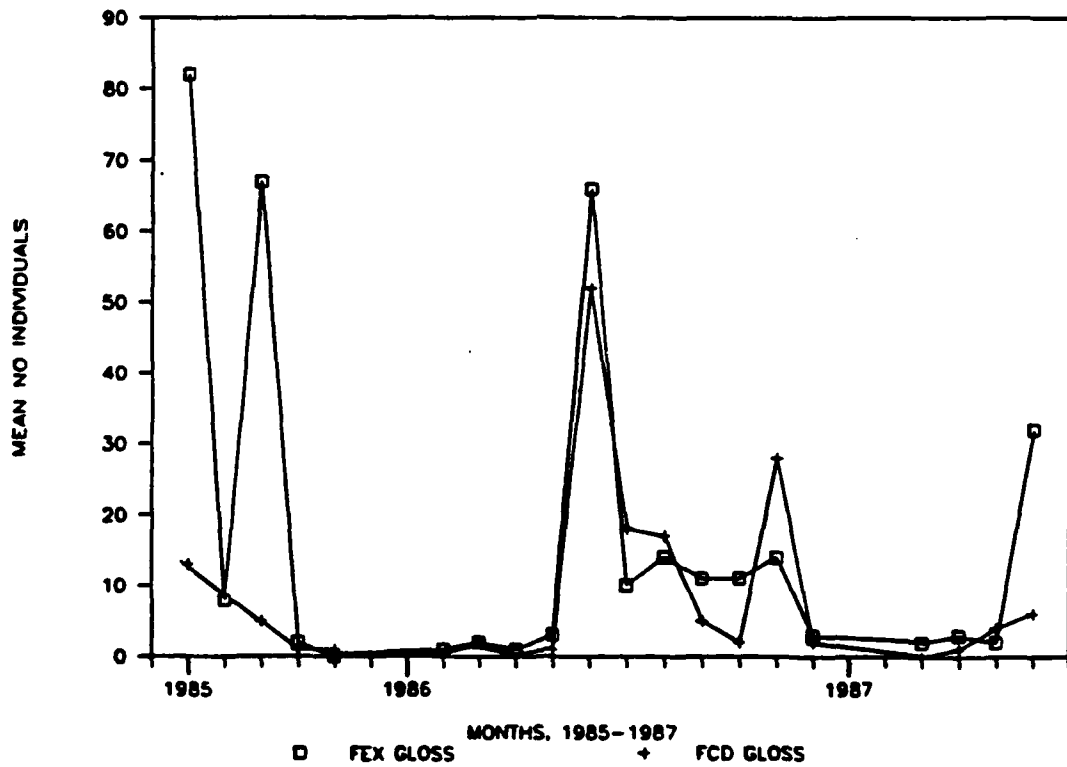
Figure 4.12A. Mean Dry Weight per Individual (MDW/IND) for _Glossosoma_ _nigrior_ at FEX and FCD, July 1985 to June 1987.

Figure 4.12B. Mean Numbers of _Glossosoma_ _nigrior_ at FEX and FCD, July 1985 to June 1987.

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PROTOPTILA AT FEX AND FCD

PROTOPTILA AT FEX AND FCD

Figure 4.13A. Mean Dry Weight per Individual (MDW/IND) for Protoptila
sp. at FEX and FCD from July 1985 to June 1987.

Figure 4.13B. Mean Numbers of Protoptila sp. at FEX and FCD from July
1985 to June 1987.

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means with these sorts of biological data, biological transition times being one of the most critical, so variances will be analyzed around those times. Two seasonal plots of variances regressed against means for total biomass data were done for the present data set. The first plot was spring "transitional" data (January-April) and the second plot was for a "stable" period (June-August). The results are intriguing (Figure 4.14A, B). The transition periods have higher variance relative to mean values for total insect biomass than do the stable periods. Variability analyses will be performed for pre- versus post-operational periods. to see if FEX differs from FCD as a function of E.L.F. fields.

We will also look at differences between abundances at FEX and FCD, using a BACI (Before and After at Control and Impact sites) design (Stewart-Oaten et al. 1986). In this design the difference between the means are plotted rather than the means themselves. If there is no change, one would expect a horizontal line. Changes would be reflected in the direction, amplitude, and frequency of change. Our data and design appear to fit the criteria necessary for the application of the method.

A paper will be written in the summer of 1988, using data from this element. Up to now, these data have not been published in a peer-reviewed journal. During that process, analyses will include degree day analysis for functional community parameters. The changes in MDW/IND values for selected insects may be more meaningful if degree day water temperatures are used rather than chronological time.

Summary

Taxon diversity (H') and evenness (J') from 1983 to 1984 were highly correlated with one another. Both parameters had their highest values in the summer months and their lowest values during the winter months. Both H' and J' were higher at FEX than at FCD. High chironomid abundances greatly affected H' and J' and are highly correlated with those two parameters. The affects of chironomids on H' and J' were most pronounced at FCD, owing to the higher ratio of chironomid abundances relative to other species abundances. When chironomids were excluded from benthic insect analyses, correlation coefficients for J' with respect to H' were lower -- especially at FCD, which is the site containing high numbers of chironomids relative to other species abundances. This indicates that high numbers in the Chironomidae biases H' and J'. If we had the time to separate the family to species level, this bias would be erased.

Distinct seasonal patterns were found for insect total biomass over a five year period. These patterns were highly correlated with diatom densities and water temperatures at FEX and FCD combined until the 1986 - 1987 season. Unusually mild weather conditions is suspected as being the principal factor that altered regression coefficients among the
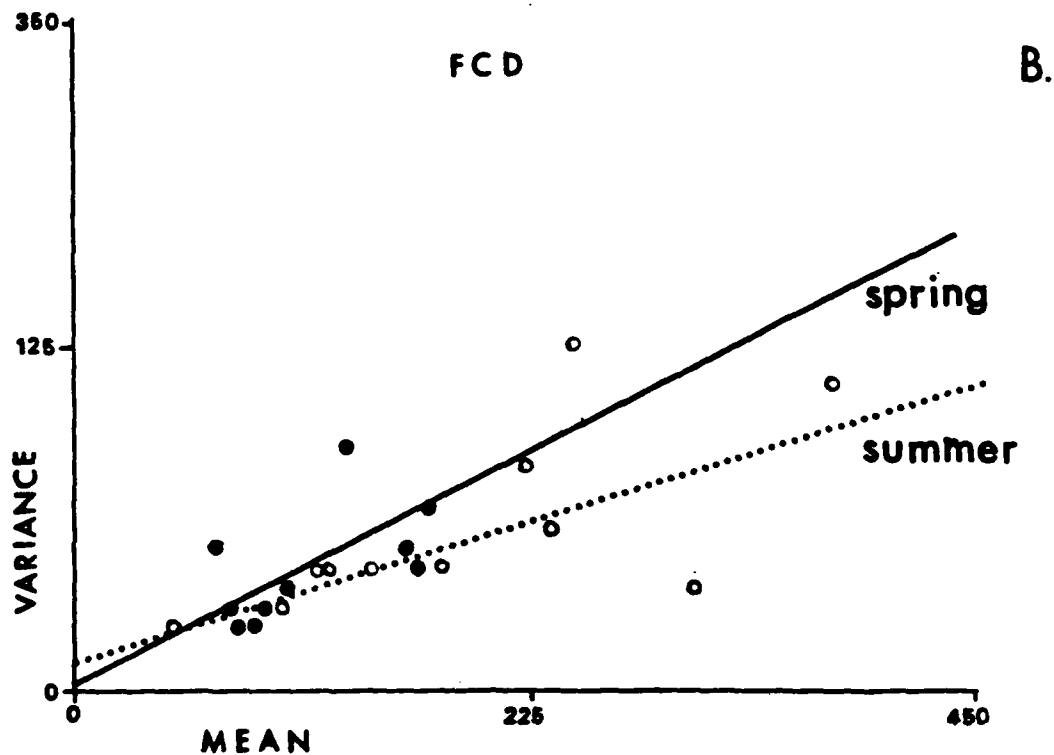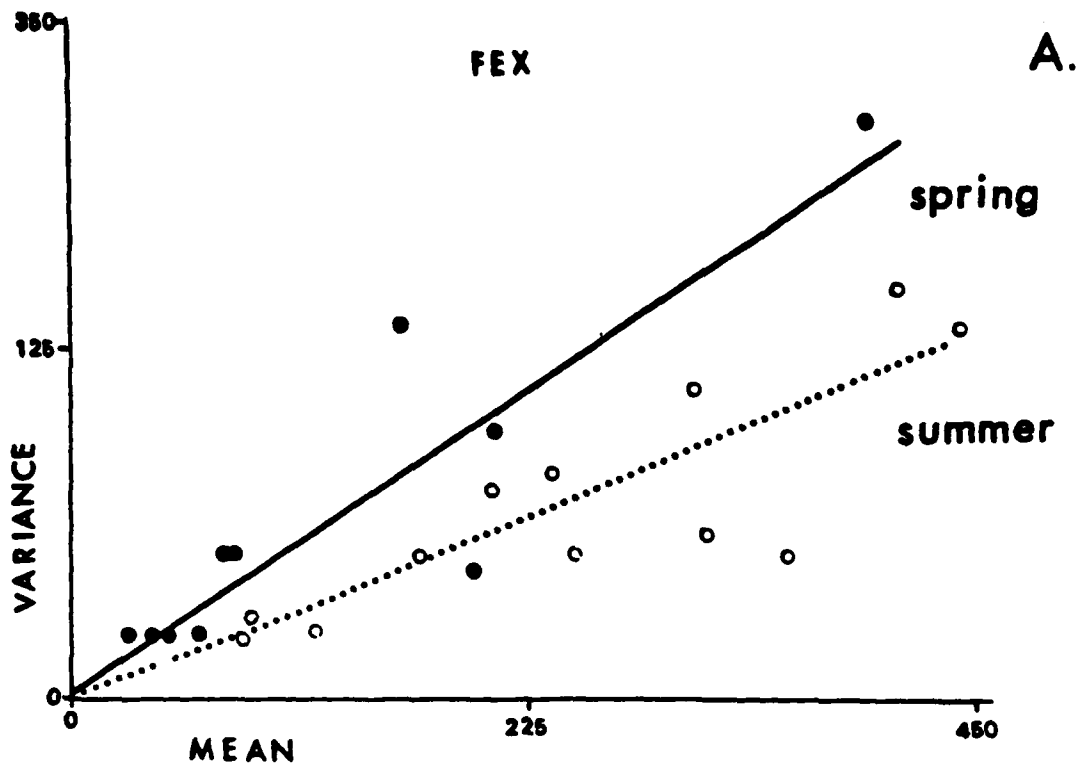
Figure 4.14A. Variance Against Mean for Insect Total Biomass. Solid
line: January through April each Year at FEX (slope = 0.714). Dashed
line: June through August each Year at FEX (slope = 0.427).
Figure 4.14B. Variance Against Mean for Insect Total Biomass. Solid
line: January through April each Year at FCD (slope = 0.419). Dashed
line: June through August each Year at FCD (slope = 0.340).

three parameters. It appears that water temperature alone was
not the controlling factor for diatom and insect biomass
values. We suspect that air temperatures and days of sun,
along with ground water inputs have a great affect on diatom
and insect biomass. From November through March, no daily
readings for these parameters are taken. Weather data from
nearby weather stations should be gathered to determine whether
ambient air temperatures and solar radiation has more affect on
diatom and insect biomass values than do the monthly water
temperature during the colder months of the year.

Functional feeding groups, collector-gatherers,
collector-filter feeders, and predators were highly correlated
with diatom densities until 1986-1987. Shredder biomass
values were never highly correlated with diatom densities.
These seasonal patterns will continue to be investigated,
using additional ambient monitoring data.

Biomass values, when coupled with numerical abundances
of certain taxa, had low variance over time. The following taxa
showed consistent size class patterns (MDW/IND) from 1983 to
1987 at both sites: Chironomidae, Paraleptophlebia mollis,
Ephemerella invaria, E. subvaria, Optioservus sp., Glossosoma
nigrior and Protoptila. They will continue to be monitored.
Optioservus is a holobiotic genus. Both adults and larvae are
found in samples, and so separate analyses for adults and larvae
will continue to be performed. MDW/IND data for this genus is
less reliable than those data for other species, given the fact
that adults and larvae co-occur. Glossosoma and Protoptila were
added to the list of taxa to be followed. Its total numbers
followed diatom density, water temperature, and total insect
biomass over the years. Both genera graze on diatoms.

From September of 1986 through December of 1987 we
collected 7 replicates per site at each collection date.
Unusually high numbers of insects in the samplers forced us to
process only 5 of the 7 samples for each site. If time permits
in the future, those additional 2 samples will be processed.

Literature Cited

A.I.B.S. 1985. Biological and human health effects of
    extremely low frequency electromagnetic fields. Amer.
    Inst. of Biol. Sci., Arlington, VA. 23 pp.

Goodman, E. M., B. Greenebaum and M. T. Marron. 1979.
    Bioeffects of extremely low frequency electromagnetic
    fields: variation with intensity, waveform and individual
    or combined electric and magnetic fields. Radiation Res.
    78: 485-501.

Halberg, F., et al. 1975. Circadian rhythms in plants, insects
    and mammals exposed to ELF magnetic and/or electric fields
    and currents. NTIS, Springfield, VA.

Meier, P. G., D. L. Penrose and L. Polak. 1979. The rate of colonization by macro-invertebrates on artificial substrate samplers. Freshwater Biology 9:381-892.

Merritt, R. W. and K. W. Cummins, 1984. An introduction to the aquatic insects of North America. Kendall/Hunt Publ. Co., Dubuque, Iowa, 722 pp.

Sheppard, A. R. and M. Eisenbud. 1977. Biological effects of electric and magnetic fields of extremely low frequency. New York Univ. Press, New York.

Walters, E. and E. L. Carstensen. 1986. Test for the effects of 60-Hz magnetic fields on fecundity and development in Drosophila. Bioelectromagnetics 8: 351-354.

Smock, L. A., 1980. Relationships between body size and biomass of aquatic insects. Freshwater Biology. 10:375-383.

Stewart-Oaten, Allan, W. W. Murdock and K.R. Parker. 1986. Environmental impact assessment:"pseudoreplication" in time? Ecology, 67:929-940.

Element 5 - Movement Patterns of Selected Aquatic Invertebrates

Changes from the Original Synopsis - None.

Objectives

To monitor short-term movement patterns of a dominant insect predator, the dragonfly Ophiogomphus colubrinus.

Extremely low frequency electromagnetic fields may affect orientation and movements of birds, fish and honeybees (Greenberg and Bindokas 1981, Larkin and Sutherland 1977, N.A.S. 1977, Williams et al. 1976). They also may affect movement and orientation of aquatic insects. We selected a highly abundant predator whose normal travel distances are short enough (5 m per 24 hr) to study feasibly. If E.L.F. alters orientation and movements rates of this predator, we expect (given the numbers of individuals and recapture success) to be able to detect differences, if they occur, under the influence of E.L.F.

Materials and Methods

In June and July, 1987, movement studies of naiads of the dragonfly, Ophiogomphus colubrinus, were conducted at FEX and at FCD. The same riffle at FEX (directly upstream from the ambient monitoring station) was used in 1984 through 1987. The riffle used at FCD was 160 m downstream from the ambient monitoring station there.

Prior to initiating mark-recapture studies, one-meter square grids were established with flagged stakes. Direction of flow, and water depths were taken, using the stakes as reference points. Flow directions were mapped by placing an orange between each upstream stake and tracking the orange's course downstream. Directions were taken prior to initiation of each mark-recapture series. Depths were taken at one meter intervals along four transects perpendicular to the flow. Each transect was four meters apart, going downstream. Discharge values from June 23 through July 6 from the FEX and FCD were used to compare velocities.

Naiads were collected downstream of the riffle, using a one meter square handscreen. The naiads were placed in a holding pan with stream water until sufficient numbers had been collected. No naiads smaller than 9mm were used. Naiads were removed from the holding pan, measured, blotted dry with a "Kimwipe", and marked with Testors enamel paint on the dorsal and lateral surfaces of the abdomen. They were placed in a second holding pan for approximately five minutes to allow the paint to dry. After drying, the naiads were placed in a third holding pan with stream water to test the adherance of the paint. Those individuals on which the paint did not adhere were remarked as described above.

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Naiads were released in the upper end of the study grid
one meter square area (figs 5.1, 5.2). The holding pan,
containing the marked individuals, was placed in the stream
at the upper end of the release area. Naiads were allowed
to wash out of the pan to drift downstream. Some made
contact with the substrate and held on. Those that conti-
nued to drift were captured in a kickscreen held one meter
downstream from the release site. The kickscreen was
then laid parallel to the substrate surface, with the
upstream side facing the substrate. The naiads on the
screen were allowed to crawl from the screen to the
substrate. A second screen was held 1m downstream from the
first and 2m from the original release site. Naiads that
failed to hold onto the substrate were collected on this
screen. Those naiads were placed by hand on the substrate
in front of the screen and they were observed with a
facemask to assure that they did not release and drift
downstream.

Twenty-four hr after the initial release, the grid was
kickscreen sampled in 1m square areas, beginning at the
downstream portion of the study site and ending 2 m above the
release site. The number of marked individuals and unmarked
individuals collected from each square of the grid were
recorded and these naiads were placed in a holding pan.
After the entire site was kicked, leaving a border of at
least 2 square meters where no marked animals were
recaptured, all previously marked animals were remarked with
a new color. Additional unmarked animals were marked, giving
a total of at least 300 individuals. All animals were again
released at the original release site. Forty-eight hr later,
the area was resampled. The 48 hr recaptured animals were
those with the second day marks. After recapturing animals
left in the stream 48 hr, another color was placed on at
least 300 more animals for a 72 hr recapture experiment.
Twenty-four, 48 and 72 hr experiments were performed at FEX
and at FCD from 25 June through 5 July. Percent recapture
success, distances and directions travelled, and comparisons
between and within sites for distances travelled were made,
usikng Chi Square analysis. Population estimates, based on
the Lincoln Index (Southwood, 1966) were determined, using
data from the 24 hr release experiment.

Results

Physical Differences Between FEX and FCD.-- Mean
discharge values were lower at FEX than at FCD (FEX: 0.551
meters cubed per sec; FCD: 0.756 meters cubed per sec; t =
-19.11, d.f. 13, p <.0001). Mean water depths were not
significantly different between the two sites, FEX = 17.8
cm., FCD = 17.9. Water depths in June and July of 1987 were
the lowest recorded for any mark-recapture series. However,
heavy rains in August prevented mark-recapture experiments
from being repeated.
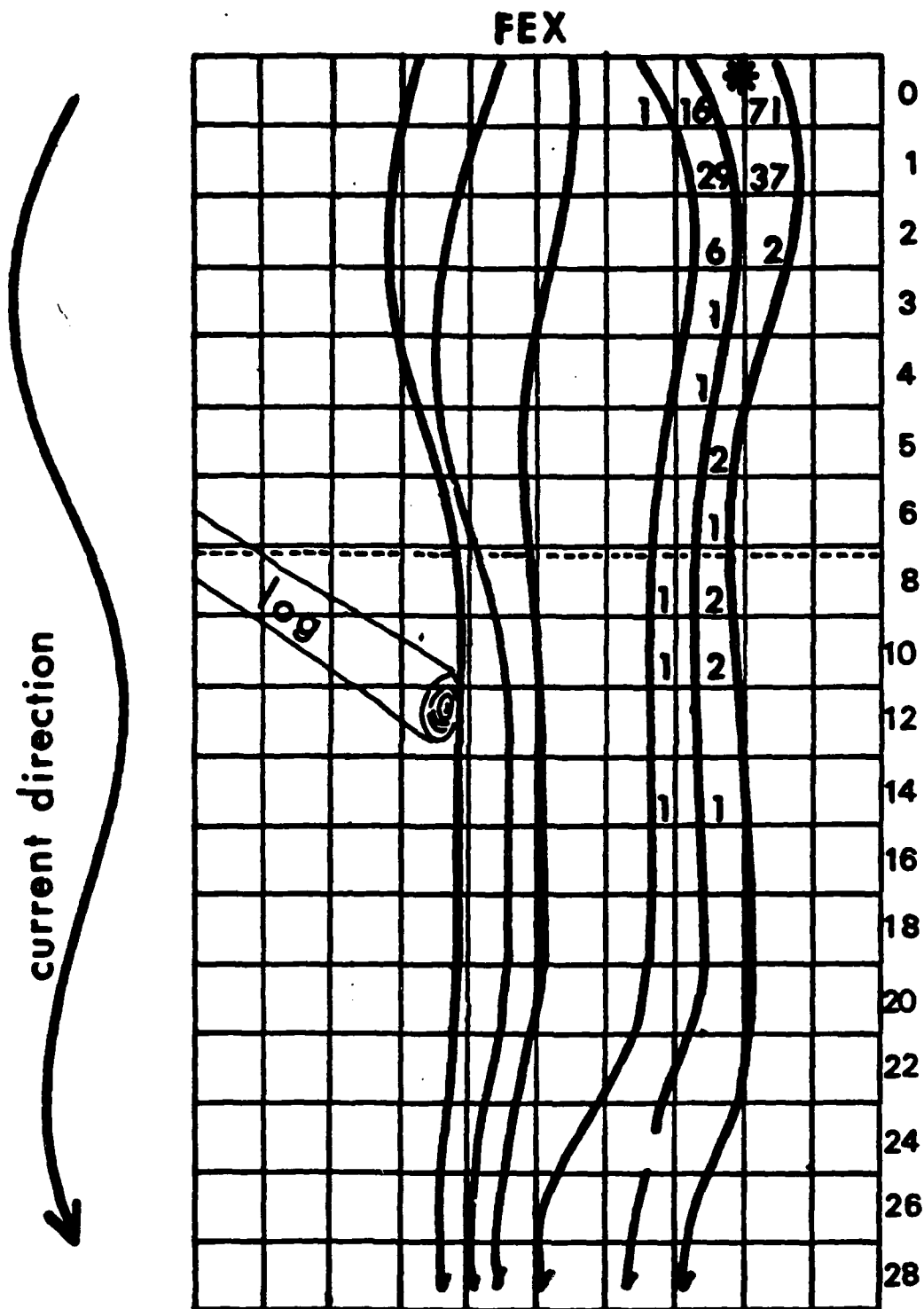
Figure 5.1   Map of FEX with number of marked animals recaptured
in one meter square grids.   24 Hour Recapture,
June 26, 1987.   Asterisk marks release point,
arrow indicates flow direction.
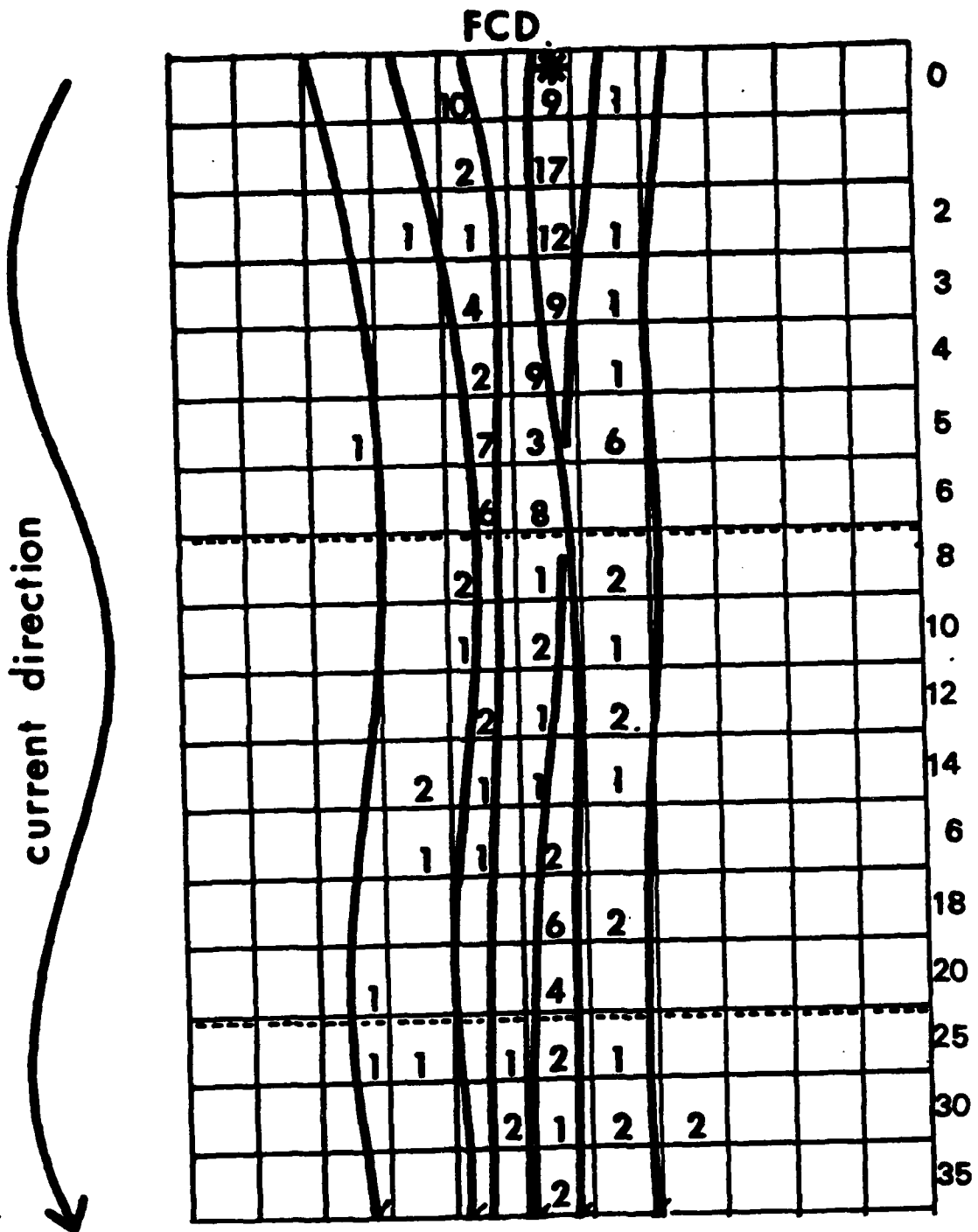
Figure 5.2 Map of FCD with number of marked animals recaptured
in one meter square grids. 24 Hour Recapture,
June 30, 1987.

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Mark-Recapture Results.-- Naiads of O. colubrinus were rather sessile. The net movement direction was downstream, and the marked animals were recaptured along the current flows below the release site. Figures 5.1 and 5.2 show the current flow pattern, along with numbers of marked animals found in each meter square grid. Figure 5.1 shows results from the 24 hr recapture in June at FEX. Figure 5.2 shows data for the same time period at FCD. The pattern of recovery was similar to flow patterns. Distances travelled downstream were relatively short. Table 5.1 and figures 5.3 and 5.4 show that over 60% of recaptured individuals were taken within 6 m of the release site, with one notable exception. Prior to the 72 hr recapture at FCD, a heavy rainstorm occurred, causing water depth at the FCD ambient monitoring station to increase by 10 cm. Percent recapture success on 5 July at FCD was low (Table 5.3), and recapture distances were longer (Table 5.1) Over 26 m distance was necessary before 60% of the marked animals were recovered. Similar rains did not occur for any of the other mark-recapture series in 1987.

TABLE 5.1

Distances and Directions Travelled by Ophiogomphus colubrinus at FEX and FCD after 24, 48 and 72 Hours

TIME	MAXIMUM DISTANCE	MEDIAN DISTANCE	GEOMETRIC MEAN	%LEFT RECOVERED	%CENTER ALONG	%RIGHT WIDTH
		FEX SITE				
24 hrs						
26/VI/87	15	0	1.03	1.71	34.29	64.00
48 hrs						
28/VI/87	28	1	5.37	3.52	88.73	7.75
72 hrs						
1/VII/87	41	1.1	5.03	9.15	88.24	2.61
		FCD SITE				
24 hrs						
30/VI/87	36	5.5	8.24	5.26	77.63	17.11
48 hrs						
2/VII/87	36	3	6.38	9.09	84.42	6.49
72 hrs						
5/VII/87	44	21	18.92	23.81	71.42	4.76

The marked animals at FCD required more labor to recapture, as they were found both farther downstream and across more stream widths. Table 5.2 presents an index of difficulty in recapturing animals; i.e., the area that was necessary to recapture one percent of the total marked animals recaptured. The table also gives the total number of square meters sampled for each recapture experiment.
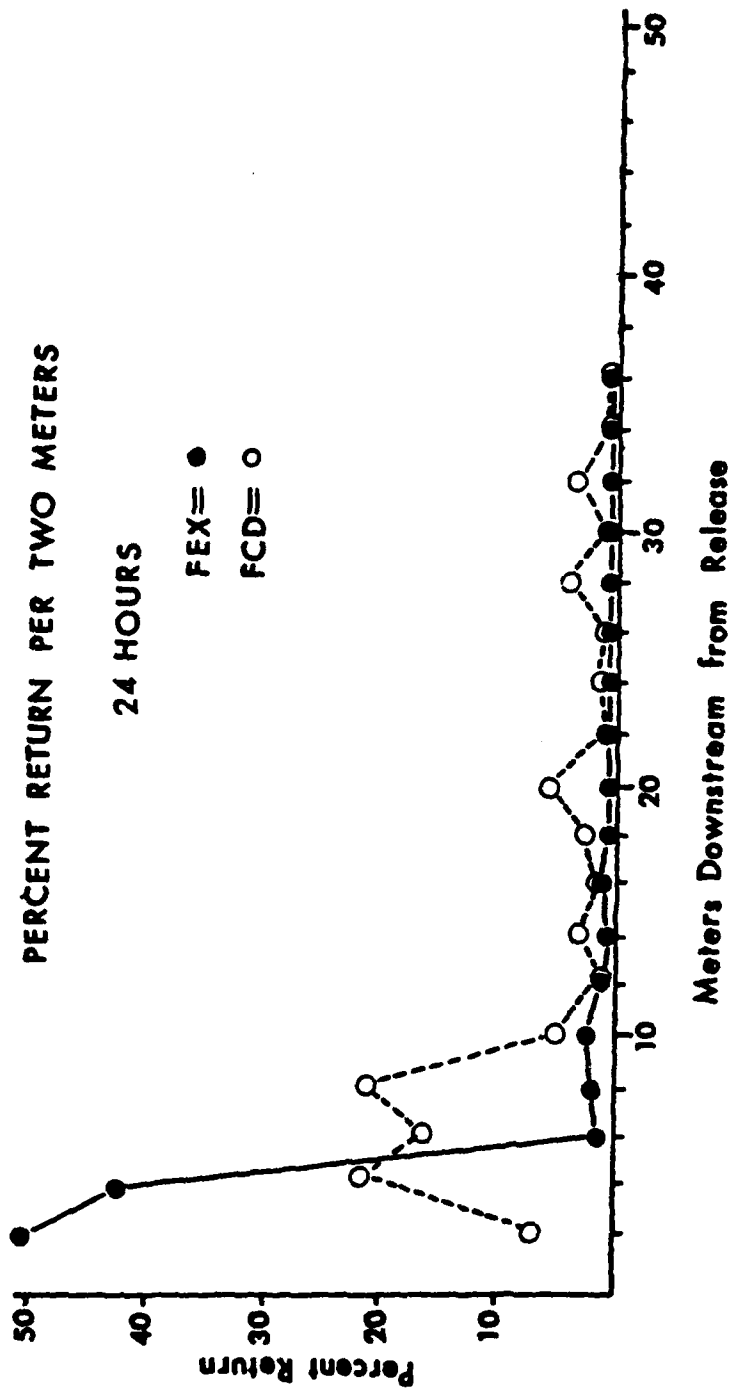
Figure 5.3 24 Hour recaptures: percent recaptured every 2
meters from release point to farthest downstream
recovery site. FEX = ●   FCD = ○ .
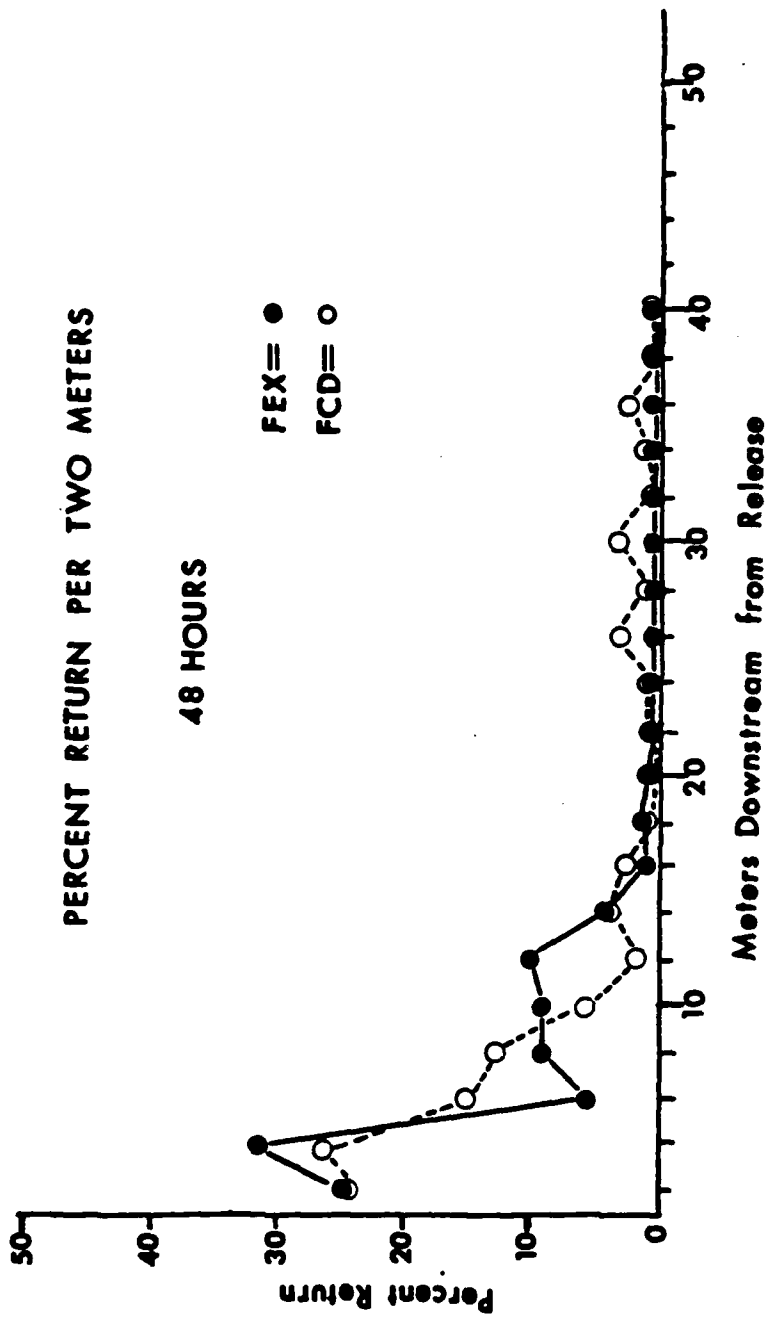
Figure 5.4   48 Hour recaptures: percent recaptured every 2
meters from release point to farthest downstream
recovery site. FEX = ●   FCD = ○ .

Just after releasing marked animals for the FCD 72 hr
experiment, it rained heavily. The rain and increased water
depths appear to have increased the difficulty we had in
recapturing marked animals. Over 17 meters were necessary to
capture 1% of the animals and we had to sample 366 square
meters before we had two meter square areas devoid of marked
animals, our criterion for ending searches downstream and
upstream of the site.

TABLE 5.2

Index of Difficulty in Recapturing Animals
(Square Meters Sampled to Obtain 1% Marked Animals)

SITE	HOURS AFTER RELEASE			SQUARE METERS SAMPLED
	24	48	72	
FEX	1.65	3.33	4.74	91, 155, 226
FCD	5.35	5.19	17.66	271, 258, 366

Table 5.3 gives the overall percent recapture
success as well as population estimates for both sites.
Recapture success was always over 45% with one exception (72
hr at FCD). We do not assume that marked animals
randomly assorted themselves among the rest of the unmarked
population, owing to the sessile nature of the animals. Thus,
estimates of population size include that bias. Lincoln Index
estimates were computed using 24 hour recapture data for each
site.

TABLE 5.3

Percent Recapture Success
and Population Estimates of O. colubrinus

SITE	PERCENT RECOVERY SUCCESS			POPULATION ESTIMATES
	24 hrs	48 hrs	72 hrs	(no.animals/square m.)
FEX	55.21	61.83	47.66	$317/175 = X/329$
				$\dfrac{}{18 \text{ sq.meters}} = 22.7$ per sq.meter
FCD	54.00	49.68	20.72*	$300/162 = X/1187$
				$\dfrac{}{60 \text{ sq.meters}} = 36.6$ per sq.meter

* Heavy rains intervened between release and recapture

Figures 5.3, 5.4 and 5.5 show the percent marked animals
recaptured across the stream every two meters downstream from
the release site (zero on the x axis) to the last recapture
site after 24 , 48, and 72 hours. Animals tended to move

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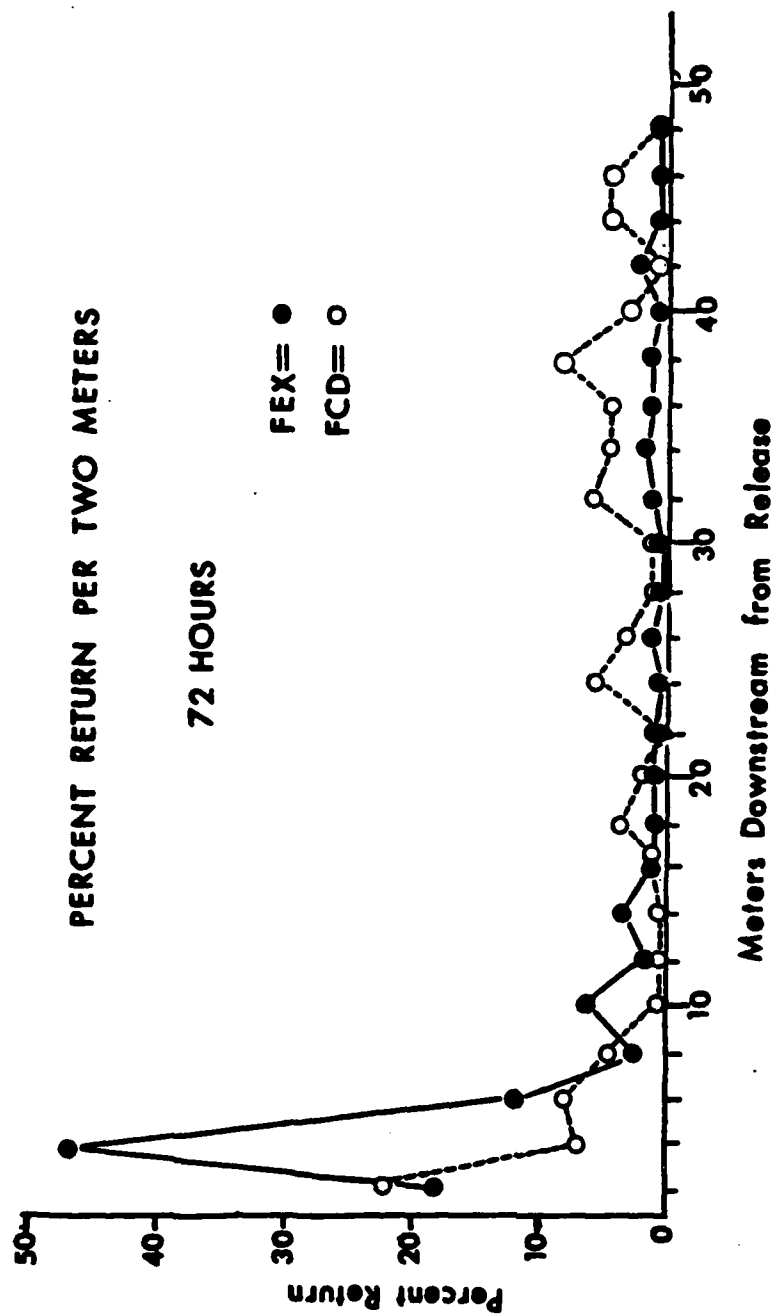
Figure 5.5 72 Hour recaptures: percent recaptured every 2
meters from release point to farthest downstream
recovery site. FEX = ●   FCD= O   .

longer distances with longer recapture intervals, which is to be expected. However, animals tended to move farther downstream at the FCD than at the FEX site for each time period. The figures show rather a negative exponentional pattern, indicating that most animals were found near the release site. Unlike in previous years, there was no kickscreening between releases and recaptures for the 48 and 72 hr experiments. All figures are similar in pattern, with the longer intervening periods of recapture showing longer distribution tails to the right. The only figure (5.5) that deviates is for the 72 hr recapture at FCD where rains affected locations of the animals.

Chi Square tests were used to compare distances the animals moved at FEX and FCD after 24, 48 and 72 hours in 1987 (Table 5.4). The values above the slash marks show the observed number of marked animals over a 10 m distance. Values below the slash marks show the expected number of marked animals.

TABLE 5.4

Chi Square Test for Distances Moved by Ophiogomphus colubrinus at FEX and and FCD in 1987

| Meters down-stream | FEX SITE | | | FCD SITE | | |
	24 hrs	48 hrs	72 hrs	24 hrs	48 hrs	72 hrs
0 - 10	172/148	114/120	130/122	109/124	121/123	26/35
11- 20	3/16	17/13	12/13	23/13	13/13	4/4
21- 30	0/12	11/9	3/10	15/10	12/10	12/3

Difference Between Observed & Expected

0 - 10	+24	-6	+8	-15	-2	-9
11- 20	-13	+4	-1	+10	0	0
21- 30	-12	+2	-7	+5	+2	+9

Chi Square = 78.18, d.f. = 10, p <.001

There are significant differences between sites and intervals between recaptures. By looking at the signs for the differences between observed and expected, one can see a tendency for more animals than expected being found close to the release site at FEX as compared with FCD. Also, more animals than expected were found at the downstream sections at FCD than at FEX.

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Data from 1985, 1986 and 1987 were selected for a further Chi Square analysis across years. Data were collected in June-July of those years, and only 24 hr recapture data were used, as in 1985 and 1986 we kickscreened between the 48 and 72 hr experiments. Results appear in Table 5.5.

TABLE 5.5

Chi Square Tests for Distances Moved by Ophiogomphus colubrinus at FEX and FCD in 1985, 1986 and 1987

Distances Down-stream	FEX SITE			FCD SITE		
	24 hr	48 hr	72 hr	24 hr	48 hr	72 hr
0 - 10	91/83	115/124	172/150	95/90	110/120	109/126
11- 20	6/11	27/17	3/20	10/12	24/16	23/17
21- 30	0/3	3/4	0/5	0/3	6/4	15/4
Difference between Observed and Expected						
0 - 10	+8	-9	+22	+5	-10	-17
11- 20	-5	+10	-17	-2	+8	+6
21- 21	-3	-1	-5	-3	+2	+11

Chi Square = 79.6, d.f. = 10, p < .001

The same pattern holds for the 1985 through 1987 data set. There is a tendency for more animals than expected to be recaptured near the release site at FEX as compared with FCD, and a tendency for more animals than expected to be recaptured at the downstream sections of FCD as compared with FCD. Biological reasons for the differences in recaptures between the two sites are: FEX has a mean lower velocity, it has more more pebbles of larger size, and it has a shorter run before ending in a pool area than FCD. Differences between the two sites with respect to location of marked animals exist. But those differences appear to be consistent for the 24, 48 and 72 hr periods as well as across years. If these patterns change after ELF is turned on, the electromagnetic waves may become suspect as causing movement pattern changes.

Discussion

1987 Studies.--This dragonfly predator, in searching prey, appears to travel short distances -- at least during summer months. Owing to its rather sessile habits, high recapture success is possible. Also, movement patterns can be determined with good reliability. On the other hand, one assumption for population estimates based on mark-recapture studies cannot be met: We cannot assume that marked animals resort themselves randomly in the population after release.

Rather, they are rather sessile and they also appear to respond to current flow patterns more than to the substrate when they do move. Thus, population estimates are subject to question. We chose to base population estimates using grids that included marked animals. Bias owing to nonrandom reassortment were hopefully minimized by excluding grids devoid of marked animals.

The most powerful results from this element are those showing distances travelled over time. If ELF effects alter movements of these animals such that they travel significantly longer distances, we should be able to detect differences if we repeat mark-recapture studies under similar physical and temporal conditions. Because gathering the necessary data is labor intensive, and other elements must be considered as well, we plan to run the 24, 48 and 72 studies at both sites only once during succeeding field seasons.

Comparison With Earlier Studies.-- Percent recapture sucess was higher in 1987 than in 1984, 1985 or 1986. The success rates for all years were very high, relative to most mark-recapture aquatic invertebrate studies (Stout, 1978, 1981, Bovbjerg, 1952). The direction of movement for these animals over all years was the same: downstream. The distances travelled were also similar, Table 5.6.

TABLE 5.6

Distances Travelled and Percent Recapture Success Results for
June-July of 1985, 1986 and 1987

A. ·24 Hour Recaptures

| | FEX | | | | FCD | | | |
Year	Geo. Mean	Median Dist.	Max Dist.	% Return	Geo. Mean	Median Dist.	Max Dist.	% Return
1985	4.9	5	13	31.45	3.6	3	17	33.85
1986	5.4	3	23	43.70	10.7	6	56	46.67
1987	1.0	0	15	55.21	8.2	5	36	50.67

B. 48 Hour Recaptures

1985	7.5	5	25	30.92*	7.0	6	17	27.20*
1986	5.5	2	22	23.33*	15.5	11	40	41.14*
1987	5.4	1	28	65.83*	6.4	3	36	49.68*

C. 72 Hour Recaptures

1985	10.9	11	24	22.17*	6.8	5	14	6.47*
1986	10.4	6	30	1.76*	24.4	24	49	32.76*
1987	5.0	1	41	47.66	18.9	21	44	20.72

* = Intervening kickscreening prior to recapture.

In 1984, the maximum distance after 24 hr at FEX was 10 m and after 96 hr it was 7 m. No similar studies were done at FCD that year.

Summary

Naiads of O. colubrinus travelled in a downstream direction at both sites for all mark-recapture studies. Percent recapture success is high (usually from 30 to 50%) making us rather confident that the data reflect the actual movement patterns of this predator. Finally, owing to their numerical dominance, "markability", and sessile behavior, these animals are very appropriate animals by which movement patterns can be monitored in the event that ELF affects movement patterns of this sit-and-wait dragonfly predator.

Literature Cited

Bovbjerg, R. V., 1952. Ecological aspects of dispersal of the snail Campeloma decism. Ecology, 33:169-176.

Greenberg, B. and V. P. Bindokas. 1981. The effects of high voltage transmission lines on honey bees: interim report. Bioconcern, Chicago, Illinois (EPRI report EA-1809).

Larkin, R. P. and P. J. Sutherland. 1977. Migrating birds respond to Project Seafarer's electromagnetic field. Science 195: 777-779.

National Academy of Science. 1977. Biologic effects of electric and magnetic fields associated with proposed Project Seafarer. Report of Comm. on Biosphere Effects of Extremely Low Frequency Radiation, Wash., D.C.

Williams, T. C., et al. 1976. A radar investigation of the effects of extremely low frequency electromagnetic fields on the free flying migrant birds. N.T.I.S., Springfield, VA. (N.T.I.S. A.D.A. 035725).

Southwood, T. R. E., 1966. Ecological methods. Methuen & Co., Ltd., London. 391 pp.

Stout, R. J., 1978. Migration of the aquatic hemipteran Limnocoris insularis (Naucoridae) in a tropical lowland stream (Costa Rica, Central America). Brenesia, 14:1-11.

Stout, R. J., 1981. How abiotic factors affect the distribution of two species of tropical predaceous aquatic bugs. Ecology, 62:1170-1178.

Element 6 - Leaf Litter Processing

Changes from the Original Synopsis - None.

Objectives

1) To monitor fresh and autumn-abscissed leaf processing rates during the fall-winter of 1987-88; 2) to monitor colonization patterns of insects on fresh and autumn-abscissed leaves during the fall-winter of 1986-87 and, 4) to compare 1986-1988 results with those from prior years.

Processing rates of leaves incorporate the functional responses of fungi, bacteria, other micro-organisms and certain aquatic insects as they use leaves as both a nutritive and substrata resource. Alterations in leaf processing rates and microbial and insect colonization onto leaves in streams have been correlated with a number of perturbation regimes; e.g., chemical (Fairchild et al. 1984, Stout and Cooper 1983, Wilhm and Dorris 1966), thermal stress (Gersick and Brusven 1981), forest cutting practices (Webster and Waide 1982). If E.L.F. alters any of those communities, differences in processing rates of the leaves themselves should be expected. As data thus far show that fresh green and autumn senescent leaves have predictable and consistent leaf processing rates, rate changes as a function of E.L.F. should be detectable.

Insects colonize leaves in a general sequential pattern: After conditioning by bacteria and fungi, insect functional feeding groups such as shredders, scrapers, collector-gatherers, filter-feeders and predators arrive in sequence. If any of those sequence "groups" are missing as a function of E.L.F., not only the sequence pattern, but relative abundances and growth rates of insects on leaves over time can be altered. Changes would be detected via changes in numbers and/or biomasses of functional feeding groups as well as size class structural alterations. Changes in biomass for the functional feeding groups shredders, collector-gatherers and predators (adjusted to changes in leaf mass) are analyzed. In addition, size class changes for three aquatic insect species are determined. A collector-gatherer mayfly, _Ephemerella invaria_, and a stonefly predator, _Isoperla transmarina_ were selected as target species as they are common on leafpacks and show consistent changes in size classes over time. A mayfly collector-gatherer _Paraleptophlebia mollis_ is also included so that its size class changes on leaves can be compared with its changes in the benthos over time (Element 4).

Materials and Methods:
A. Leaf Processing

On September 10, 1986, fresh tag alder leaves (_Alnus rugosa_) were collected from a grove adjacent to the Ford River, weighed into 5.20 to 5.30 gm fresh weight leafpacks and taken to

FEX and FCD that day. (A regression of leaf fresh weight against leaf dry weight had an r2 of 0.94, showing that initial dry weight estimates could be made from having fresh leaf weights). Seven replicates per site were collected after 3, 9, 27, 58, and 106 days. Autumn abscissed leaves were collected daily from parachutes placed under tag alder trees. After drying leaves for 48 hr at 60oC, leafpacks ranging in dry weight from 2.30 to 2.40 gm were lashed to bricks and placed at FEX and FCD sites September 19. Seven replicates per site were collected after 3, 9, 27, 58 and 88 and 106 days. This Report describes the leaf processing rates and the colonization of insects on those leaves.

On August 28, 1987, freshly picked tag alder leaves were prepared the same way as for the 1986 study and taken to the Ford River at the FEX and FCD sites, lashed to bricks and placed in the river. The previous year's autumn leaves, prepared the same way as for the 1986 study, were placed at the sites on August 28th. Leaves were recovered after 7, 14, 21, 26, 50 and 76 days' immersion. This report describes leaf processing rates of the two types of leaves. The next Annual Report will describe the insects on those leaves.

Leaf processing rates (-k) were computed after Petersen and Cummins, 1975. Final dry weights for each collection date were used. Data analysis for individual years included linear regressions for -k values and Two-Way ANOVAS for tests of site versus treatment differences for each collection date. Co variance analysis was used to compare leaf processing rates among years.

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 taxonomic breakdown below the order level. Identified insects were then measured to the nearest mm for later computation of biomass values. Species diversity (H'), richness (S) and evenness (J') were computed for each sample. Numbers of individuals and total biomass for each sample were computed. For select taxa, percent numerical dominance and/or mean biomass per individual were determined. Finally, total biomass values for functional feeding group categories (including a special category, Chironomidae) were computed (after Merritt and Cummins, 1984). Coefficient of variation (C.V.) values for each estimated parameter from each set of samples were computed. A power test was used to determine if sufficient replicates had been collected to have, 95% of the time, confidence that the mean varied no more than ± 40% with an alpha of .05. (Seven replicates were sufficient if the parameter had a C.V. value of 20% or less.) If values for any parameter were not normally distributed, they were trans-formed prior to analysis (e.g., percent data).

Results and Discussion

Leaf Processing Rates

1986 Data:

Processing coefficients for fresh leaves were 0.0101 at FEX and 0.0107 at FCD. Coefficients for autumn-abscissed leaves were 0.0034 at FEX and 0.0028 at FCD, Figure 6.1. Petersen and Cummins (1974) categorized rates of leaf loss into three categories: $-k > .010$ = fast; $.010 > -k > .005$ = intermediate, and $-k < .005$ = slow. Thus, green tag alder leaves were processed fast and autumn-abscissed leaves were processed slowly. The differences were significant (two-tailed t-test for slope differences: FEX, t = -5.90, d.f.: 68; FCD, t = -3.48, d.f.: 60).

Table 6.1 shows 2-Way ANOVA values for tests of site versus treatment differences. Treatments (fresh vs. autumn) were significantly different on days 3, 27 and 58. Sites differed significantly on days 3 and 27. Green leaves were processed faster at FEX than at FCD. Although ANOVA tests could not be done after Day 54, owing to collection date differences, Figure 6.1 shows that values between autumn and fresh leaves after Day 54 were different, irrespective of site.

TABLE 6.1
Comparisons between Fresh and Autumn-Abscissed Leaf Losses, Ln Percent Remaining Dry Mass Values
FEX and FCD, 1986. Two-Way ANOVA for Site Versus Treatment

Days in Stream	Source	d.f.	MSS	F-ratio	Prob.
3	site	1	.063	92.664	<.0000001
	treatment	1	.029	42.233	<.000001
	interaction	1	.001	1.537	.227
	error	24	.00068		
9	site	1	.0007	.350	.5598
	treatment	1	.0012	.576	4555
	interaction	1	.016	7.690	.003
	error	24	.002		
27	site	1	.153	9.635	.0048
	treatment	1	.072	4.506	.0443
	interaction	1	.136	8.500	.0073
	error	16	.016		
58	site	1	.0068	.082	.7774
	treatment	1	2.779	33.187	<.00001
	interaction	1	.049	.583	.453
	error	16	.084		

LEAF MEAN DRY WEIGHTS, FEX AND FCD
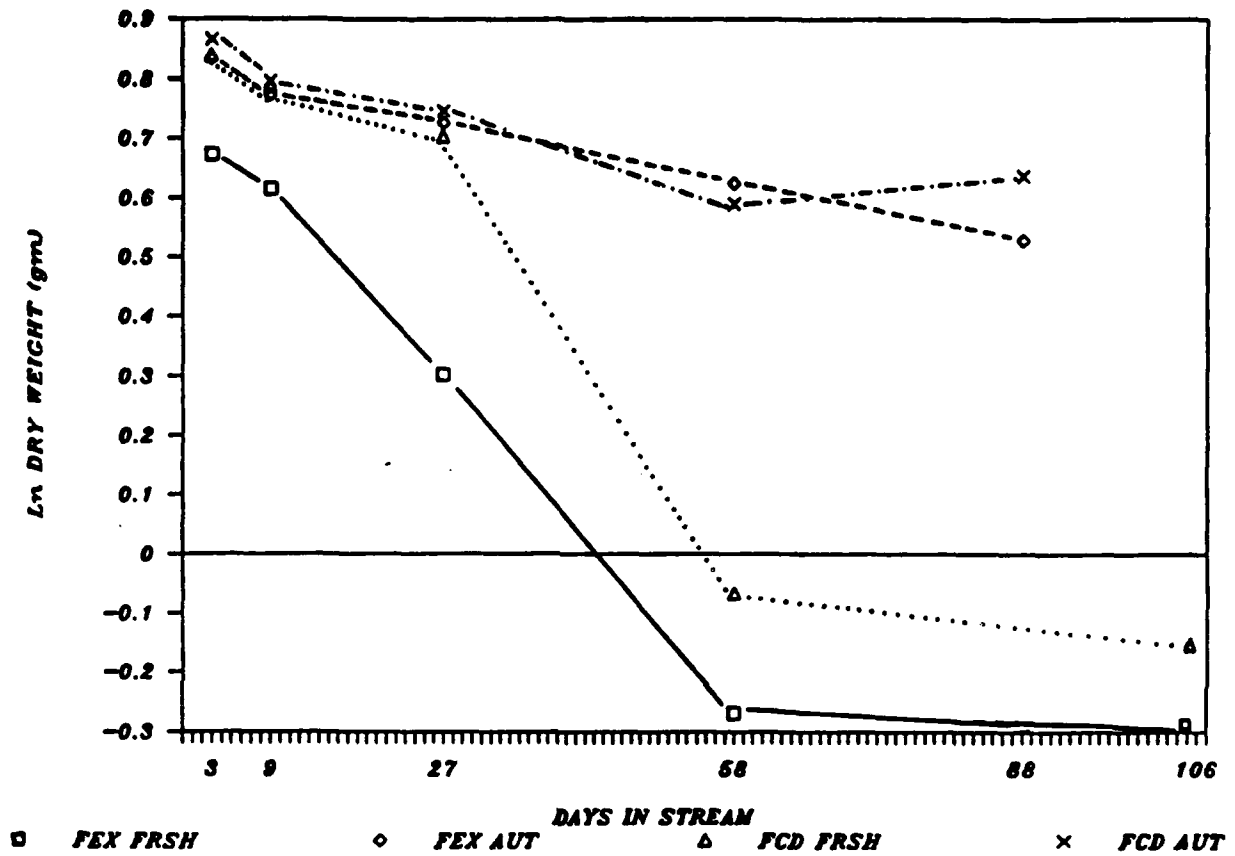
Figure 6.1 1986 Leaf processing for fresh and autumn leaves at FEX and FCD. Processing coefficients, -k: FEX fresh = 0.0101, FEX autumn = 0.0034, FCD fresh = 0.0107, FCD autumn = 0.0028.

1987 Data:

Processing coefficients were higher for fresh than for autumn leaves at both sites, Figure 6.2. At FEX and FCD fresh leaves were processed fast (-k = 0.0115 and 0.0130 respectively). Autumn-abscissed leaves were processed at intermediate to slow rates at FEX and FCD (-k = 0.0070 and 0.0049 respectively). Fresh leaves were processed significantly faster than autumn-abscissed leaves (two-tailed t-test for differences in slopes: FEX, t = -3.60, d.f.: 82; FCD, t = -4.33, d.f.: 82.). Table 6.2 shows Two-Way ANOVA tests for the 1987 leaf loss data for days 7, 14, 26, 50 and 76. There were significant treatment differences for days 7, 14 and 50 and 76. Figure 6.2 shows that fresh green leaves were processed faster than were autumn-abscissed leaves at both sites. At no time were there site differences.

TABLE 6.2

Comparisons between Fresh and Autumn-Abscissed Leaf Losses, Ln Percent Remaining Dry Mass Values
FEX and FCD, 1987. Two-Way ANOVA for Site Versus Treatment

Days in Stream	Source	d.f.	MSS	F-ratio	Prob.
7	site	1	.0002	.043	.837
	treatment	1	.175	38.210	<.00001
	interaction	1	.001	.538	.227
	error	24	.0024		
14	site	1	.0092	1.973	.1730
	treatment	1	.101	21.743	<.0001
	interaction	1	.002	.526	.476
	error	24	.0046		
26	site	1	.0024	.262	.6133
	treatment	1	.009	.986	.3306
	interaction	1	.008	.839	.3688
	error	24	.0093		
50	site	1	.027	.710	.4079
	treatment	1	.370	9.852	.0044
	interaction	1	.378	9.947	.0041
	error	24	.038		
76	site	1	.074	1.267	.2714
	treatment	1	.877	14.990	.0007
	interaction	1	.076	1.288	.2649
	error	24			

LEAF MEAN DRY WEIGHTS, FEX AND FCD 1987
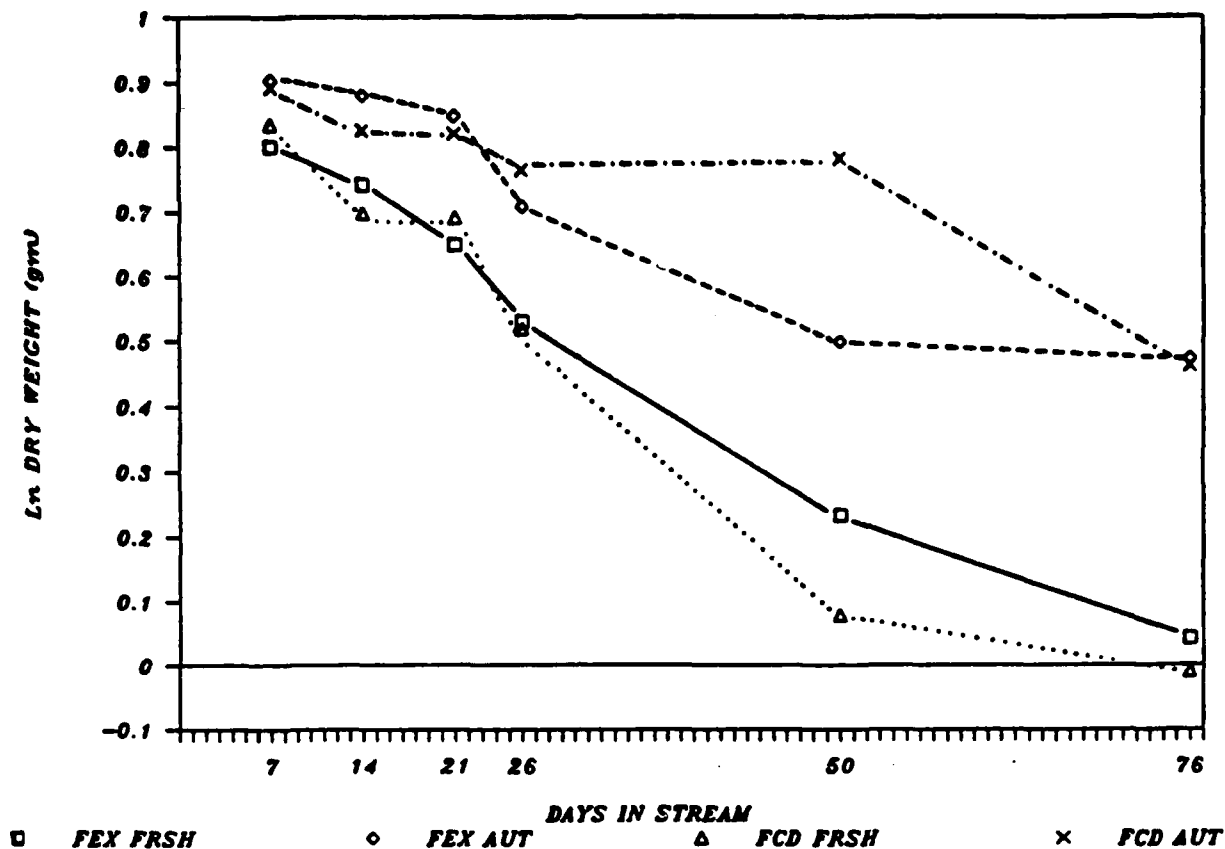
Figure 6.2   1987 leaf processing for fresh and autumn leaves at FEX and FCD. Processing coefficients, -k: FEX fresh = 0.0115, FEX autumn = 0.0070, FCD fresh = 0.0130, FCD autumn = 0.0049.

Comparisons Among Years, 1982 - 1987:

Table 6.3 presents processing coefficient values (-k) from 1982 through 1987. Fresh leaves or oven-dried fresh leaves were processed significantly faster than were autumn-abscissed leaves for all the studies. A two-tailed t-test for differences between slopes for a linear regression of fresh leaf dry weights at FS1 in 1982-1983 (days 3 through 111) and at FEX in 1984 (days 3 through 91) showed no significant difference (t = 0.965, d.f. = 44, p> 0.10). The same comparison at FEX for autumn abscissed leaves also showed no significant difference in slopes (t = 0.200, d.f. = 44, p> 0.10). Further two-tailed t-tests were run between 1985-86 fall-winter study of fresh leaves and summer of 1986 fresh leaves. At FEX and at FCD, there were no significant differences between slopes for fresh leaves (FEX, t = .699, d.f. = 42, p = .244; FCD, t = 1.443, d.f. = 44, p = .078).

Table 6.3
Processing Coefficients (-k) For Fresh and Autumn Leaves
on the Ford River

Season and Year	FEX		FCD	
	Fresh	Autumn	Fresh	Autumn
Fall, Winter 1982-83*	.0171	.0086	–	–
Fall, Winter 1984-85	.0152	.0081	.0150	.0060
Fall, Winter 1985-86	.0320	–	.0150	–
Summer (excluded from grand means) 1986	.0206	–	.0266	–
Fall,Winter 1986-87	.0101	.0034	.0107	.0028
Fall,Winter 1987	.0115	.0070	.0130	.0049
MEAN	.0170	.0068	.0134	.0046
S.D.	.0089	.0023	.0020	.0016
N	5	4	4	3

*1982-1983 site was FS1, 2 km upstream of FEX.

The high -k values for fresh leaves at FEX in the fall-winter of 1985-86 may have been related to extensive flooding and scouring prior to Day 54 collections. (FEX contains more cobble and pebbles than does the FCD site.) One would expect that the

processing rates for fresh leaves during the summer months (see summer of 1986 values) would be higher than those for fresh leaves put into the Ford River during the fall when water temperatures and bacterial activities lower. If the leaf losses in the fall of 1985 at FEX are attributable to more extensive scouring there and more deposition of sand at the FCD site, the data agree with what one would expect for summer versus fall-winter differences in processing rates.

Insects Colonizing Leafpacks

Structural Community Parameters:
1986 Data

Taxon diversity values after Day 9 decreased rather linearly over time irrespective of site or treatment (Fig. 6.3). The reduction in the evenness component (Fig. 6.4) of the diversity index depresses the diversity index values. That reduction is attributable to the steady increase in chironomids over time (Fig. 6.5). The family was treated as a single taxon in the analysis. Taxon richness, the other component of diversity, had its major peak at Day 27 for autumn leaves at both sites and for fresh leaves at FCD (Fig. 6.6). The peak for fresh leaves at FEX occurred at Day 58 just after more than 50% of leaf mass had been processed. Had we sufficient time to identify chironomids to lower taxonomic levels, the diversity and evenness indices may have more closely approximated the richness index.

Table 6.4 shows site and treatment differences in taxon diversity. FEX usually had a more diverse insect community and autumn leaves at each site supported a more diverse community than fresh leaves.

TABLE 6.4
Comparison of Taxon Diversity Values for Insects on
Fresh and Autumn Leaves at FEX and FCD
Two-Way ANOVA for Site Versus Treatment Differences

Days in Stream	Source	d.f.	MSS	F-ratio	Prob.
3	site	1	.037	.568	.458
	treatment	1	.204	3.111	.090
	interaction	1	.206	3.169	.088
	error	24	.065		
9	site	1	.563	8.94	.006
	treatment	1	.909	14.44	.0009
	interaction	1	.0002	.003	.955
	error	24	.063		
27	site	1	.391	2.760	.110
	treatment	1	1.919	13.535	.001
	interaction	1	.270	1.901	.180
	error	24	.142		

DIVERSITY, ALL SITES, TREATMENTS
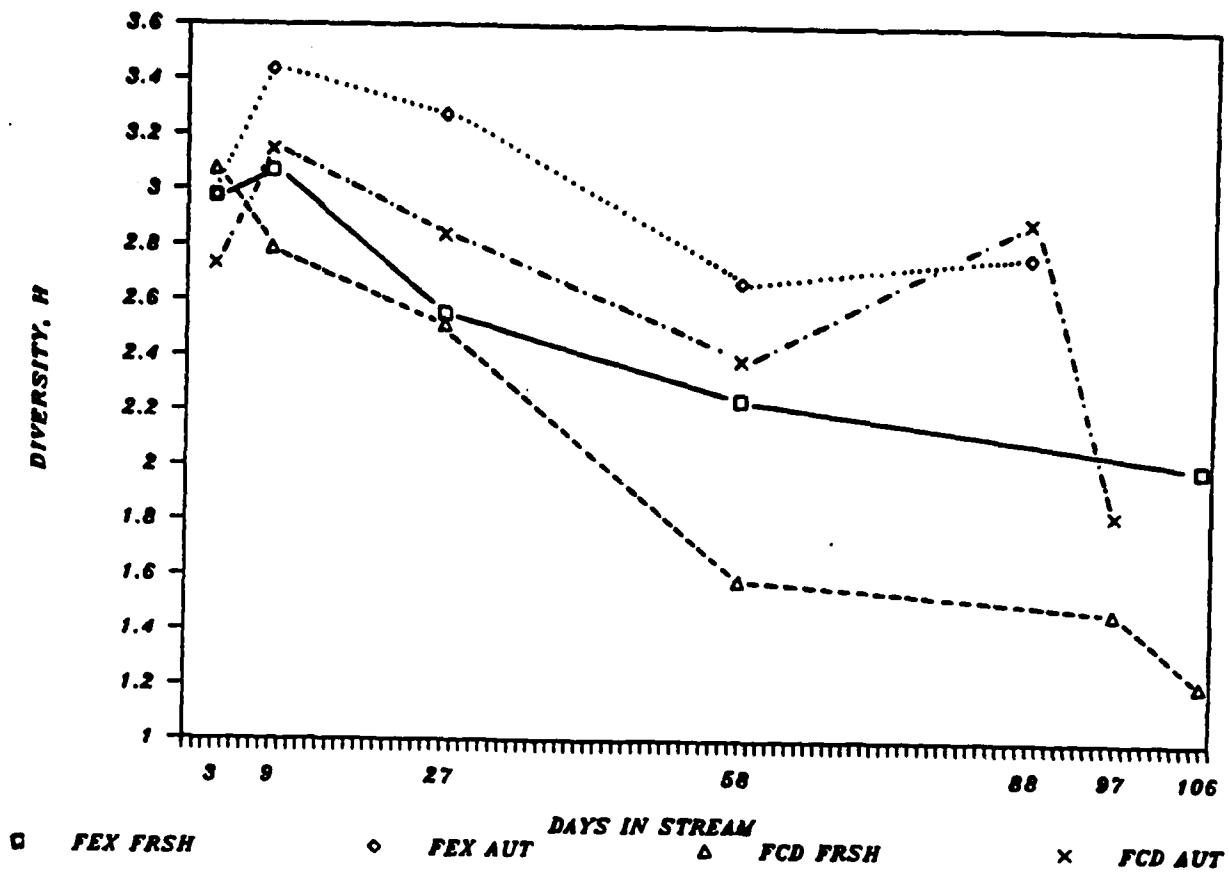
Figure 6.3   1986 taxon diversity values for insects on FEX
             fresh, FEX autumn, FCD fresh and FCD autumn
             leaves. (Shannon-Weiner Diversity Index, H')

EVENNESS, SITES AND TREATMENTS
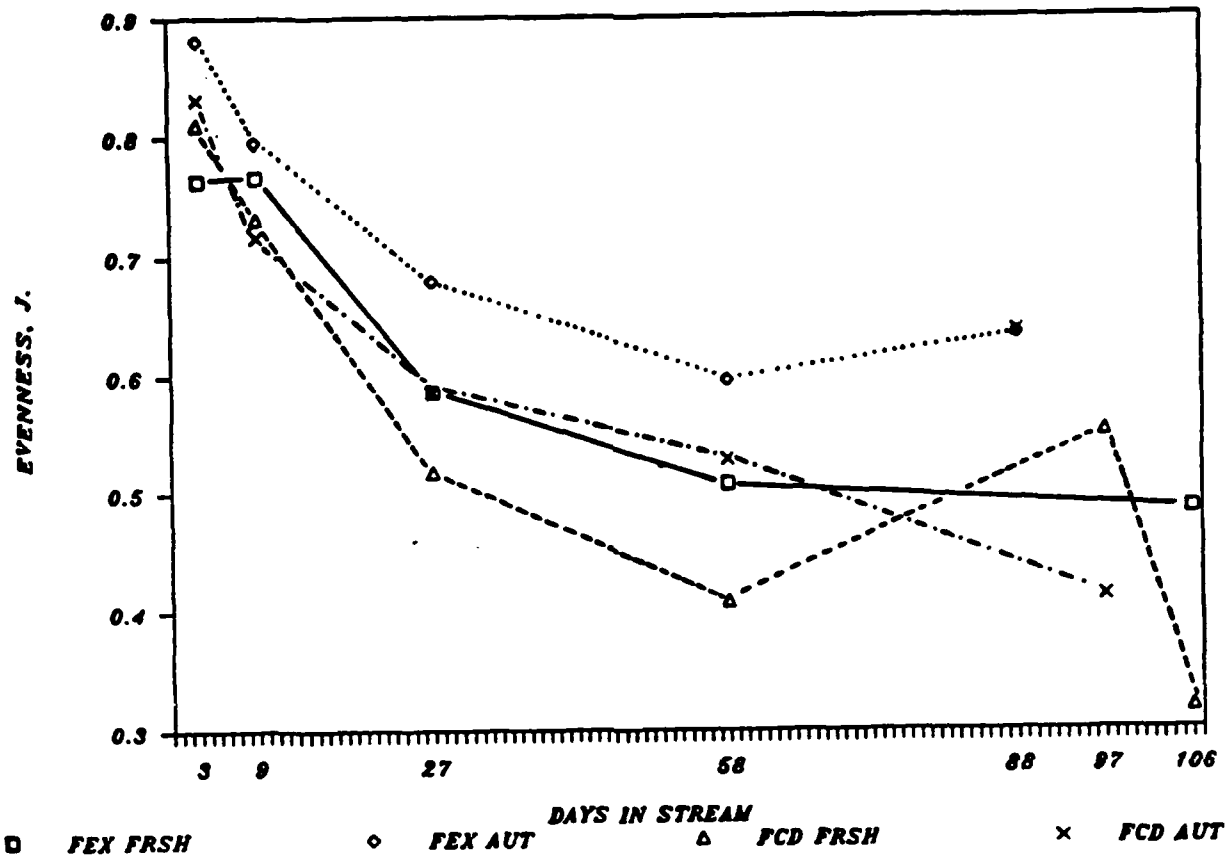
Figure 6.4   1986 taxon evenness values for insects on FEX fresh, FEX autumn,FCD fresh and FCD autumn leaves.

CHIRONOMID DOMINANCE
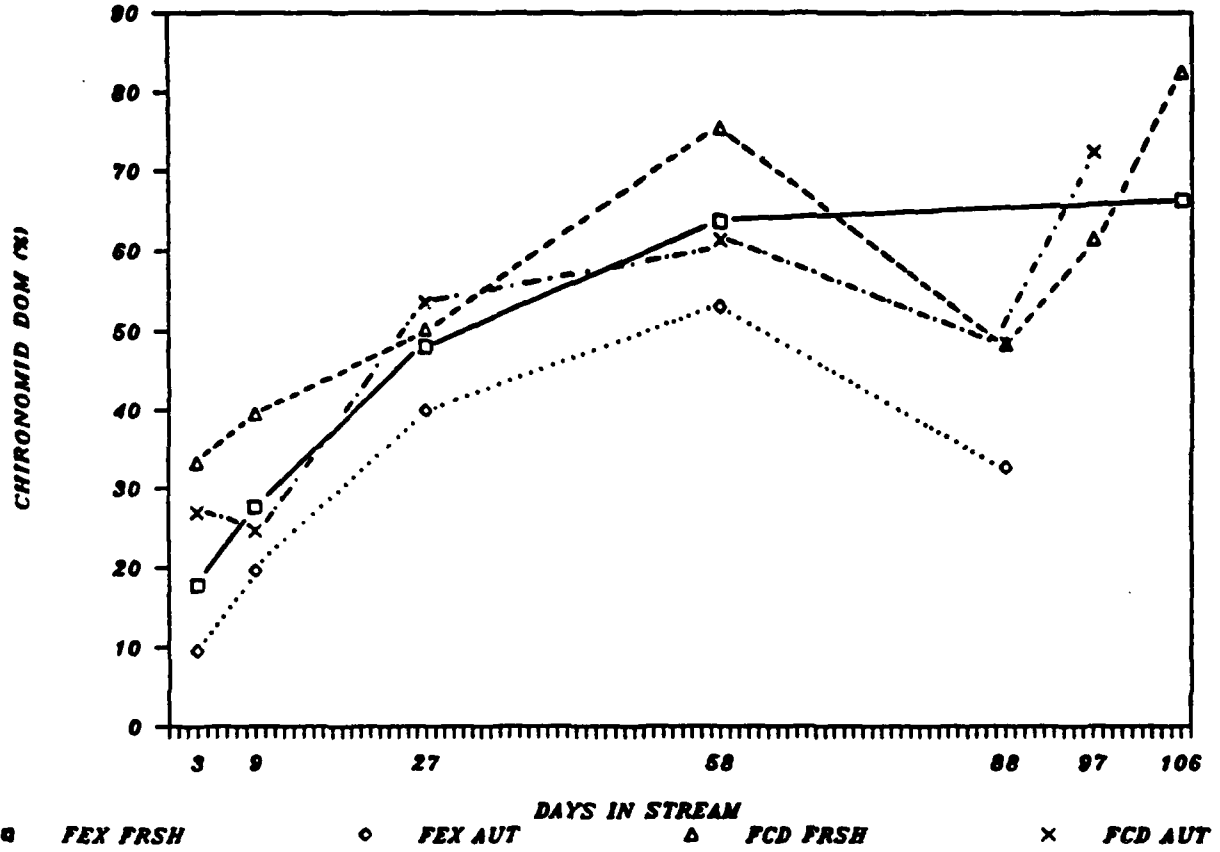
Figure 6.5   1986 chironomid dominance values (number of
chironomids/total number of all insects) for
insects on FEX fresh, FEX autumn, FEX fresh
and FCD autumn leaves.

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RICHNESS, SITES AND TREATMENTS
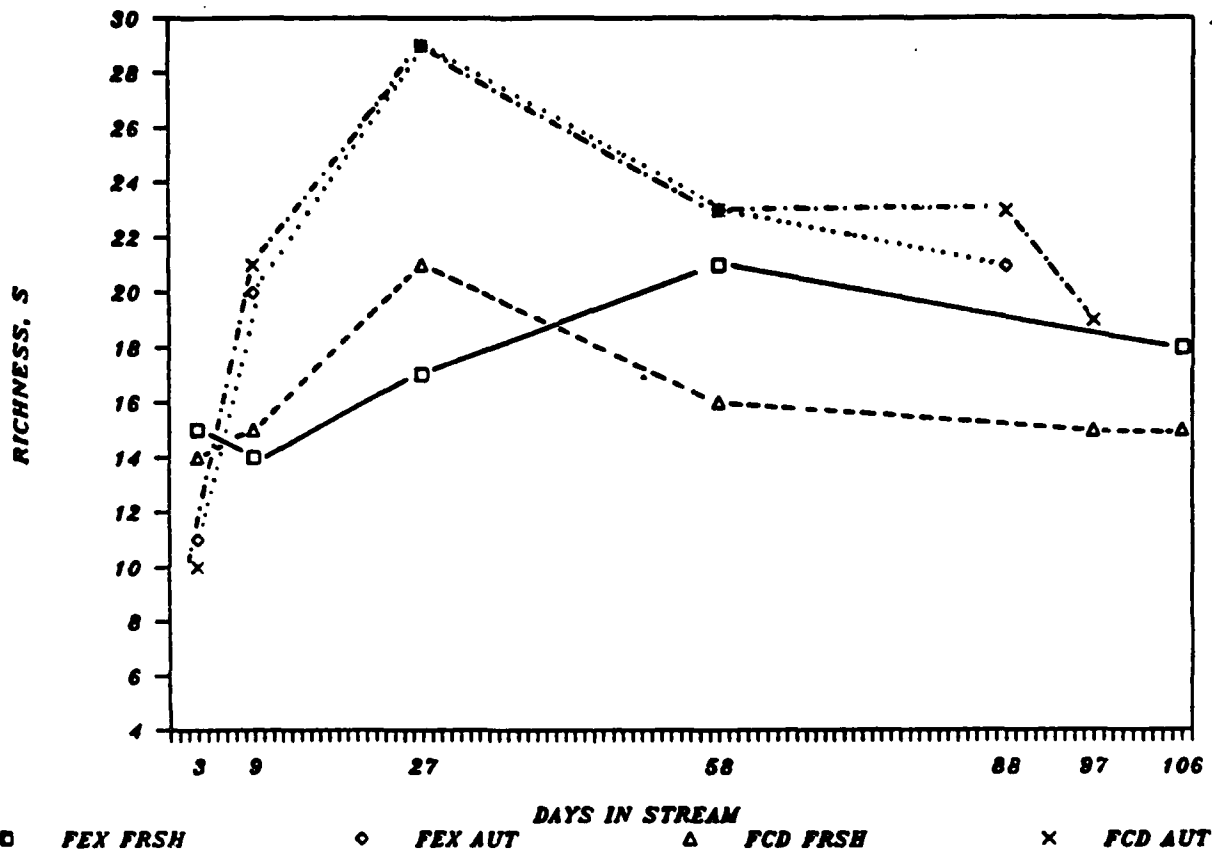
Figure 6.6   1986 taxon richness values for insects on FEX
fresh, FEX autumn, FEX fresh and FCD autumn
leaves.

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Table 6.3, continued

Days in Stream	Source	d.f.	MSS	F-ratio	Prob.
58	site	1	1.551	8.474	.008
	treatment	1	2.663	14.550	.0008
	interaction	1	.250	1.366	.254
	error	24	.183		

Evenness values (J') lowered with time (Fig. 6.4). After Day 9, there were both site and treatment differences (Table 6.5). Evenness indices were higher at FEX than at FCD. FCD substrata contain more sand than FEX substrata. FCD supports more chironomids (Element 4). A more equitably distributed community was found on autumn leaves than on fresh leaves. It may be that chironomids prefer fresh over autumn leaves. Coefficient of variation values for this index were less than 20% through Day 54. Thus, sufficient samples had been taken to reduce the probability of a Type II error.

TABLE 6.5
Comparison of Evenness Values for Insects on Fresh and Autumn
Leaves at FEX and FCD (Arcsine Transform of Data)
Two-Way ANOVA for Site Versus Treatment Differences

Days in Stream	Source	d.f.	MSS	F-ratio	Prob.
3	site	1	.911	.136	.715
	treatment	1	178.265	26.689	.00003
	interaction	1	93.294	13.968	.001
	error	24	6.679		
9	site	1	84.356	14.444	.0009
	treatment	1	.179	.031	.862
	interaction	1	22.393	3.834	.0619
	error	24	5.840		
27	site	1	96.534	5.021	.035
	treatment	1	93.733	4.876	.037
	interaction	1	26.132	1.359	.255
	error	24	19.224		
58	site	1	165.094	5.421	.029
	treatment	1	257.975	8.471	.008
	interaction	1	6.176	.203	.656
	error	24	30.454		

Chironomid dominance consistently increased through Day 58 (Fig. 6.5). The increase in chironomid numbers depressed both the diversity (Fig. 6.3) and evenness (Fig. 6.4) indices. Table 6.6 shows site and treatment differences, with chironomids being more dominant at FCD and within leaf treatments, more common on fresh than on autumn leaves (See Fig. 6.5). Again, had we sufficient time to identify chironomids to lower taxon levels, the effect of increasing chironomid numbers would not have been reflected in a lowering of both the diversity and evenness indices.

TABLE 6.6

Comparisons Among Numerical Dominance Values for
Chironomids on Fresh and Autumn Leaves at FEX and FCD
Two-Way ANOVA for Site Versus Treatment Differences
(Arcsine Transformation of Data)

Days in Stream	Source	d.f.	MSS	F-ratio	Prob.
3	site	1	1211.247	22.430	.00008
	treatment	1	367.213	6.800	.015
	interaction	1	58.349	1.080	.309
	error	24	54.000		
9	site	1	211.420	10.462	.0035
	treatment	1	371.134	18.365	.0003
	interaction	1	27.761	1.374	.253
	error	24	20.209		
27	site	1	175.350	4.395	.047
	treatment	1	14.674	.368	.550
	interaction	1	79.195	1.985	.172
	error	24	39.901		
58	site	1	263.836	6.706	.016
	treatment	1	409.275	10.403	.004
	interaction	1	12.052	.306	.585
	error	24	39.342		

At FEX, taxon richness (S) values for fresh and dried leaves generally increased through Day 26 and then diminished afterward (Fig. 6.6). In general, richness peaked at Day 27. There were treatment differences but no site differences for this index (Table 6.7). Autumn leaves supported a richer community than did fresh leaves over time (See Fig. 6.6). Coefficient of variation values were usually below 25% from Day 3 through Day 58 (mean = 19.98%, s.d. = 10.41, n = 16).

MEAN NUMBER INDIVIDUALS
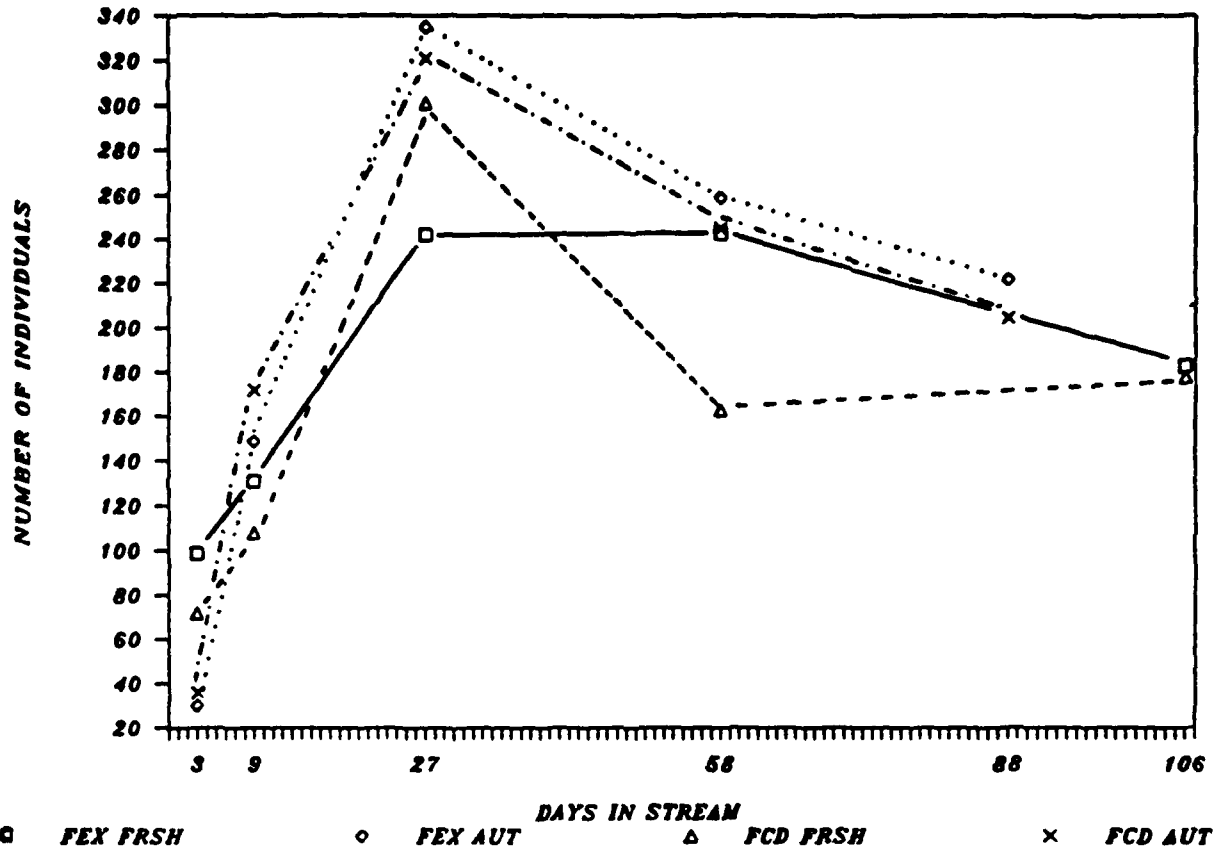
Figure 6.7 1986 numbers of individuals found on FEX fresh, FEX autumn, FCD fresh and FCD autumn leaves.

TABLE 6.7
Comparisons Among Taxon Richness Values (S) for Insects on Fresh and Autumn Leaves at FEX and FCD
Two-Way ANOVA for Site Versus Treatment Differences

Days in Stream	Source	d.f.	MSS	F-ratio	Prob.
3		1	4.321	.965	.336
	treatment	1	132.893	29.689	.00001
	interaction	1	.036	.008	.930
	error	24	4.476		
9	site	1	.893	.084	.774
	treatment	1	170.036	16.066	.0005
	interaction	1	15.750	1.488	.234
	error	24	10.583		
27	site	1	14.286	.984	.331
	treatment	1	302.286	20.830	.0001
	interaction		11.571	.797	.381
	error	24	14.512		
58	site	1	46.286	3.289	.082
	treatment	1	137.286	9.756	.005
	interaction	1	69.143	4.914	.036
	error	24	14.071		

Numbers of individuals peaked at Day 27 (Fig. 6.7). There was no general trend with respect to site or treatment differences (Table 6.8). Coefficient of variation values were higher than for previously described parameters (mean = 27.22, s.d. = 13.65, n = 16), an expected result.

TABLE 6.8
Comparisons Among Numbers of Individuals on Fresh and Dried Leaves at FEX and FCD
Two-Way ANOVA for Site Versus Treatment Differences

Days in Stream	Source	d.f.	MSS	F-ratio	Prob.
3	site	1	803.571	4.506	.044
	treatment	1	19451.571	109.067	<.0000001
	interaction	1	1922.286	10.778	.003
	error	24	178.345		
9	site	1	.0009	.0005	.982
	treatment	1	11726.036	7.107	.014
	interaction	1	3726.036	2.258	.146
	error	24	1650.012		

Table 6.7, continued

Days in Stream	Source	d.f.	MSS	F-ratio	Prob.
27	site	1	3543.750	.444	.511
	treatment	1	22458.893	2.817	.106
	interaction	1	9694.321	1.216	.281
	error	24	7973.631		
58	site	1	15228.893	3.826	.062
	treatment	1	16758.036	4.210	.051
	interaction	1	7656.036	1.923	.178
	error	24	3980.750		

Comparisons, 1982 - 1986

The patterns for diversity (H') changes over time were similar for 1982, 1984, 1985, and 1986. After the 9 days conditioning phase, diversity continually declined over time. The same patterns existed for evenness (J') for all leaf treatments. In 1982, numbers of taxa decreased steadily over time; in 1984 and 1986 numbers of taxa increased for the first month's incubation period and then declined thereafter. In 1985-86 there was no significant change for the first month; afterwhich, the number of taxa decreased. Thus, after three to four weeks, taxon richness trends were similar for all the years. Mean numbers of individuals peaked at three weeks of leaf incubation for all years we conducted the studies. The increase in numbers of individuals each year was primarily attributable to an increase in chironomids. Percent dominance of chironomids increased over time for all four studies.

Functional Community Parameters

1986 Data:

Total biomass values (adjusted to leaf biomass) showed a consistent upward trend over time (figs. 6.8A, 6.8B). A 2-Way ANOVA showed site differences (with higher biomass at FEX) on days 3 and 58 and treatment differences (higher on fresh leaves on Day 3 and higher on autumn leaves on Day 9), Table 6.9. Coefficient of variation values for this parameter were very high (mean = 46.04%, s.d. = 25.82, n = 16). When total biomass was separated according to functional feeding groups, the coefficient of variation values were lower.

TOTAL BIOMASS, FRESH LEAVES 1986
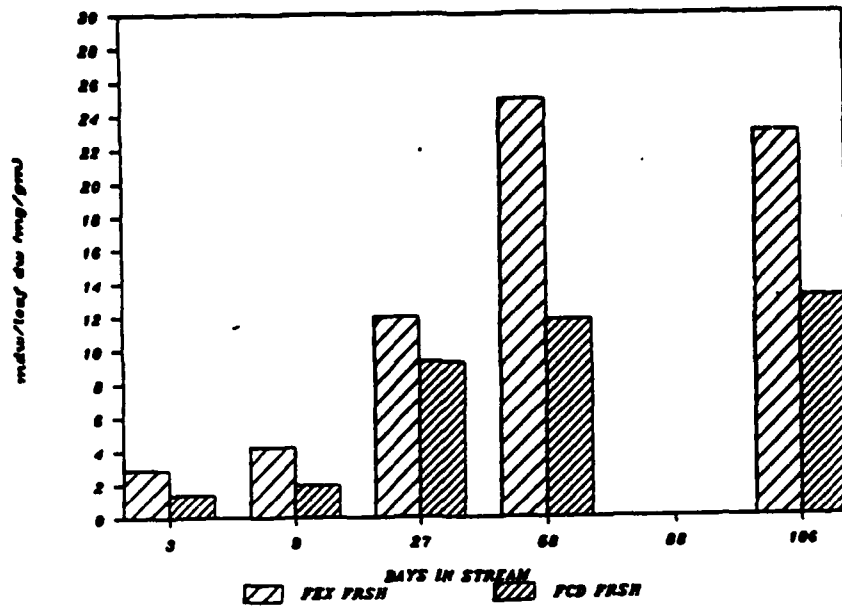
TOTAL BIOMASS, AUTUMN LEAVES 1986
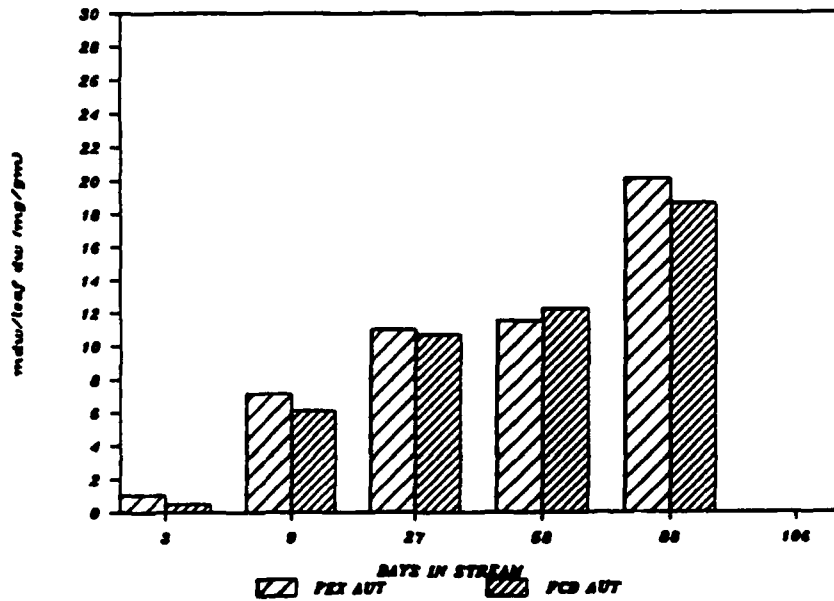
Figure 6.8A Total biomass of insects (adjusted to leaf mass) on fresh leaves for FEX and FCD sites.

Figure 6.8B Total biomass of insects (adjusted to leaf mass) on autumn leaves for FEX and FCD sites.

TABLE 6.9

Comparisons of Total Insect Biomass (Adjusted to Leaf Biomass) Between Fresh and Autumn Leaves at FEX and FCD. Two-Way ANOVA for Site Versus Treatment Differences

Days in Stream	Source	d.f.	MSS	F-ratio	Prob.
3	site	1	7.465	10.802	.003
	treatment	1	12.547	18.156	.0003
	interaction	1	1.682	2.434	.132
	error	24	.691		
9	site	1	22.323	3.093	.091
	treatment	1	94.152	13.046	.001
	interaction	1	1.851	.265	.617
	error	24	7.217		
27	site	1	15.103	.892	.354
	treatment	1	.163	.006	.923
	interaction	1	10.089	.596	.448
	error	24	16.939		
58	site	1	270.467	15.328	.0006
	treatment	1	300.386	17.024	.0004
	interaction	1	334.602	18.963	.0002
	error	24	17.645		

Collector-gatherer biomass on fresh leaves peaked by Day 27 and then decreased (Fig. 6.9A). This occurred on autumn leaves as well, except for an additional rise on Day 88 (Fig. 6.9B). Two-Way ANOVA tests show that within collection dates collector-gatherer biomass was higher on autumn than on fresh leaves after Day 3 (Table 6.10). Shredder biomass was higher on fresh than on autumn leaves (Fig. 6.10A versus Fig. 6.10B). and leaves irrespective of treatment supported more shredders at FEX than at FCD (figs. 6.10A and 6.10B). Two-Way ANOVA tests show that on Day 3 and Day 27 more shredders were on fresh than autumn leaves; shredder biomass was higher at FEX than at FCD for each of the collection dates analyzed (Table 6.10. Figures 6.11A and 6.11B show that biomass peaks for predators for the first 54 days were at Day 27 for fresh leaves at both sites and for autumn leaves at FCD. Predator biomass consistently rose on autumn leaves at FEX. After Day 9, no site nor treatment differences were found for predators (Table 6.10).

COLLECTORS, FRESH LEAVES 1986
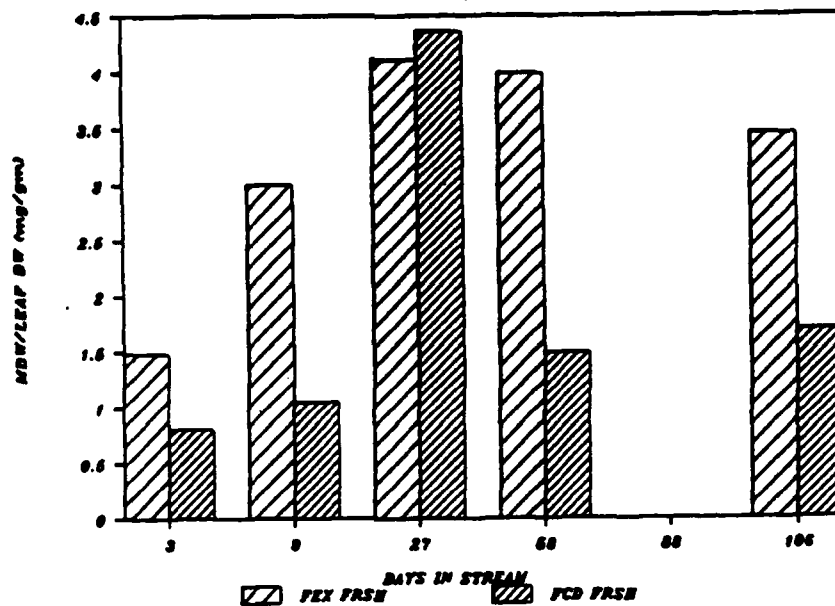
COLLECTORS, AUTUMN LEAVES 1986
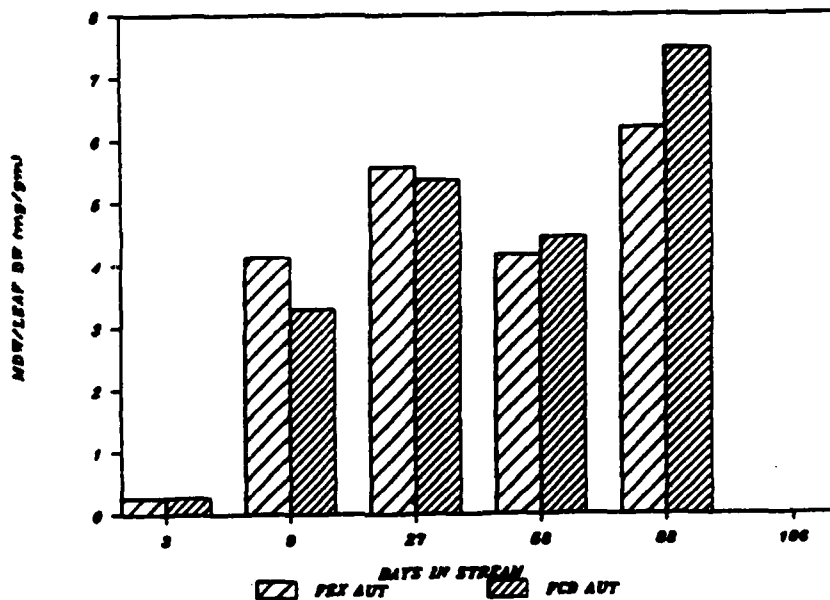
Figure 6.9A   Biomass of collectors (adjusted to leaf biomass)
on fresh leaves for FEX and FCD sites.

Figure 6.9B   Biomass of collectors (adjusted to leaf biomass)
on autumn leaves for FEX and FCD sites.

SHREDDERS, FRESH LEAVES 1986
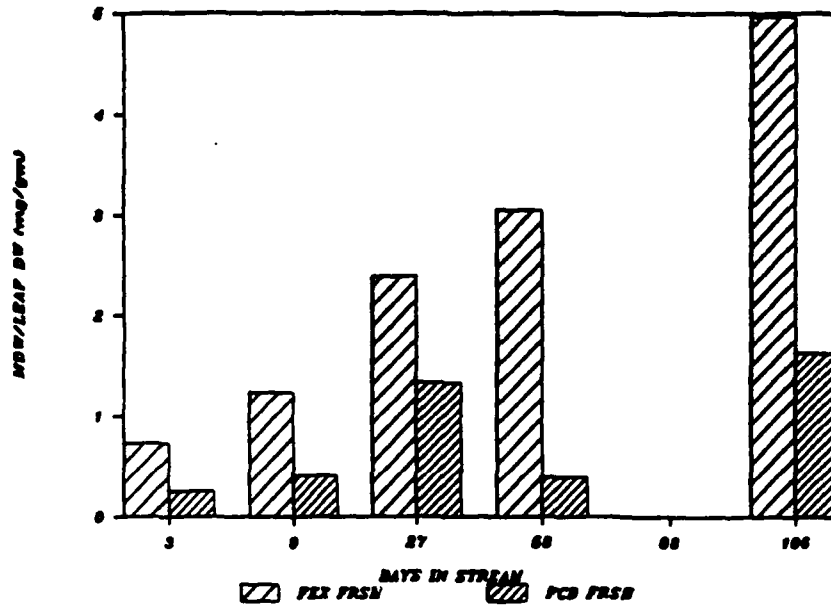
SHREDDERS, AUTUMN LEAVES 1986
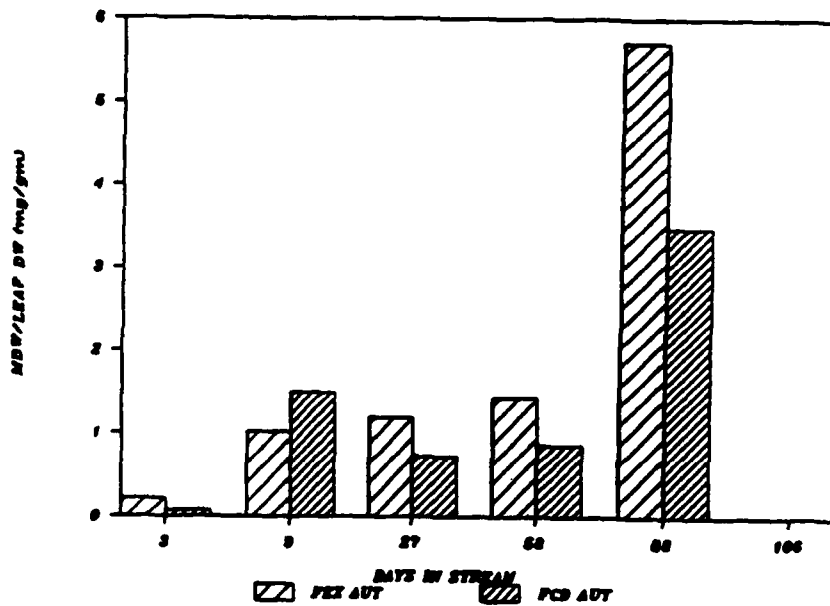
Figure 6.10A   Biomass of shredders (adjusted to leaf biomass)
on fresh leaves for FEX and FCD sites.

Figure 6.10B   Biomass of shredders (adjusted to leaf biomass)
on autumn leaves for FEX and FCD sites.

PREDATORS, FRESH LEAVES 1986
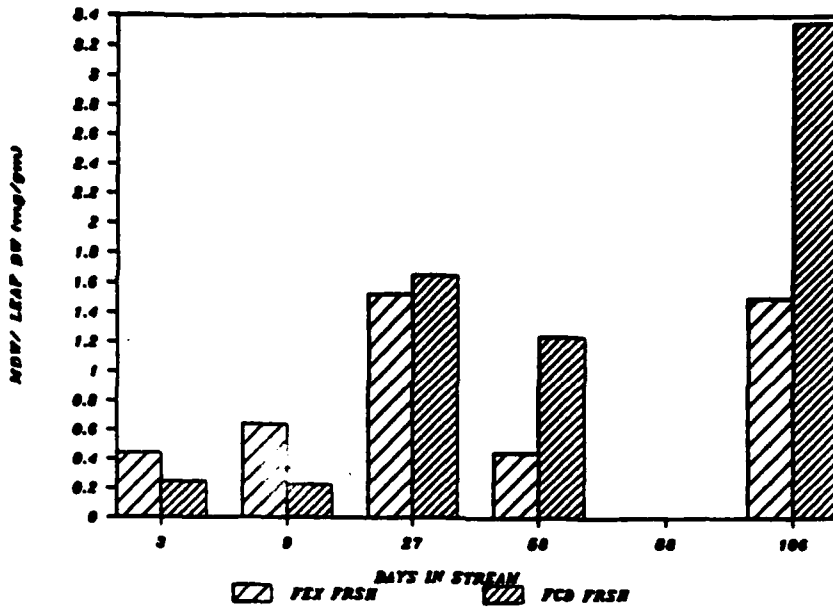
PREDATORS, AUTUMN LEAVES 1986
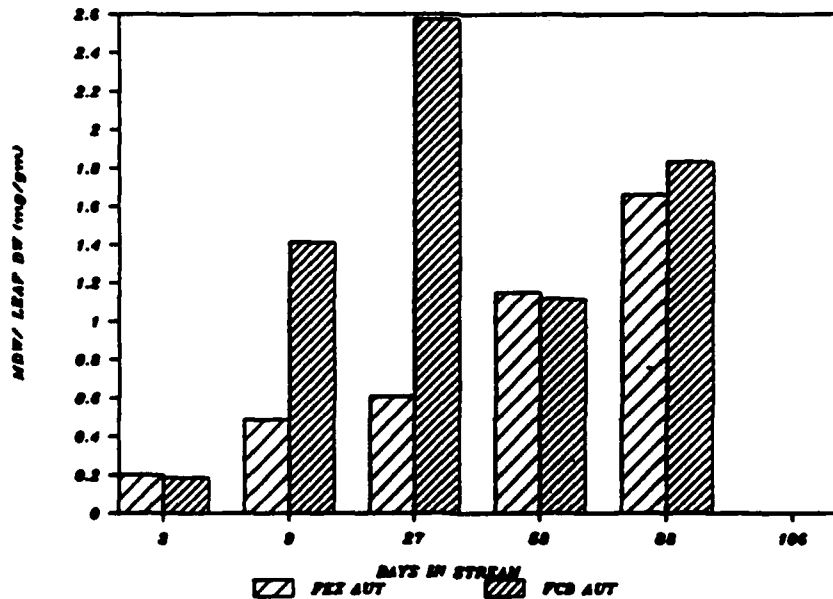
Figure 6.11A   Biomass of predators (adjusted to leaf biomass) on fresh leaves for FEX and FCD sites.

Figure 6.11A   Biomass of predators (adjusted to leaf biomass) on autumn leaves for FEX and FCD sites.

TABLE 6.10

Comparisons for Collector-Gatherer, Shredder and Predator
Biomass. Fresh vs. Autumn Leaves at FEX and FCD
Two-Way ANOVA for Site Versus Treatment Differences

Days in Stream	Source	d.f.	MSS	F-ratio	Prob.
A. COLLECTOR-GATHERERS:					
3	site	1	.649	2.036	.166
	treatment	1	4.981	15.630	.0006
	interaction	1	.676	2.119	.158
	error	24	.319		
9	site	1	4.996	4.388	.047
	treatment	1	41.089	36.095	.000003
	interaction	1	.246	.216	.646
	error	24	1.138		
27	site	1	.003	.005	.982
	treatment	1	10.637	1.799	.192
	interaction	1	.373	.063	.804
	error	24	5.914		
58	site	1	8.597	2.904	.101
	treatment	1	17.049	5.760	.024
	interaction	1	13.626	4.603	.042
	error	24	2.960		
B. SHREDDERS:					
3	site	1	.588	45.572	<.000001
	treatment	1	.755	58.512	<.0000001
	interaction	1	.150	11.538	.002
	error	24	.013		
9	site	1	2.039	10.885	.003
	treatment	1	.032	.169	.684
	interaction	1	.548	2.930	.100
	error	24	.187		
27	site	1	4.067	9.331	.005
	treatment	1	5.967	13.689	.001
	interaction	1	.616	1.413	.246
	error	24	.436		
58	site	1	18.722	10.782	.003
	treatment	1	2.504	1.442	.242
	interaction	1	7.426	4.278	.050
	error	24	1.736		

Table 6.10, continued

Days in Stream	Source	d.f.	MSS	F-ratio	Prob.
C. PREDATORS					
3	site	1	.068	2.186	.152
	treatment	1	.133	4.280	.050
	interaction	1	.088	2.839	.105
	error	24	.031		
9	site	1	.452	1.156	.293
	treatment	1	2.603	6.652	.016
	interaction	1	2.592	6.629	.017
	error	24	.391		
27	site	1	8.270	2.723	.112
	treatment	1	.011	.004	.952
	interaction	1	5.399	1.778	.195
	error	24	3.037		
58	site	1	.726	.702	.410
	treatment	1	.375	.363	.553
	interaction	1	1.559	1.506	.232
	error	24	1.035		

Because insect biomass values according to functional feeding groups incorporate many species, the C.V. values are sometimes high. For this reason, individual species from the collector-gatherer and predator functional feeding groups were analyzed separately.

The mean dry weight per individual (MDW/IND) of one collector-gatherer mayfly, Ephemerella invaria, increased over time on both fresh and oven-dried leaf packs (Fig. 6.12A). This was also the case for a predator, Isoperla transmarina (Fig. 6.12B). An additional species, Paraleptophlebia mollis was included in the analysis, as it is very common on leaf-packs and in substrates (Fig. 6.12C). This latter species showed no size class trend, which was expected, as its major growth occurs in May-June of each year. (See Element 4 of this report).

Comparisons, 1984 - 1986:

In 1984 and 1985 and 1986 the total insect biomass was higher on leaves at FEX than at FCD. In 1984, there were no collector-gatherer biomass differences between the two sites. In 1985, collector-gatherer biomass was higher at FEX than at FCD on Day 26. In 1986 collector-gatherer biomass was higher at FEX than at FCD on Days 9 and 58. Thus, across years, both total
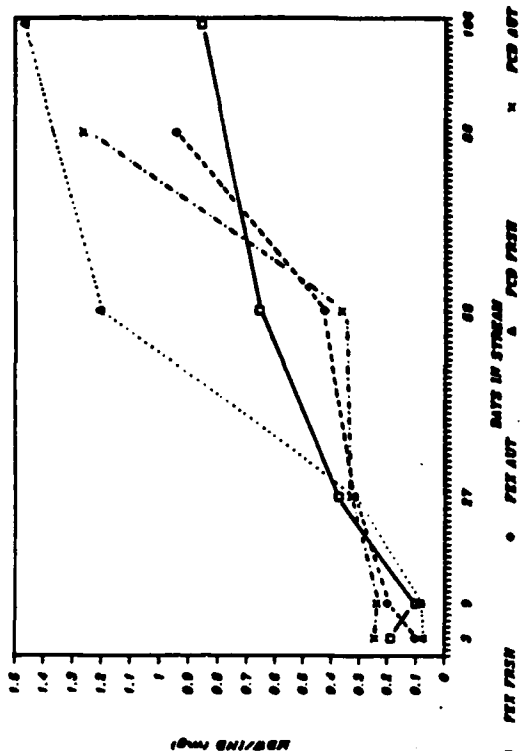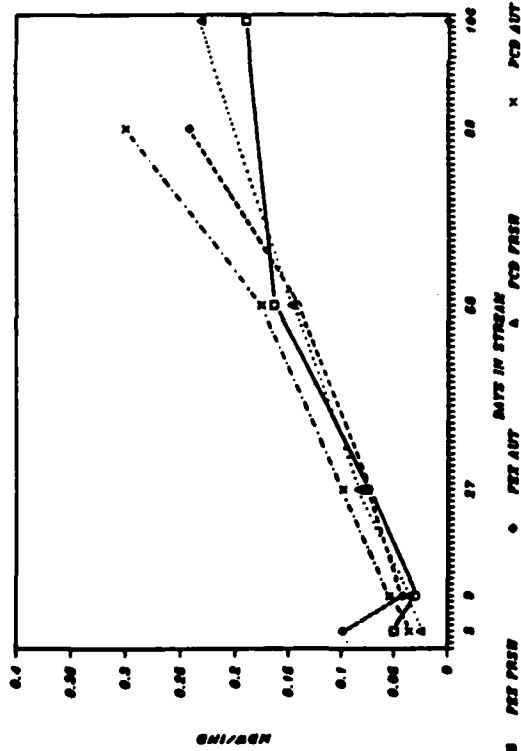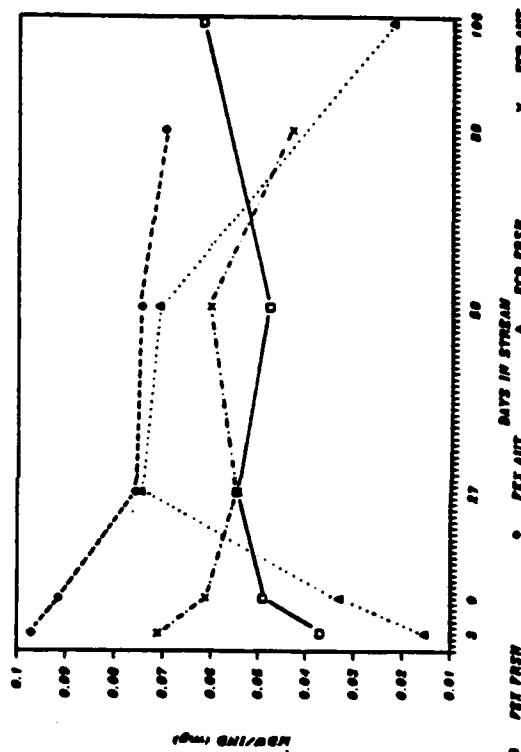
Figure 6.12A. Mean dry weight per individual values for Ephemerella invaria over time on FEX fresh, FEX autumn, FCD fresh and FCD autumn leaves.

Figure 6.12B. Mean dry weight per individual values for Isoperla transmarina over time on FEX fresh, FEX autumn, FCD fresh and FCD autumn leaves.

Figure 6.12C. Mean dry weight per individual values for Paraleptophlebia mollis over time on FEX fresh, FEX autumn, FCD fresh and FCD autumn leaves.

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insect biomass and biomass of the major F.F.G. on the leaves, collector-gatherers, were higher at FEX than at the FCD site.

In 1982 and 1984 shredder biomass was higher on fresh than on autumn leaves over time. Shredder biomass in 1985-86 was significantly higher on fresh than on dried leaves on days 26, 105, and 135. In 1986 shredder biomass was significantly higher on fresh than on autumn leaves on days 3 and 27. It is possible that both autumn senescent and oven-dried green leaves are less "attractive" to shredders than are fresh, green Tag Alder leaves.

The mean dry weight of the mayfly collector, Ephemerella invaria, consistently increased at similar rates over time at FEX and FCD on all leaf treatments over the years, suggesting that we are monitoring seasonal growth rates of this species, rather than site effects or leaf nutritive quality.

Although no repeatable pattern emerged for predator biomass in general, the stonefly predator, I. transmarina, showed a consistent and similar increase in MDW/IND in 1984, 1985 and 1986.

In general, total insect biomass values tended to show repeatable patterns across years; biomass values according to functional feeding groups did not; but MDW/IND values for particular species within each functional feeding group showed the most consistent and similar patterns across years.

Future Plans for this Element

Next year (1988), the fresh and autumn abscissed leaf studies will be initiated on the same day (early September), as we collected sufficient abscissed leaves in 1987.

Coefficient of Variation (C.V.) values for $-k$, H', J', S and biomass of selected species were low. Using a power test, five replicates per treatment were sufficient over most of the collection dates to state that 95% of the time the true mean was within $\pm$ 40% of the estimated mean at an alpha level of .05. Even so, seven replicates per treatment per collection date were taken in 1985, 1986 and 1987 to increase the probability that C.V. values would be below 18% for most parameters throughout all collection periods. Seven replicates per treatment per site will continue to be taken in future years, as there is sufficient person-power to process the additional leafpack samples.

All parameters previously used will continue to be followed at the FEX and FCD sites. Changes in predator biomass along with selection of the most common predator species, Isoperla transmarina, will continue to be included in future work for this element.

The next Annual Report will include an analysis of covariance for processing rates of fresh and autumn leaves over the years. It also will include comparisons across the years for insect structural and functional community parameters. Data for insects found on leaves in 1987 will be ready the summer of 1988 so that comparisons across years prior to full initiation of E.L.F. can be done. They will be used for comparisons of data after E.L.F. is fully operational.

Summary

Leaf processing rates (-k) were not significantly different for 1982, 1984, 1985, 1986 and 1987 . H'and J' values were also similar. Numbers of species (S) remained higher over time in 1984, but in 1982-1983, 1985 and 1986 taxon richness peaked at three weeks and thereafter decreased. Percent dominance of chironomids on leaves was similar for all the studies. The MDW/IND values for E. invaria, a collector-gatherer, and for I. transmarina, a predator, were similar in 1984, 1985 and 1986. (1984 was the first year they began being monitored.) C.V. values, except for total biomass and functional feeding group biomass, were below 18%.

Literature Cited

Fairchild, J. F., T. P. Boyle, E. Robinson-Wilson and J. R. Jones, 1984. Effects of inorganic nutrients on microbial leaf decomposition and mitigation of chemical perturbation. Jour. Freshwater Ecol. 2: 405-416.

Gersich, F. M. and M. A. Brusven. 1981. Insect colonzation rates in nearshore regions subjected to hydroelectric power peak flows. Jour. Freshwater Ecol. 1: 231-236.

Merritt, R. W. and K. W. Cummins, 1984. An introduction to the aquatic insects of North America. Kendall/Hunt Publ. Co., Dubuque, Iowa, 722 pp.

Petersen, R. W. and K. W. Cummins, 1974. Leaf processing in a woodland stream. Freshwater Biology, 4:343-368.

Stout, R. J. and W. E. Cooper 1983. Effect of p-cresol on leaf decomposition and invertebrate colonization in experimental outdoor streams. Can. Jour. Fish. & Aquat. Sci. 40: 1647-1647.

Webster, J. R. and J. B. Waide. 1982. Effects of forest clear-cutting on leaf breakdown in a southern Appalachian stream. Freshwater Biol. 12:331-344.

Wilhm, J. L. and T. C. Dorris. 1966. Species diversity of benthic macroinvertebrates in a stream receiving domestic and oil refinery effluents. Amer. Midl. Nat. 76:427-449.

Element 7 - Fish Community Composition and Abundance

Changes from Synopsis - An analysis of the relationship between fixed gear catch and actual fish densities was added.

Objectives

The overall objective of this element is to examine the effects of the Navy's ELF project on the fish community structure and movement in the Ford River. The specific objectives are to determine and monitor: 1) The fish community species composition, structure and relative abundance at both ELF sites; 2) The relative mobility of the fish community excluding brook trout in the Ford River; and 3) The age, growth, and condition of selected species in the Ford River. An additional objective was added in 1987 to determine a functional relationship between fixed gear catches and actual densities.

Materials and Methods

A. Community Composition Studies

Two fyke net sites (FCD and FEX) and two weir sites (FCU and TM) were used in this study (Figure 7.1). The two fyke net sites were used in all parts of the study, and weir sites were operated only for the capture of fish marked at the lower sites for the fish community movement study. Sampling dates for 1983 through 1986 were reported in previous annual reports. Sampling for the 1987 season commenced on June 5 and continued when weather permitted until October 31. The number of sampling days for each year is reported in Table 7.1.

At FCD and FEX, two 1/2 inch bar mesh fyke nets were fished (one facing upstream and one facing downstream). At FCU and TM, a weir constructed of 1/2 inch hardware cloth was used. The weir design was a variation of those used by Hall (1972). All gear was fished continuously for 4 sampling days per week when possible and checked every 24 hours.

All fish were enumerated, measured, weighed and marked by a fin clip distinctive for that site. The live fish were then returned to the water upstream or downstream from the station in the direction of travel.

B. Fixed Gear Calibration Study

Fixed gear calibration was performed using electrofishing gear, specifically a 250 volt DC unit, at sites at least one linear mile from net/weir sites to minimize site contamination. Sites were selected with similar habitat characteristics as the actual research areas. Site locations, sampling dates and length are shown in Table 7.2. FCD and FEX were sampled on two dates each and FCU, TM and FS1 were shocked only once. At least three weeks were allowed between shocking dates to assure site recovery.

Table 7.1.   Number of net-days at each site from 1983-87.

Site	Year				
	1983	1984	1985	1986	1987
TM	---	122	61	51	32
FCU	---	47	54	52	32
FEX	20	77	46	45	53
FCD	20	93	56	52	58

Table 7.2.   Location and description of electrofishing sites for
             fixed gear calibration objective 1987.

Site	Dates Sampled	Site Description	Length of Section
FEX	870701 870826	1.6 linear miles downstream of FEX net site.	200 meters
FCD	870727 870829	1.2 river miles downstream of FCD net site. 300 meters upstream of Norway Lake Rd. Bridge.	200 meters
FCU	870818	300 meters downstream of weir site.	100 meters
TM	870817	1 river mile downstream of weir site. Directly upstream of Turner Truck Trail bridge.	200 meters
FS1	870914	Directly downstream of the sediment trap.	200 meters

Population estimates were calculated using a three stage removal technique, the DeLury method. Three electrofishing passes were made at each site. All fish were enumerated and held in a holding cage constructed of 1/2 inch mesh hardware cloth until electrofishing was complete. Brook trout and burbot were additionally measured to obtain size distributions for comparison with net data.

Calculations were performed using the methodology outlined in Ricker (1975). Biomass estimates, for selected species, were made from the mean weight of the fish collected multiplied by the estimated number. Fixed gear catches will be related to electrofishing estimates using regression analysis. Brook trout density and site size structure data is reported in element 8.

Results and Discussion

A. Species composition

Sixteen species from five orders and eight families were collected at FEX in 1987 (Table 7.3) using 1/2 inch bar mesh fyke nets. One less order and two fewer families were observed in 1987 compared to 1986, but three new species were captured. Two species, rainbow trout (Salmo gairdneri) and pumpkinseed (Lepomis gibbosus), were added to the species list in 1987. The number of families was two less than 1985 and 1984 and one less than 1983. The changes in the overall FEX species composition can be attributed to changes in the catch of rare species.

The catch at FCD in 1987 consisted of fourteen species from eight families and five orders (Table 7.4). This represents a decline of two species, four families and two orders from previous years. Again, as in the FEX samples, the only changes in the species composition occurred in the rare species which occur in low numbers.

Contrary to prior years, the species composition was higher at FEX than at FCD. All of the differences in the community composition between sites were in the uncommon species, thus overall the two sites continued to be similar in species composition.

B. Species abundance

Numeric. The fish community at FEX was dominated by five species with the majority of the individuals caught from the cyprinid family (Table 7.5). Common shiners and creek chubs consisted of approximately 50% of the catch and this percentage has been consistent from year to year. The species structure was stable from year to year with all species having coefficients of variation on their combined percent catch of less than 50%. The catch component made up of burbot was the most stable with a combined percent catch coefficient of variation of 12.3%. Common shiners and brook trout demonstrated the greatest fluctuations in number with coefficients of variation of 47% and 35.1% respectively. Overall, the community at FEX continued to be stable in relative numeric abundance with creek chubs and common

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Table 7.3. Fish species collected at FEX from May 1983 to October 1987 using 1/2" mesh fyke nets. Scientific and common names are from Robbins et al. 1980.

Scientific Name	Common Name	1983	1984	1985	1986	1987
Cypriniformes						
Catastomidae						
Catastomus commersoni (Lacepede)	White sucker	x	x	x	x	x
Hypentelium nigricans (Leseur)	Northern hog sucker		x	x		
Cyprinidae						
Notropis cornutus (Mitchill)	Common shiner	x	x	x	x	x
Rhinichthys atratulus (Hermann)	Blacknose dace	x	x		x	x
Rhinichthys cataractae (Valenciennes)	Longnose dace	x	x	x	x	x
Semotilus atromaculatus (Mitchill)	Creek chub	x	x	x	x	x
Semotilus margarita (Cope)	Pearl dace	x	x		x	x
Gadiformes						
Gadidae						
Lota lota (Linnaeus)	Burbot	x	x	x	x	x
Perciformes						
Centrarchidae						
Ambloplites rupestris (Rafinesque)	Rock bass	x	x	x	x	x
Micropterus dolomieui (Lacepede)	Smallmouth bass	x	x			x
Micropterus salmoides (Lacepede)	Largemouth bass	x	x		x	x
Lepomis gibbosus (Linnaeus)	Pumpkinseed					x
Cottidae						
Cottus bairdi (Girard)	Mottled sculpin	x	x	x	x	
Percidae						
Percina maculata (Girard)	Blackside darter	x	x	x	x	

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Scientific Name	Common Name	FEX				
		1983	1984	1985	1986	1987
Petromyzontiformes						
Petromyzontidae						
Ichtymyzon fossor (Reighard and Cummins)	Northern brook lamprey			x		
Petromyzon marinus (Linnaeus)	Sea lamprey		x	x	x	
Salmoniformes						
Esocidae						
Esox lucius (Linnaeus)	Northern pike	x	x	x	x	x
Salmonidae						
Salvelinus fontinalis (Mitchill)	Brook trout	x	x	x	x	x
Salmo gairdneri (Richardson)	Rainbow trout				x	x
Umbridae						
Umbra limi (Kirtland)	Central mudminnow	x	x	x	x	x

Table 7.4. Fish species collected at FCO from May 1983 to October 1987 using 1/2" mesh fyke nets. Scientific names are from Robins et al. 1980.

Scientific Name	Common Name	FCO				
		1983	1984	1985	1986	1987
Clupeiformes						
Clupeidae						
Alosa pseudoharengus (Wilson)	Alewife	x				
Cypriniformes						
Catostomidae						
Catostomus commersoni (Lacepede)	White sucker	x	x	x	x	x
Hypentelium nigricans (Lesueur)	Northern hog sucker		x	x		
Cyprinidae						
Notropis cornutus (Mitchill)	Common shiner	x	x	x	x	x
Pimephales promelas (Rafinesque)	Fathead minnow				x	
Phoxinus eos (Cope)	Northern redbelly dace	x				
Rhinichthys atratulus (Hermann)	Blacknose dace	x	x	x	x	x
Rhinichthys cataractae (Valenciennes)	Longnose dace	x	x	x	x	x
Semotilus atromaculatus (Mitchill)	Creek chub	x	x	x	x	x
Semotilus margarita (Cope)	Pearl dace	x	x	x	x	x
Gadiformes						
Gadidae						
Lota lota (Linnaeus)	Burbot	x	x	x	x	x
Perciformes						
Centrarchidae						
Ambloplites rupestris (Rafinesque)	Rock bass	x	x	x	x	x
Lepomis gibbosus (Linnaeus)	Pumpkinseed	x	x	x	x	x
Micropterus dolomieui (Lacepede)	Smallmouth bass		x	x	x	x
Micropterus salmoides (Lacepede)	Largemouth bass		x			x
Cottidae						
Cottus bairdi (Girard)	Mottled sculpin	x	x	x	x	x
Percidae						
Percina maculata (Girard)	Blackside darter	x	x	x	x	

Scientific Name	Common Name	FCD				
		1983	1984	1985	1986	1987
Petromyzontiformes						
Petromyzontidae						
Petromyzon marinus (Linnaeus)	Sea lamprey			x	x	
Salmoniformes						
Esocidae						
Esox lucius (Linnaeus)	Northern pike	x	x	x	x	x
Salmonidae						
Salvelinus fontinalis (Mitchill)	Brook trout	x	x	x	x	x
Umbridae						
Umbra limi (Kirtland)	Central mudminnow	x	x	x	x	x
Siluriformes						
Ictaluridae						
Ictalurus nebulosus (Lessueur)	Brown bullhead			x		

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Table 7.5.   Percent catch by number of the dominant fish species
              at FEX and FCD from May 1983 to October 1987 using
              1/2" mesh fyke nets.

Species

	1983	1984	1985	1986	1987	Combined
			FEX			
Brook trout	12.3	10.2	16.0	10.6	14.7	12.8 ± 2.5
Burbot	20.1	24.1	12.9	13.4	11.5	16.4 ± 5.4
Common shiner	23.0	27.1	24.7	24.9	24.7	24.9 ± 1.5
Creek chub	22.7	16.6	33.3	29.7	22.4	24.9 ± 6.6
White sucker	8.8	8.6	5.6	14.8	20.8	11.7 ± 6.1
Other species	13.0	13.2	7.5	6.6	5.9	9.2 ± 3.6
			FCD			
Brook trout	13.8	11.3	10.6	6.7	4.9	9.5 ± 3.6
Burbot	17.0	6.0	8.3	9.5	4.8	9.1 ± 4.8
Common shiner	33.9	35.6	38.6	37.4	31.9	35.5 ± 2.7
Creek chub	21.1	25.4	26.2	27.9	31.9	26.5 ± 3.9
White sucker	5.5	13.1	7.6	9.3	21.3	11.4 ± 6.2
Other species	8.6	8.1	8.7	9.2	5.2	8.0 ± 1.6

shiners the dominant two species.

The relative numeric abundance of the catch at FCD was dominated by the same species as at FEX with the majority of the catch from the cyprinid family (Table 7.5). Common shiners and creek chubs were again the dominant species with over 60% of the catch and this percentage was consistent from year to year. This site also demonstrated a stable species abundance with all species having combined percentage catch coefficients of variation under 50%. Burbot and brook trout maintained the most stable catch components at FCD with a catch percentage coefficient of variation of 6.6% and 8.2% respectively. Common shiners displayed the highest variability with a catch percentage coefficient of variation of 49.5%. The major difference between the two sites was the higher percent catch of common shiners at FCD and lower percent catch of brook trout and burbot at FCD. These differences can probably be attributed to the differences in habitat between the two sites. Overall, the sites continued to be similar in species composition and demonstrated stable relative abundances from year to year.

Biomass. Catch percentage by biomass showed different trends in community structure than by number at both sites (Table 7.6). The FEX fish community was dominated in biomass by the same five species as was found by the numeric analysis although the dominant species changed. Brook trout and white suckers dominated the catch biomass with just under 60% of the catch. Percent catch by biomass was comparable to percent catch by number at FEX with coefficients of variation of less than 50%. Burbot biomass was the most consistent (C.V.=32.3%) and white sucker catches were the most variable (C.V.=49.4%).

The catch biomass at FCD showed similar trends to FEX with the same five species dominating the catch (Table 7.6). Brook trout and white suckers were the dominant species with the cyprinid biomass being higher than at FEX. Coefficients of variation, however, were substantially higher at FCD than at FEX with values approaching 80%. Common shiner percent catch by biomass was the most stable (C.V.=32.2%) and brook trout percent catch by biomass were the most variable (C.V.=78.9%). Overall, the relative abundance by biomass showed similar trends at both sites with the major difference in the increase in percent cyprinid biomass at FCD.

Diversity. Shannon-Weiner diversity values showed an increase at both sites in 1987 (Table 7.7). 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 (Mann-Whitney U Test, p=0.05). Overall, diversity values continued to be similar between sites and generally similar from year to year.

C. Catch Statistics

Catch rates. Catch rates at both FEX and FCD showed a large amount of variance for all species as one would expect from

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Table 7.6.   Percent catch by biomass of the dominant fish species
              at FEX and FCD from May 1983 to October 1987 using
              1/2" mesh fyke nets.

Species

	1983	1984	1985	1986	1987	Combined
FEX						
Brook trout	33.4	23.2	60.3	24.7	31.3	34.6 ± 15.0
Burbot	16.2	13.6	9.2	12.3	9.3	12.1 ± 3.0
Common shiner	10.1	3.5	9.7	13.8	11.5	9.7 ± 3.8
Creek chub	16.9	7.5	15.9	23.5	13.3	15.4 ± 5.8
White sucker	17.8	46.4	4.1	20.8	32.2	24.3 ± 15.9
Other species	5.6	5.8	0.8	4.9	2.4	3.9 ± 2.2
FCD						
Brook trout	29.0	35.5	43.3	25.9	18.5	26.4 ± 14.6
Burbot	12.6	2.0	8.6	6.9	5.7	7.2 ± 3.9
Common shiner	17.2	4.0	18.5	18.6	20.8	15.8 ± 6.7
Creek chub	22.5	6.2	17.6	21.9	24.3	18.5 ± 7.3
White sucker	7.7	49.9	7.6	15.6	28.4	19.8 ± 19.2
Other species	11.0	2.4	4.4	10.1	2.3	6.0 ± 4.2

Table 7.7. Mean daily Shannon-Wiener diversity index values for FEX and FCD from 1983-1987.

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

catches having a negative binomial distribution (Table 7.8). White suckers, common shiners and creek chubs all have high spring-early summer catch rates because of spawning movements. Brook trout and burbot catch rates are also high in the early summer but this is attributed to water temperatures increasing above optimal for both species. White suckers also show an additional peak, in juvenile fish, in the late summer-early fall.

FEX catch rates for brook trout, common shiners and creek chubs generally stayed the same from 1983-1986, however, in 1987 these species increased quite dramatically in catch per day. White suckers showed a similar trend in 1987 (Figure 7.2) after maintaining fairly low catch rates from 1983-1986. Burbot catches showed no significant change during the 1983-1987 period.

Catch rates at FCD for common shiners, creek chubs and white suckers followed patterns similar to FEX with abnormally high patterns. Brook trout and burbot remained stable in average catch per day (Figure 7.2).

Catch rates were similar for brook trout, creek chubs and white suckers at both sites from 1983-1987. Common shiner catch rates were consistently higher at FCD than FEX, and burbot catch rates were consistently higher at FEX than FCD. These differences can be attributed to habitat differences between the sites. Overall, catch rates continued to be similar and both sites showed a trend toward increasing catch rates for Cyprinid species. FEX also showed increased catch rates for brook trout and burbot.

Catch length. Mean length of most fish at FEX showed no trends from 1983-1987 (Figure 7.3). Creek chubs showed a decline in mean size from 1984-85 but have leveled off since then and brook trout mean length increased over 1986. This indicates that the size structure is consistent from year to year within the mobile fish community at FEX.

FCD also showed no consistent trend in mean length except for brook trout which have decreased in length every year since 1984 (Figure 7.3). Brook trout, common shiners and burbot were all generally significantly larger in mean length at FCD than FEX and white suckers were smaller at FCD than FEX. Creek chubs showed no significant difference in mean length between sites (TTest P<0.05). Overall, the two sites continued to be similar in mean length and in trends in mean length.

D. Fish Community Mobility

Most non-salmonid species with adequate sample sizes demonstrated site to site movement as shown by the approximately 11% recapture rate at sites other than the marking site (Table 7.9). In all, two to three times as many fish were marked in 1987 than in past years. Overall recapture percentages were similar in 1987 to previous years except for creek chubs which continue to decline in recaptures by approximately 50%. Site to site movement in 1987 for common shiners and creek chubs was similar to 1986, and down 54.2% and 140.5% respectively from 1984 and 1985. White suckers showed a slight decrease in site to site movement from 1986 but was higher than 1984-85. Burbot movement

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Table 7.8. Mean daily catch ± standard deviation for the dominant fish species at FEX and FCD from May 1983 to October 1987 using 1/2" mesh fyke nets.

Species	Year				
	1983	1984	1985	1986	1987
FEX					
Brook trout	4.3 ± 9.1	2.2 ± 2.7	2.5 ± 3.5	2.5 ± 4.4	7.8 ± 18.7
Burbot	7.0 ± 6.6	5.2 ± 4.0	2.0 ± 3.3	3.2 ± 4.7	6.1 ± 6.5
Common shiner	8.0 ± 10.1	5.9 ± 6.6	3.9 ± 5.8	6.0 ± 8.9	14.1 ± 25.7
Creek chub	7.9 ± 7.8	3.6 ± 5.5	5.2 ± 7.1	7.1 ± 9.5	12.6 ± 17.1
White sucker	3.1 ± 3.8	1.9 ± 4.0	0.9 ± 2.9	3.6 ± 9.8	11.0 ± 14.9
FCD					
Brook trout	3.8 ± 6.9	3.4 ± 5.9	2.7 ± 4.2	1.7 ± 2.6	3.1 ± 5.1
Burbot	4.6 ± 3.7	1.8 ± 2.1	2.1 ± 2.3	2.4 ± 3.0	3.0 ± 4.1
Common shiner	9.3 ± 10.0	10.7 ± 13.3	9.9 ± 11.2	9.4 ± 13.0	20.1 ± 31.1
Creek chub	5.8 ± 10.1	7.6 ± 18.9	6.7 ± 8.0	7.0 ± 7.2	20.1 ± 23.9
White sucker	1.5 ± 1.9	3.9 ± 16.4	2.0 ± 3.1	2.3 ± 3.5	12.6 ± 14.3
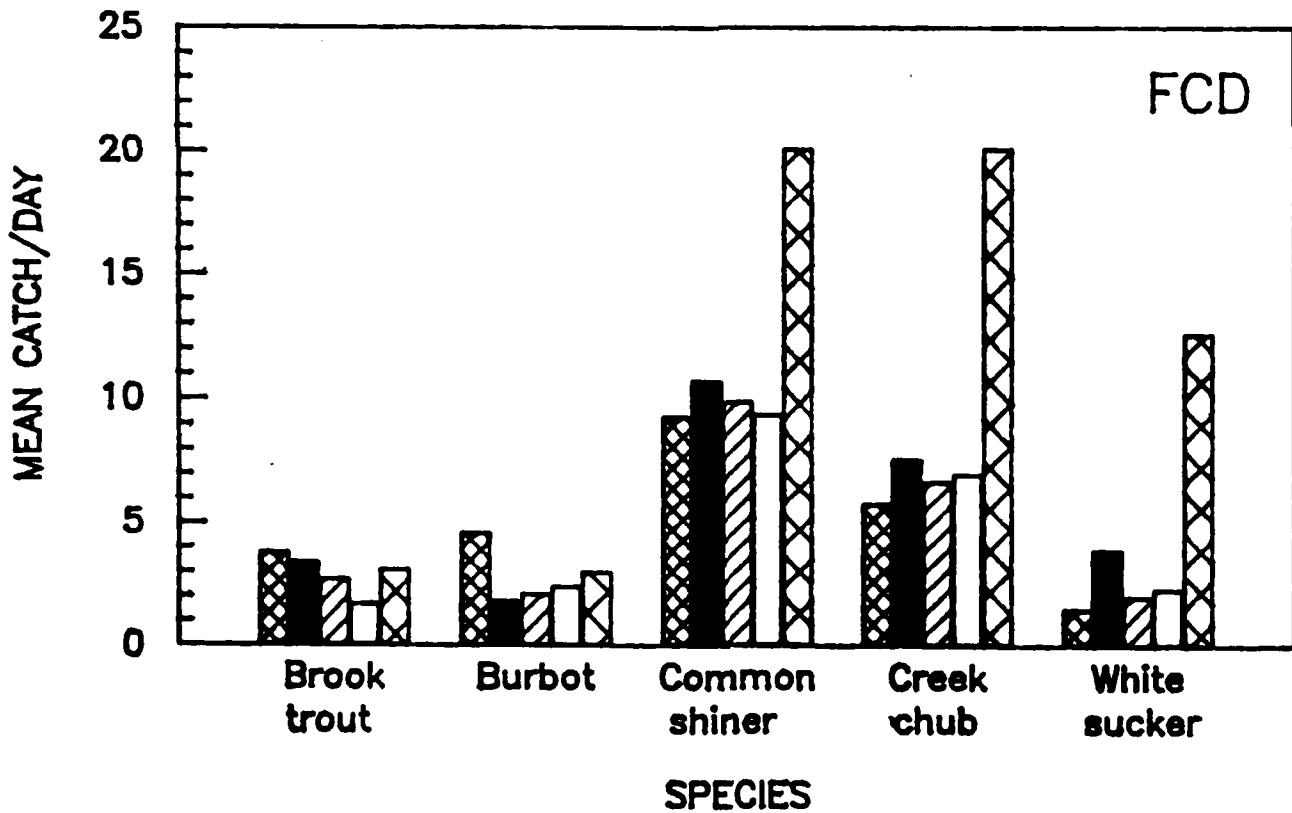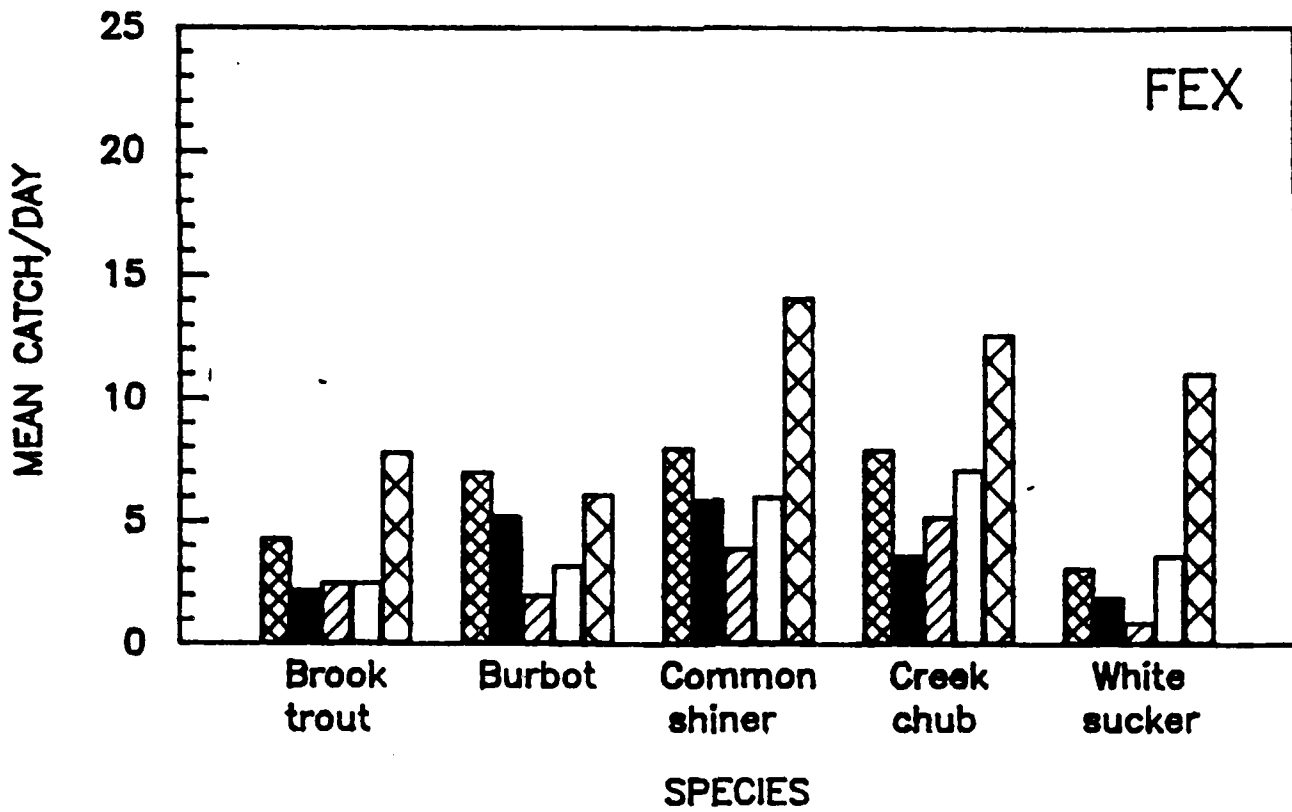
Figure 7.2. Mean daily catch for the dominant fish species at FEX and FCD from May 1983 to October 1987 using 1/2" mesh fyke nets.
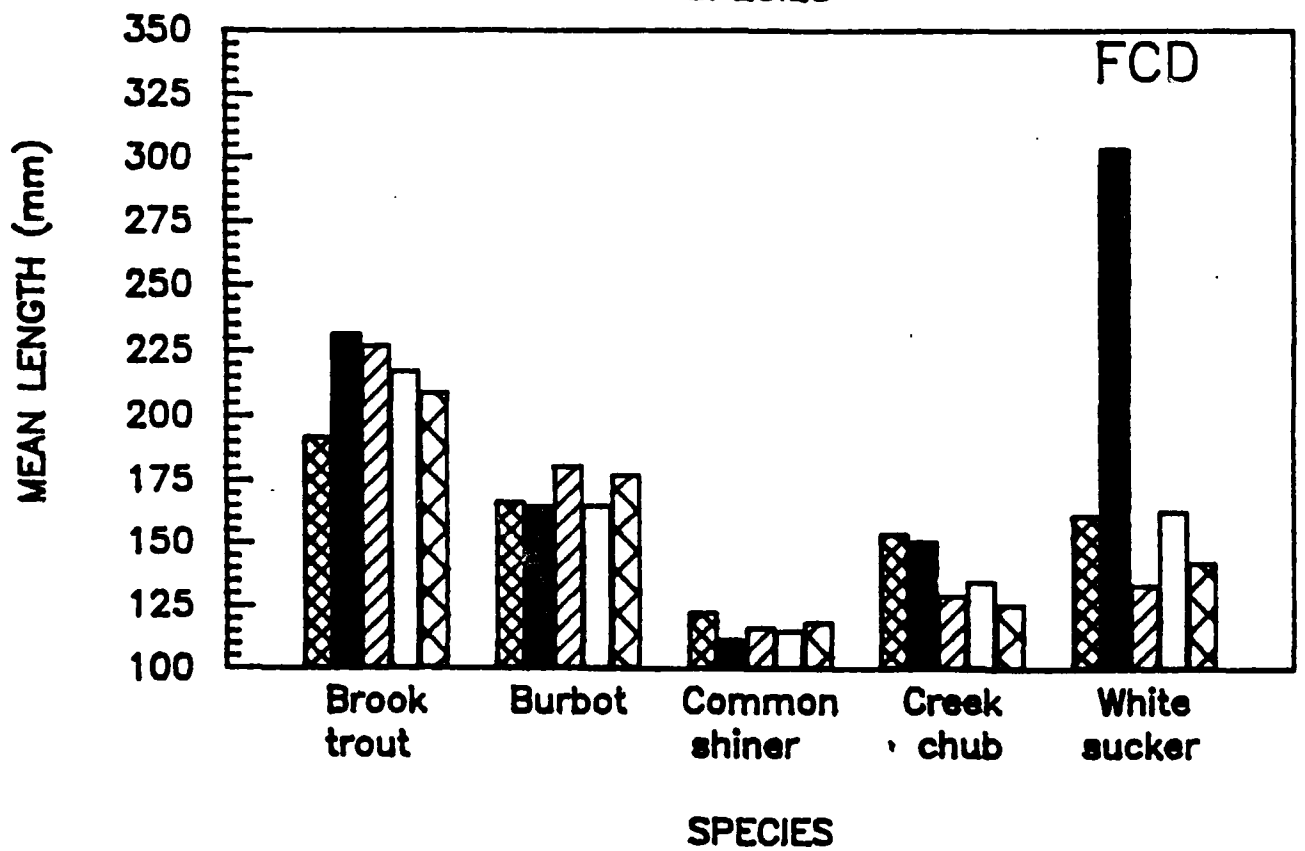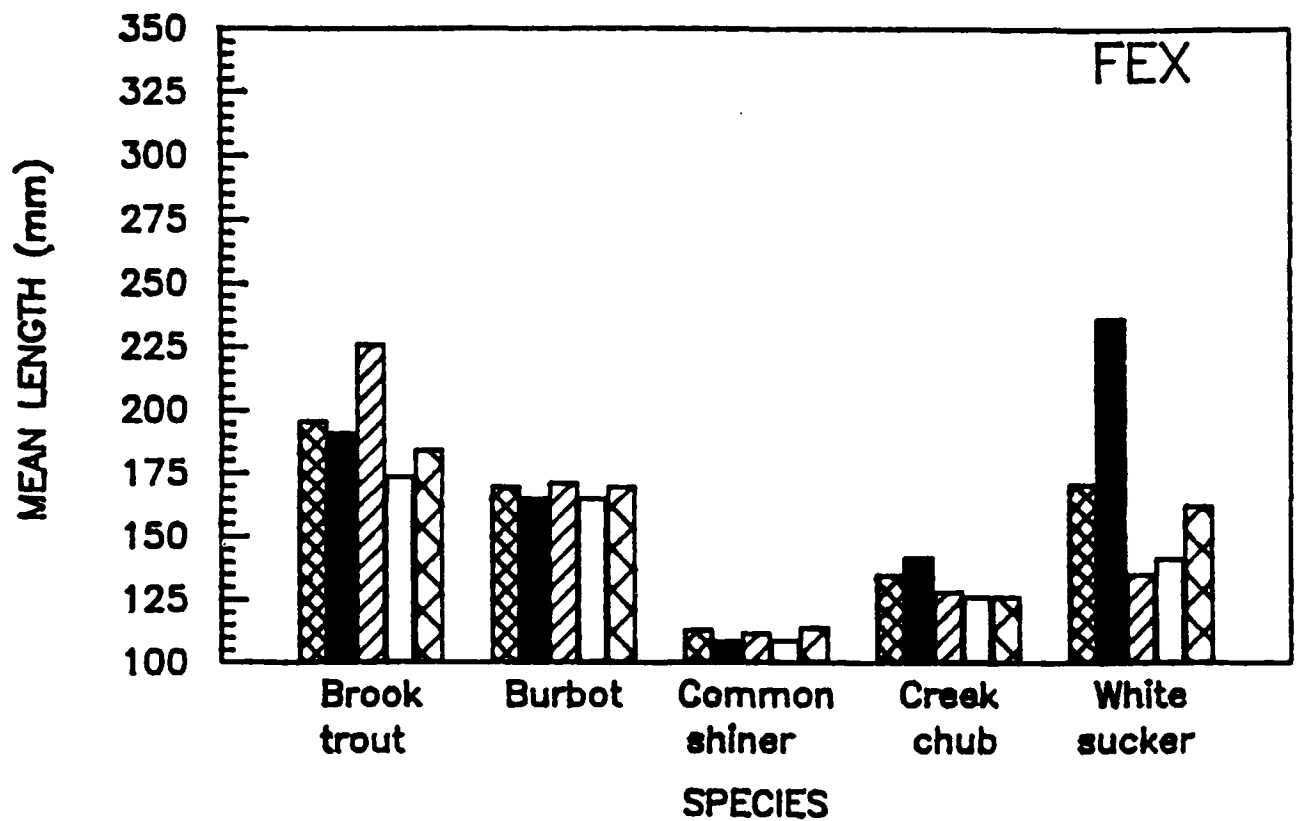
Figure 7.3. Mean length (mm) for the dominant fish species at FEX and FCD for May 1983 to October 1987.

Table 7.9. Recapture data summary for all dominant species except brook trout from FFX and FCD for 1984 - 1987.

Species	Total Marked	Number Recaptured	% Recaptured	% Recapture by Location			
				Marking Site	Upstream 1 Site	Downstream 1 Site	Upstream 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	3.2
Creek chub	520	28	5.4	82.1	14.3		3.6
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	
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	1500	42	2.7	78.6	9.5	9.5	

between sites decreased dramatically by 4.5 times from 1986, to
rates below 1984 and 1985. Movement in 1984 and 1985 was similar
for most species but showed more differences in 1986 which may be
attributable to the significantly lower discharge in 1986 than in
the previous two years (Freidman's Test, p<0.05). Differences in
movement in 1987 can also be attributed to significant differences
in the flow regime from previous years (Freidman's Test, p<0.05).
No fish were found to move more than 2 sites (26 km) in distance
in 1986 or 1987. Overall, site to site movement in 1987 was
similar to 1986 and down from 1984 and 1985 which can be
attributed to the lower spring discharges in 1986 and 1987.

E. Individual Species Analyses

Introduction. Growth and condition of fish can be important
indicators of a stressor on the well being of the fish. We have
chosen four species; common shiner, creek chub, white sucker and
brook trout as indicator species in this community to examine the
potential effects of the ELF project on these two parameters.
Brook trout data is reported on in element 8.

Age and Growth. Age and growth analyses on common shiners,
creek chubs, northern pike and white suckers are reported in Table
7.10. Only 1983 common shiner data is reported as the 1984-87
scales are presently being processed. All analyses were done
using scales and the body-scale relationship was calculated using
the technique outlined in Smale and Taylor (1987).
Backcalculation of length was done using the linear technique in
Bagenal and Tesch (1978).

Common shiners exhibited better than average growth in the
Ford River when compared to literature data in their third and
fourth year (Carlander 1969). The first and second year growth is
similar to that found in the literature. Lee's phenomenon is seen
in all years which may reflect the selectivity of our sampling 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.

Both white suckers and northern pike showed below average
growth rates in the Ford River through all the age classes
reported when compared to literature values (Carlander 1969).
Reverse Lee's phenomenon was seen in white suckers 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 the final 1988 report. Additional
investigations will include analysis of seasonal growth increment
and yearly growth increment, and an examination of the effect of
population size using CPUE and abiotic factors on growth. These
analyses should allow us to separate the environmental and
density-dependent factors from the ELF effects in the examination
of growth.

Condition. Fish condition factors for common shiners, creek

Table 7.10. Mean backcalculated lengths for common shiners, creek chubs, white suckers and northern pike for 1983 - 1986. Values in parentheses are sample sizes.

Species	Age Class	Backcalculated Length at Annulus						
		1	2	3	4	5	6	7
		x ± sd	x ± sd	x ± sd	x ± sd	x ± sd	x ± sd	x ± sd
Common shiner	1	42 ± 17.9 (7)						
	2	39 ± 16.5 (41)	81 ± 14.4 (41)					
	3	32 ± 11.6 (34)	73 ± 17.2 (34)	116 ± 21.8 (34)				
	4	31 ± 8.9 (5)	71 ± 9.5 (5)	112 ± 14.8 (5)	160 ± 13.0 (5)			
	Overall Mean	36 ± 14.8 (87)	77 ± 15.9 (80)	115 ± 20.9 (39)	160 ± 13.0 (5)			
Creek chub	1	66 ± 15.8 (42)						
	2	63 ± 15.7 (179)	105 ± 24.0 (179)					
Standard	3	63 ± 15.0 (91)	105 ± 23.0 (91)	148 ± 29.9 (91)				
Intercept=4.1749	4	69 ± 22.8 (12)	113 ± 24.6 (12)	158 ± 27.5 (12)	199 ± 30.7 (12)			
	Overall Mean	64 ± 15.8 (324)	106 ± 23.7 (282)	150 ± 29.7 (103)	199 ± 30.7 (12)			
White sucker	1	73 ± 6.0 (33)						
	2	73 ± 7.0 (35)	112 ± 13.6 (35)					
	3	73 ± 6.4 (30)	114 ± 17.4 (30)	175 ± 29.9 (30)				
	4	76 ± 10.3 (30)	126 ± 26.1 (30)	206 ± 54.0 (30)	285 ± 66.4 (30)			
	5	77 ± 7.6 (22)	124 ± 24.4 (22)	202 ± 43.5 (22)	296 ± 53.1 (22)	369 ± 56.0 (22)		
	6	75 ± 7.9 (13)	113 ± 14.3 (13)	191 ± 34.7 (13)	283 ± 45.6 (13)	360 ± 53.8 (13)	416 ± 55.5 (13)	
	7	62 (1)	110 (1)	167 (1)	215 (1)	280 (1)	346 (1)	377 (1)
	Overall Mean	74 ± 7.6 (164)	118 ± 20.6 (131)	193 ± 43.8 (96)	287 ± 58.1 (66)	363 ± 55.6 (36)	411 ± 56.5 (14)	377 (1)
Northern pike	1	186 ± 32.4 (13)						
	2	173 ± 20.9 (6)	249 ± 47.5 (6)					
	Overall Mean	182 ± 29.4 (19)	249 ± 47.5 (6)					

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=Fish weight/Ws * 100. Mean values for 25 mm length groups for common shiners and creek chubs, and 50 mm white sucker were calculated for an unweighted analysis of the data with data pooled from FEX and FCD because of the high amount of mobility seen in the Ford River.

The Ws formulas for common shiners, creek chubs and white suckers are as follows:

Common shiners log wt = -5.3907 + 3.1704*log tl (r=.999)
Creek chubs   log wt = -4.8488 + 2.9295*log tl (r=.998)
White suckers   log wt = -4.9820 + 3.0073*log tl (r=.98)

Condition factors for creek chubs and white suckers were below the species mean by from 4-20% possibly reflecting the highly variable abiotic conditions in the Ford River (Figure 7.4). Common shiner Wr values were above the species mean in all years which may be interpreted as showing that the Ford River has the proper habitat to meet the requirements of this species. Creek chubs continued to show a decline in condition in 1987 by approximately 5%. White sucker condition increased by 4% in 1987 ending a 4 year decline in relative weight values. Common shiners, which had shown a wave trend in Wr from 1984-1986, maintained a level similar to 86 in 1987. Additional analysis examining the effect of population size using CPUE and abiotic factors on Wr are in progress; and a statistical analysis of year to year variation are in progress.

F. Fixed Gear Calibration Study

This study is designed to determine a functional relationship between fixed gear catches and concurrent population densities. This relationship will allow us to calculate actual densities from all net catches and greatly increase the available analyses to examine the effects of the ELF project.

Preliminary population and biomass estimates for all sites are reported in Tables 7.11 A and B. Electroshocking efficiencies ranged from 0.441 for longnose dace to 0.805 for white suckers (Table 7.12). Overall, fish densities and biomass decline from upstream (TM and FCU) to Downstream (FEX and FCD). This can be attributed to the increased complexity of habitats found at the upstream sites. Habitat analysis from site mapping is currently in progress and will be used to statistically analyze differences in densities and biomass from site to site, and to check if electrofishing sites are comparable to actual ELF sites. Regression analysis of fixed gear and electrofishing catches will be reported on in the 1988 report so to include the 1988 samples.
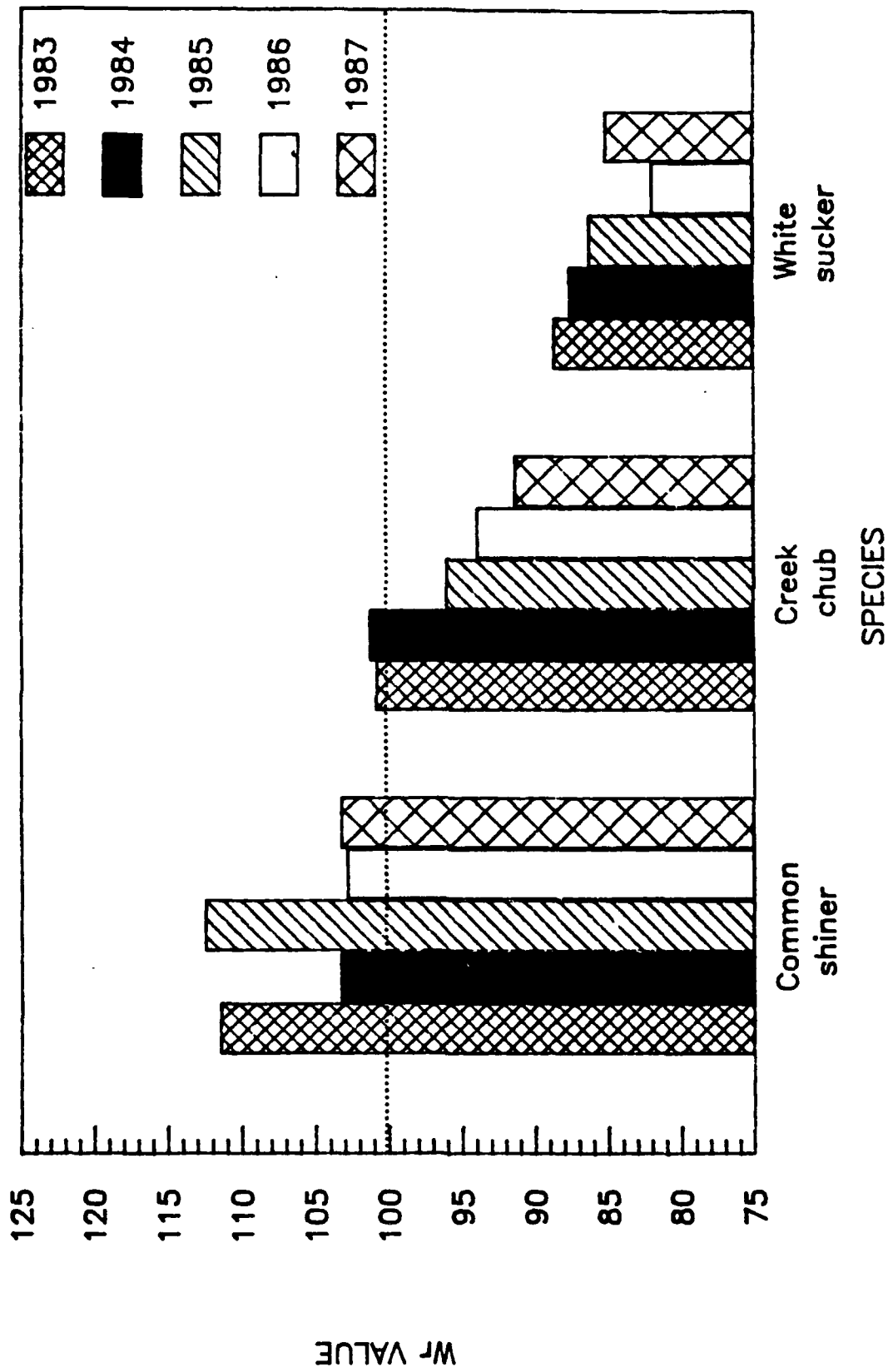
Figure 7.4. Yearly unweighted relative weight values for common shiners, creek chubs and white suckers in the Ford River. Dotted line at 100 indicates a condition equal to the average from literature populations.

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Table 7.11a. DeLury population estimates (density (number/hectare), biomass (kilogram/hectare)) for FEX and FCO in 1987.

Site	Date	Species	Lower 95% CI	Estimate	Upper 95% CI	Biomass
FEX	870701	Brook trout	0.0	16.7	36.3	1.56
		Burbot	0.0	91.7	242.1	3.66
		Creek chub	0.0	12.5	35.4	0.05
		Central mudminnow	0.0	8.3	28.7	
		Common shiner		4.2		0.02
		Longnose dace	11.8	50.0	88.2	0.18
		Mottled sculpin	0.0	83.3	170.8	0.51
	870826	Brook trout	40.8	41.7	42.5	1.73
		Burbot	51.3	79.2	107.2	2.80
		Blackside darter	0.0	83.3	304.9	
		blacknose dace	90.2	95.8	101.3	
		Creek chub	462.9	487.5	512.0	
		Common shiner	109.5	112.5	115.4	
		Central mudminnow		8.3		
		Fantail darter	28.3	36.0	46.6	
		Johnny darter		4.2		
		Longnose dace	138.7	179.2	219.6	
		Mottled sculpin	81.7	145.8	210.0	
		Rock bass		4.2		0.22
		Smallmouth bass	7.1	20.8	34.6	0.09
		White sucker	97.9	129.2	160.0	11.87
FCO	870727	Brook trout		4.2		0.32
		Burbot	67.5	70.8	74.2	2.44
		Creek chub	152.6	158.3	164.1	3.80
		Central mudminnow	20.3	29.2	38.0	
		Common shiner	49.7	54.2	58.7	
		Longnose dace	101.3	100.3	115.4	
		Mottled sculpin	67.9	75.0	82.1	
		Pearl dace		4.2		
		White sucker	59.9	62.5	65.1	1.93
	870829	Brook trout		4.2		0.28
		Burbot	44.2	54.2	64.1	1.36
		Blackside darter	140.4	162.5	184.6	
		Blacknose dace		4.2		
		Creek chub	58.8	112.5	166.3	
		Central mudminnow	29.2	25.0	26.5	
		Common shiner	0.0	8.3	63.3	
		Longnose dace	102.9	166.7	226.3	
		Mottled sculpin	145.4	166.7	187.9	
		White sucker	77.5	87.5	97.6	

Table 7.11b. DeLury population estimates (density (number/hectare), biomass (kilogram/hectare)) for FCU, TM, and FS1 in 1987.

Site	Date	Species	Lower 95% CI	Estimate	Upper 95% CI	Biomass
FCU	870818	Brook trout	97.0	122.2	147.5	4.71
		Burbot	94.7	100.0	102.5	2.63
		Blackside darter	123.2	144.4	165.7	
		Blacknose dace	606.8	844.4	1082.1	
		Creek chub	135.9	155.6	175.2	
		Longnose dace	1444.4	1622.2	1800.0	
		Mottled sculpin	537.6	577.8	617.8	
		White sucker		11.1		0.10
TM	870817	Brook trout	265.0	364.3	463.4	10.30
		Burbot	160.0	171.4	182.5	5.88
		Blackside darter	75.9	92.9	110.0	
		Blacknose dace	69.3	78.6	87.7	
		Creek chub	0.0	164.3	609.3	
		Longnose dace	2850.0	3578.6	3969.3	
		Mottled sculpin	213.9	357.1	500.0	
		White sucker		7.1		0.46
FS1	870914	Brook trout	32.3	34.4	34.4	1.83
		Burbot	15.8	41.7	67.1	1.91
		Blackside darter	0.0	575.0	1241.5	
		Blacknose dace	291.5	450.0	608.5	
		Creek chub	146.0	290.0	433.8	
		Longnose dace	0.0	1975.0	8475.0	
		White sucker	40.4	45.8	51.2	3.44

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Table 7.12. Electrofishing efficiencies for all sites in 1987.

Species	N	Mean Efficiency	SD
Brook trout	7	0.771	0.234
Burbot	7	0.619	0.225
Blackside darter	5	0.464	0.248
Blacknose dace	5	0.655	0.266
Creek chub	7	0.515	0.215
Central mudminnow	4	0.713	0.110
Common shiner	4	0.777	0.209
Fantail darter	1	0.643	
Johnny darter	1	1.000	
Longnose dace	7	0.441	0.200
Mottled sculpin	7	0.486	0.177
Pearl dace	1	1.000	
Rock bass	1	1.000	
Smallmouth bass	1	0.556	
White sucker	6	0.805	0.183

Literature Cited

Bagenal, T.B. and F.W. Tesch. 1978. Age and growth. Pages 101-136 in T.B. Bagnenal, editor. Methods for the assessment of fish production in freshwater, 3rd edition. Blackwell Scientific Publications, Oxford, England.

Carlander, K.D. 1969. Handbook of freshwater biology, volume 1. Iowa State University Press, Ames, Iowa, USA.

Hall, C.A.S. 1972. Migration and metabolism in a temperate stream ecosystem. Ecology 53:585-604.

Robins, C.R., R.M. Bailey, C.E. Bond, J.R. Brooker, E.A. Lachner, R.N. Lea, and W.B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada. American Fisheries Society, Special Publication No. 12.

Smale, M. and W.W. Taylor. 1987. Sources of back calculation error in estimating growth of lake whitefish. Pages 189-202 in R.C. Summerfelt and G.E. Hall. The age and growth of fish. Iowa State University Press, Ames, Iowa, USA.

Wege, G.J., and R.O. Anderson. 1978. Relative weight (Wr): a new index of condition for largemouth bass. Pages 79-81 in G.D. Novinger and J.G. Dillard, editors. New approaches to the management of small impoundments. North Central Division, American Fisheries Society, Special Publication 5.

Element 8 - Brook Trout Movement

Changes from synopsis - Electrofishing of similar non-ELF sites was added to calibrate fixed gear catches.

Objectives

The overall objective of this element is to examine the effects of the Navy's ELF project on brook trout (_Salvelinus fontinalis_). Brook trout are well known to be sensitive to thermal changes and appear to move to avoid suboptimal conditions in the Ford River as shown previously. Any changes by ELF could cause severe physiological problems. The specific objectives of this element are to determine: 1) The seasonal pattern and magnitude of brook trout movement through the ELF corridor; 2) Brook trout movement rates through the ELF corridor; 3) The mechanism for these movements; and 4) The population characteristics of brook trout in the Ford River.

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 traps and anesthetized with MS-222 to reduce handling stress at a 500 mg/l dosage as recommended by Meister and Ritzi (1958), and Schoettger and Julin (1967) for hard water applications. All brook trout were then enumerated, measured and weighed. A subsample of fish was tagged using strap tags affixed to the opercular cover. All fish were given a site specific fin clip, and if marked an additional clip to examine tag loss. All fish were released upstream or downstream from the site in the direction of travel after a recovery period.

Data analysis examining the role of physical and chemical factors on brook trout movement at FEX and FCD was done using ambient monitoring data. Physical and chemical data at FCU and TM was collected by the fisheries staff from 1984-87. Flow 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. Chemical data (DO, pH, and alkalinity) was collected on a bi-weekly basis at TM and FCU using standard methods and is summarized in Table 8.1.

Population estimates, in conjunction with the gear calibration, were obtained using electrofishing gear as described in element 7. Site locations are also listed in Table 7.2.

Results and Discussion

A. Marking Statistics

Numbers of fish tagged declined from a high of 314 in 1984 to 82 in 1986 because of a lack of fish caught in our gear (Table 8.2). The sample size of tagged fish increased in 1987 to 170 fish. The between site recapture rate was consistent in 1984 and 1985, fell to 0% in 1986 and remained low in 1987. Tagging

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Table 8.1. Water quality data from 1983-1987 at Two Mile
            Creek and FCU.

Parameter		Site	
		TM	FCU
DO	(mg/L)	9.3	9.9
pH		7.5	7.6
Alkalinity	(CaCO3/L)	143.6	168.8
Hardness	(CaCo3/L)	---	189.2
Turbidity	(NTU)	---	1.4
Conductivity	(umhos)	---	271.2

Table 8.2.   Brook trout marking and recapture summary for FEX and
             FCD for 1984 - 1987.

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%		
	Percent Angler Recapture	3.0%		
1987	Number Tagged		97	73
	Number Clipped		127	41
	Percent Tag Recapture	0.1%		
	Estimated Handling Mortality	7.1%		
	Percent Angler Recapture	0.6%		

mortality averaged 6.2% from 1984 to 1987 which is probably an underestimate because we are only examining fish which float back into nets and fish that we find on regular searches of the study area. The percentage of angler returns also declined from 12.1% in 1984 to 0% in 1986 and remained low in 1987 which probably reflects the decrease in the total number of fish individually tagged and the amount of angler effect.

B. Brook Trout Catch Patterns

Brook trout catches peaked in the spring-early summer at all sites except FCU. Since catch patterns were similar at all sites, data will be presented from FCD as example data in this report (Figures 8.1 a and b). In 1984, the mean daily catch was at its maximum in the first week of June at 15.8 brook trout collected per day with the high catch patterns continuing for three weeks. A similar pattern was seen in 1985 although delayed by one month until the first week of July when 11.7 brook trout per day were collected and this continued for only an one week period. Catch rates decrease rapidly after this week to between 0-1 fish per day. This pattern did not continue in 1986. Catch rates in 1986 were higher in late May and early June than later in the year but the peak catch rates of 1984 and 1985 were not repeated. Results in 1987 were similar in distribution to the 1984 catch rates although the peak occurred two weeks later. Movement in the upstream direction was significantly higher than the downstream movement in all years at all sites (Mann-Whitney U Test, $p < 0.05$). In summary, the brook trout showed a consistent upstream movement pattern in the spring-early summer of all sampling years although the intensity and timing varied from year to year.

The 1985 annual report discussed in detail the relationship between temperature and movement in 1984 and 1985. This movement was not repeated in 1986 although temperatures did exceed 16 C which is the optimal growth temperature for brook trout. An analysis of the pattern of water temperatures for each year shows that temperatures in 1984 and 1985 rose rapidly and remained high (Figure 8.2). Water temperatures in 1986, although not significantly different from 1985 (Freidman's Test with multiple comparisons, $p > 0.05$), demonstrated a cyclic nature with gradual increases to the two peaks. The pattern in 1987 water temperatures was similar to 1984 through mid-July, with the same rapid rise in temperature seen in June. Significant differences in temperature were found between 1987 and all other years (Freidman's Test with multiple comparisons, $p > 0.05$). The rapid rise and maintenance of high temperatures through July were the main differences between 1987 data and the 1984-85 data. Differences in the 1986-87 data can be attributed to the rapid cooling in late July-August. This indicates that the duration of high water temperatures and the acclimatization time to those temperatures may also play important roles in determining whether the brook trout move to more suitable habitats. Additional analysis of this trend is in progress and will be reported on in a future report.

Two additional factors, although not significant in the 1985
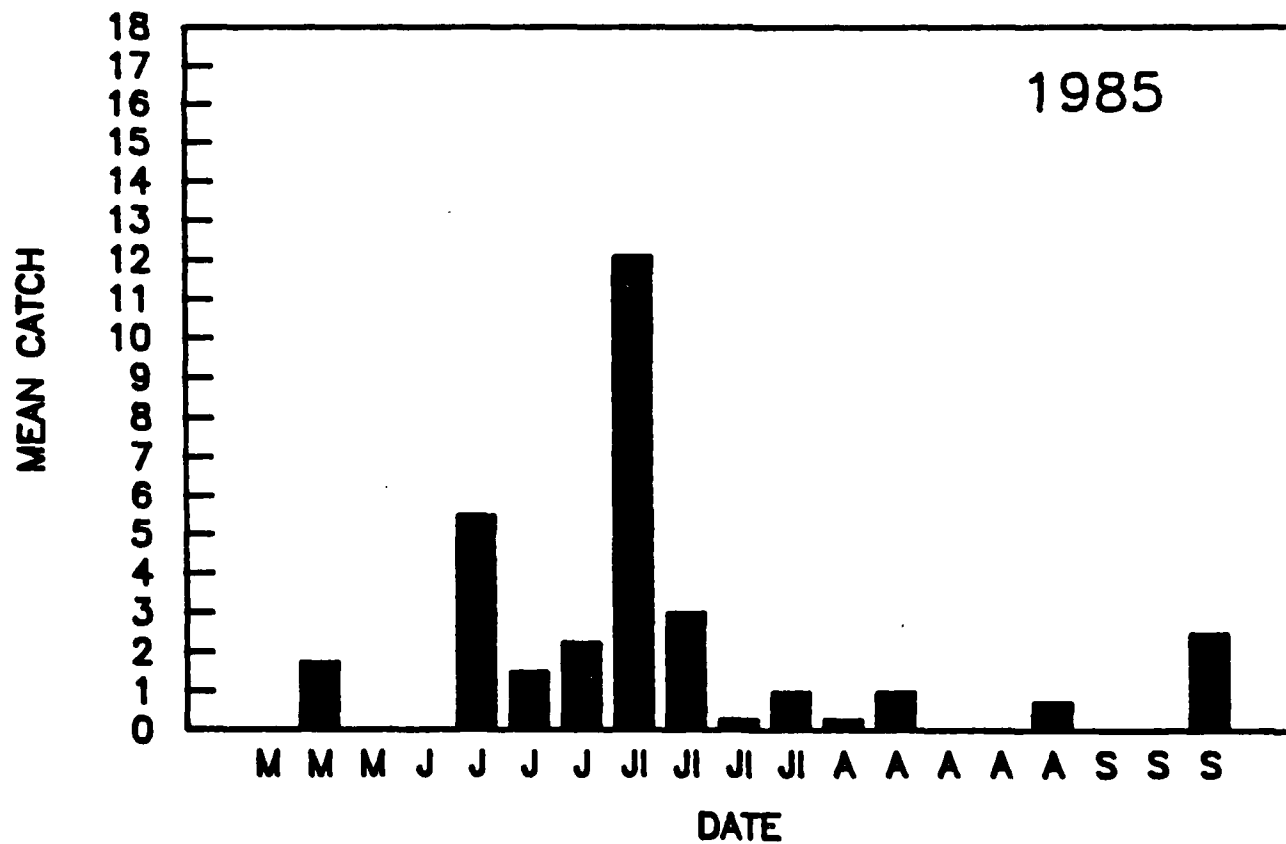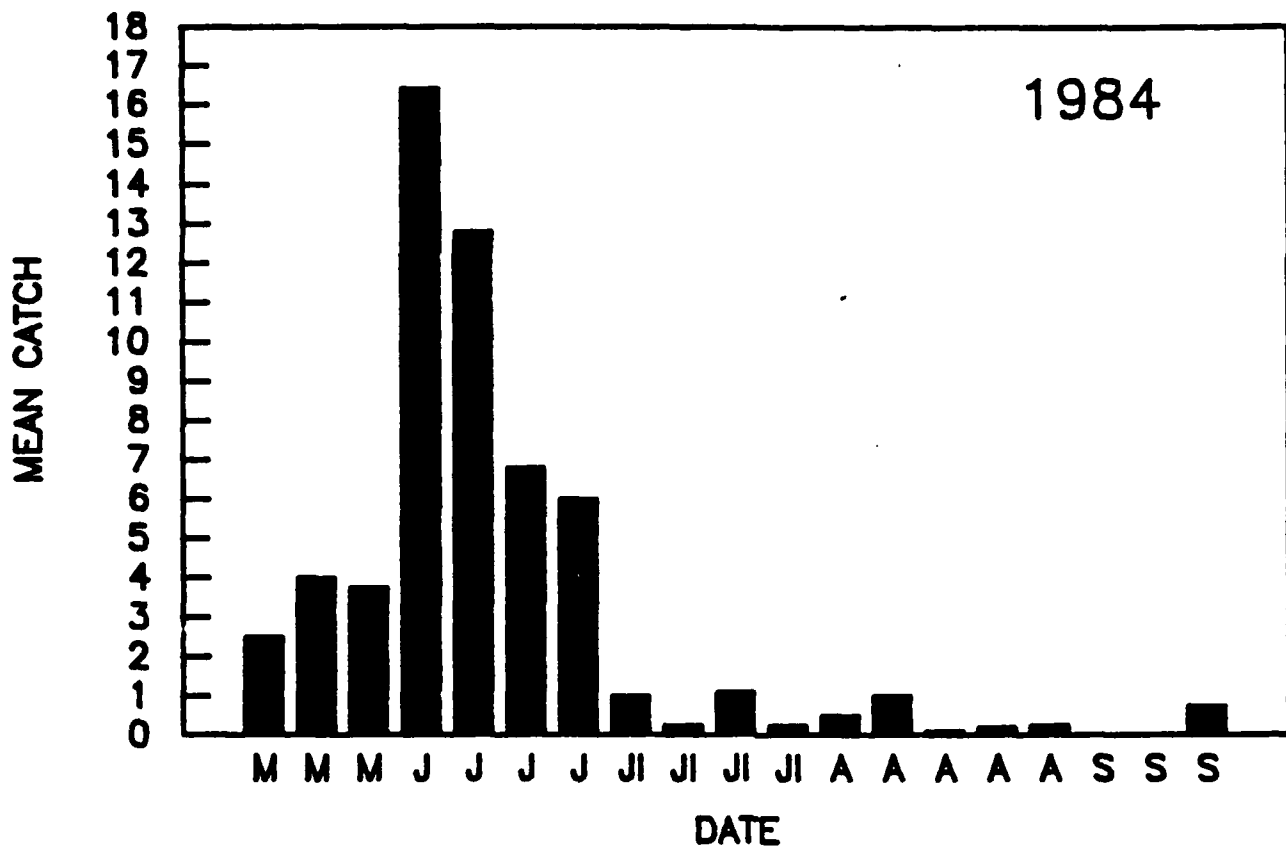
Figure 8.1a. Mean daily catch of brook trout plotted on a weekly basis at FCD from 1984 and 1985.
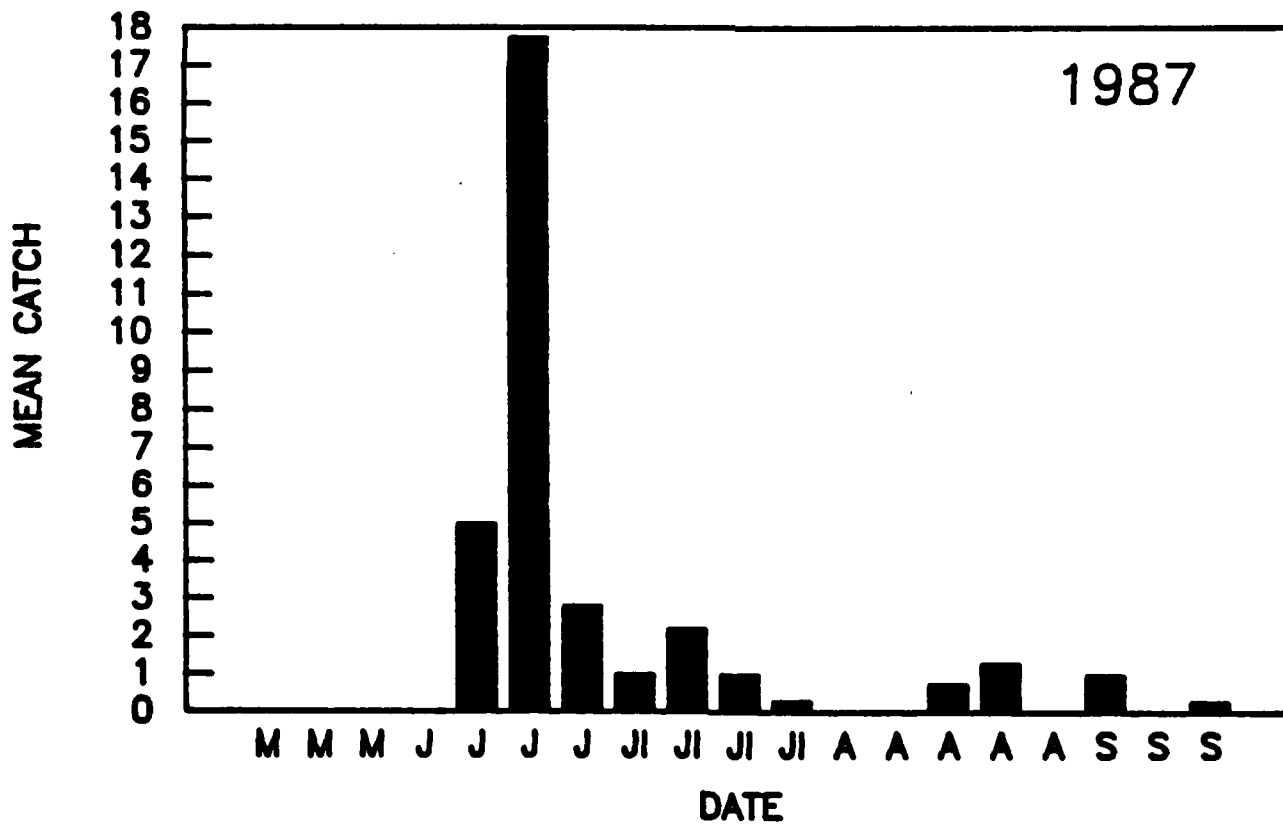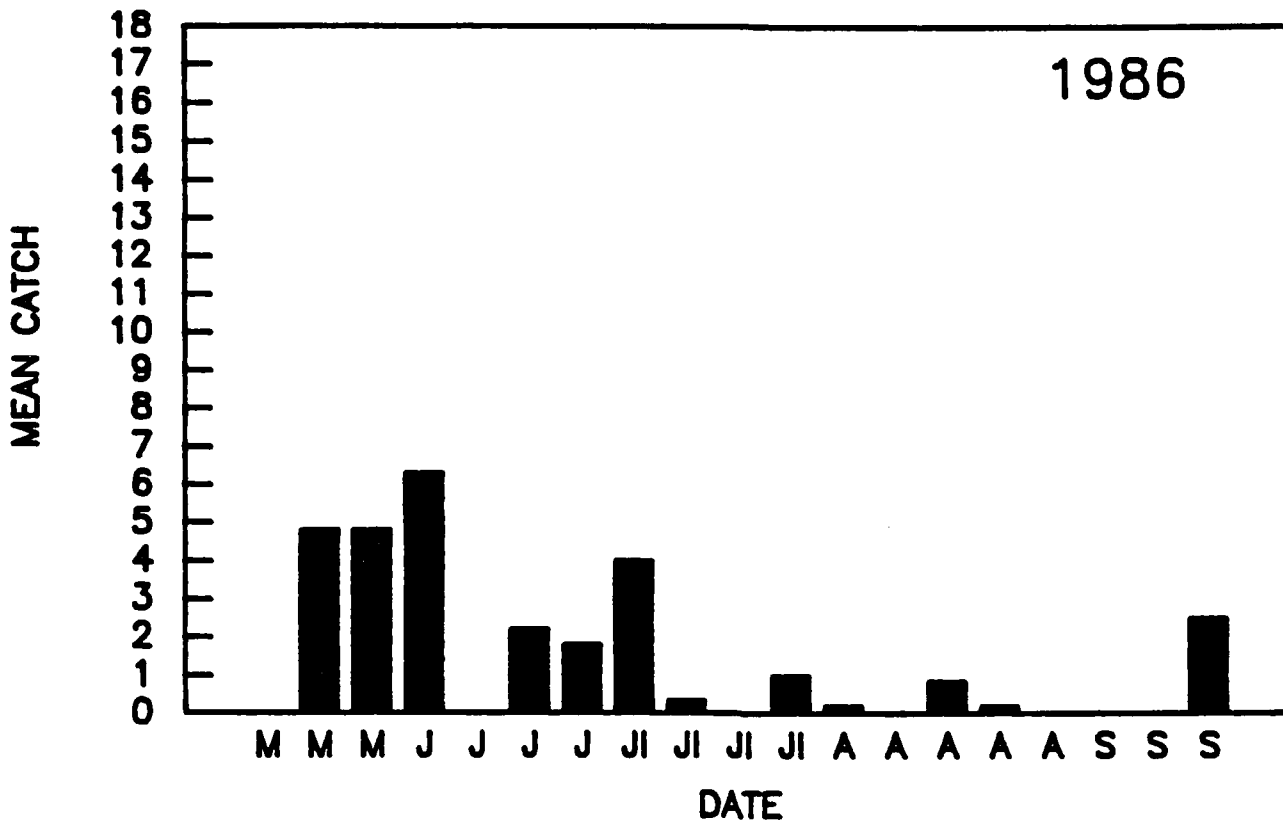
Figure 8.1b. Mean daily catch of brook trout plotted on a weekly basis at FCD from 1986 and 1987.
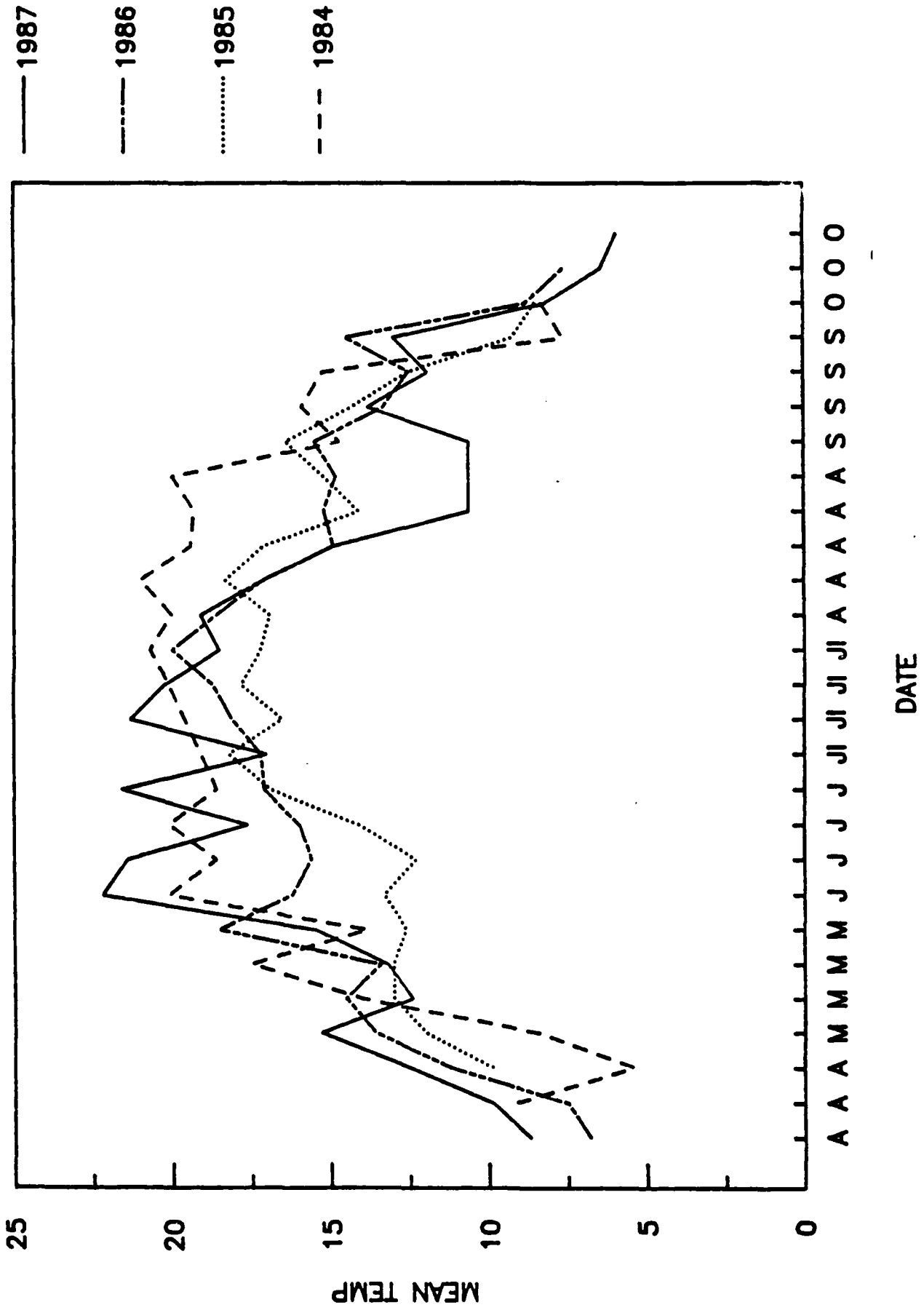
Figure 8.2. Mean daily temperature (C) plotted on a weekly basis at FCD from 1984 to 1987.

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analysis of factors, which influence this movement were discharge and population size. The spring drought created extremely low water conditions in 1986 and 1987. Comparisons between years shows that 1986 had significantly lower discharge than the other years (Freidman's Test with multiple comparisons, p<0.05) and is illustrated in Figure 8.3. Results from 1987 were also significantly lower than for 1984 and 1985 (Freidman's Test with multiple comparisons, p<0.05). These low water conditions coupled with poor groundwater inputs to the river from low spring precipitation may have created a thermal barrier to this movement in 1986 although conditions were not as severe as in 1987. The low water conditions and poor snowpack in 1987 coupled with high temperatures caused a rapid rise in temperatures which was not mitigated by ground water inputs. This situation was similar to that seen in 1984 and forced brook trout to find other thermal refugia. In 1986, low densities of brook trout may have also contributed to the lack of movement by allowing those fish impacted by high temperatures to find available cold groundwater refugia without competition from other salmonids. In 1987, the conditions were more extreme as in 1984 and the fish responded by moving. Additional analyses examining these factors are currently in progress and will be discussed in a future report.

C. Brook Trout Movement Characteristics

In general, brook trout moved from FEX and FCD upstream to the TM site on Two Mile Creek based on both gear recapture and usable angler data (Table 8.3). Only one fish was recaptured at FCU in three sampling seasons. No downstream movement from Two Mile Creek was found through November 1984 and through September 1985 or 1986. Three tag loss fish from the TM site in 1984 were collected in 1985 at FCD, thus some return movements occurred between winter and early spring. The length of the brook trout that made this movement was 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 in 1985, 1986 or 1987.

Optimal growth temperatures also appeared to be responsible for the movement up Two Mile Creek instead of continuing up the Ford River. Groundwater inputs kept TM at or near 16 C during the period from 1984 to 1986 (Figures 8.4 a and b) although reduced groundwater inputs (Figure 8.5) did force temperatures higher in 1987 than in previous years. Little difference in temperature was seen between FCU and TM which can be attributed to the poor snowpack and drought which prevented the groundwater from being recharged. FCU exceeded the temperatures in TM in each field season thus the fish "chose", when the thermal difference was available, the tributary that they could maintain better growth and survival in.

D. Brook Trout Movement Rates

Brook trout were found to move at mean rates of between 1.1 to 5.0 km/day (Table 8.3). Fish moving from FEX to TM (12.7 km)
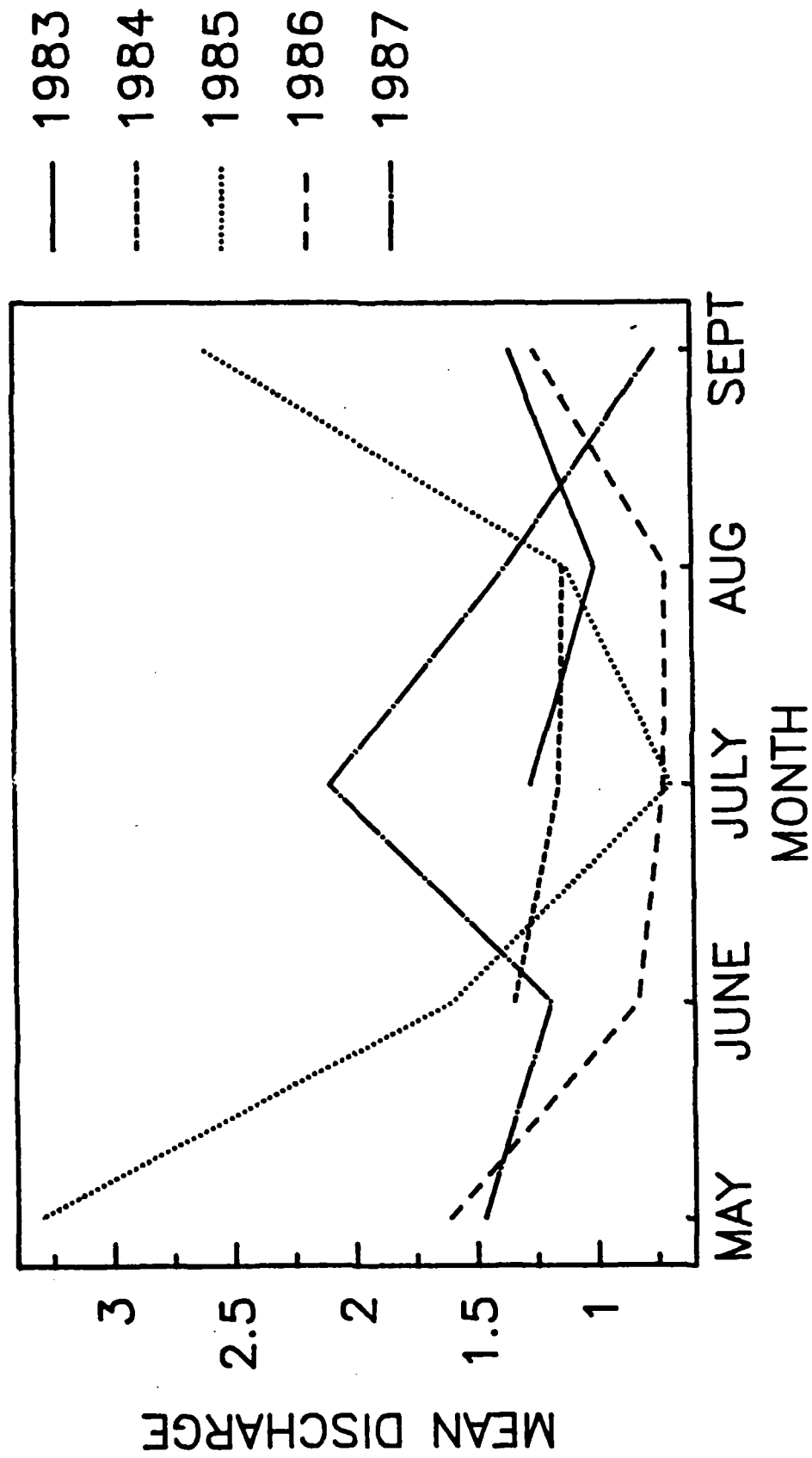
Figure 8.3. Mean monthly discharge (m^3/sec) at FCD from 1983 to 1987.

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Table 8.3. Brook trout movement rate summary for 1984-1987.

Year	Recapture Type	Site Marked to Site Recaptured	Distance (km)	N	Mean Rate (km/day ± 1SD)	Mode (km/day)
1984	Recaptured Fish					
		FEX-TM	12.7	11	1.4 ± 0.9	1.2
		FCO-TM	26.8	39	2.9 ± 1.7	2.5
		FCO-FEX	14.1	7	2.7 ± 1.6	2.0
	Angler Returns					
		FEX	7.0	1	2.5	
		FCO	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
		FCO-TM	26.8	6	5.0 ± 3.2	4.2
		FCO-FEX	14.1	3	1.2 ± 0.3	1.3
	Angler Returns					
		FCO	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					
		FCO-FS1	19.1	1	3.8	3.8
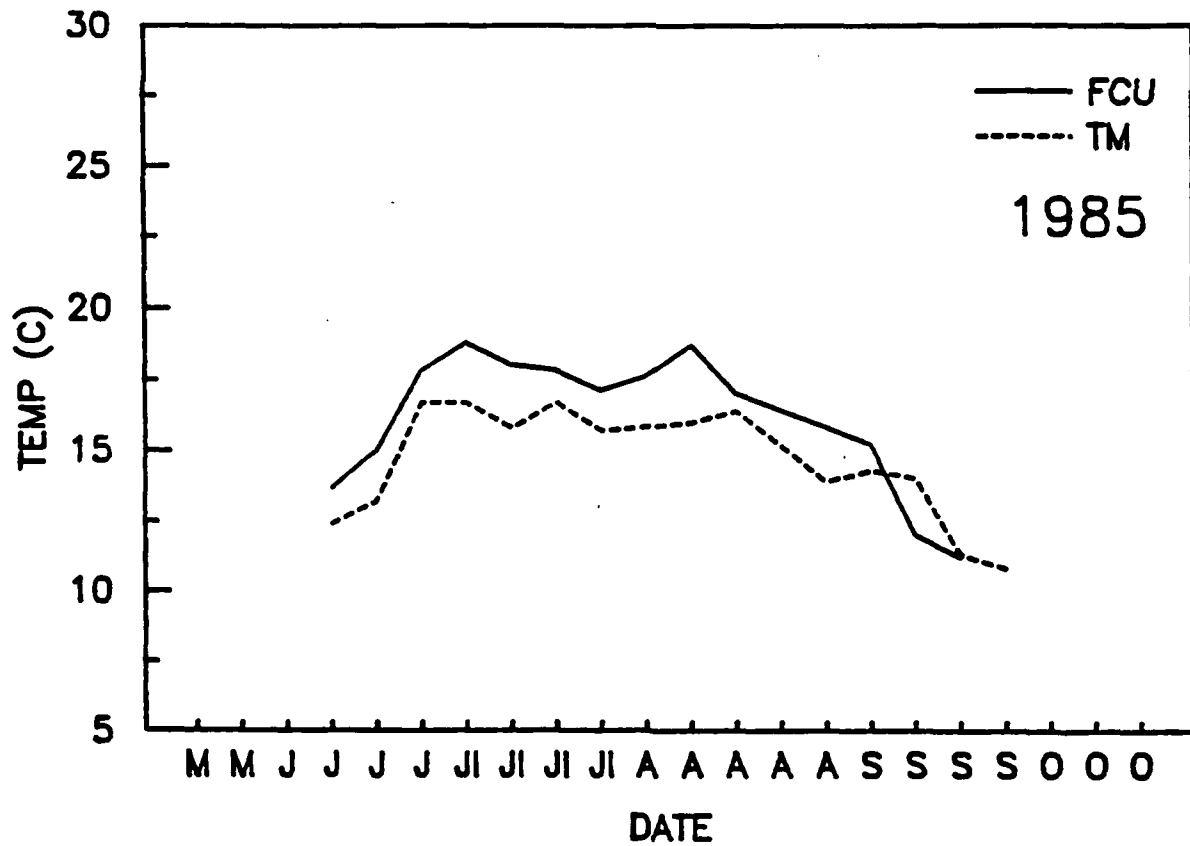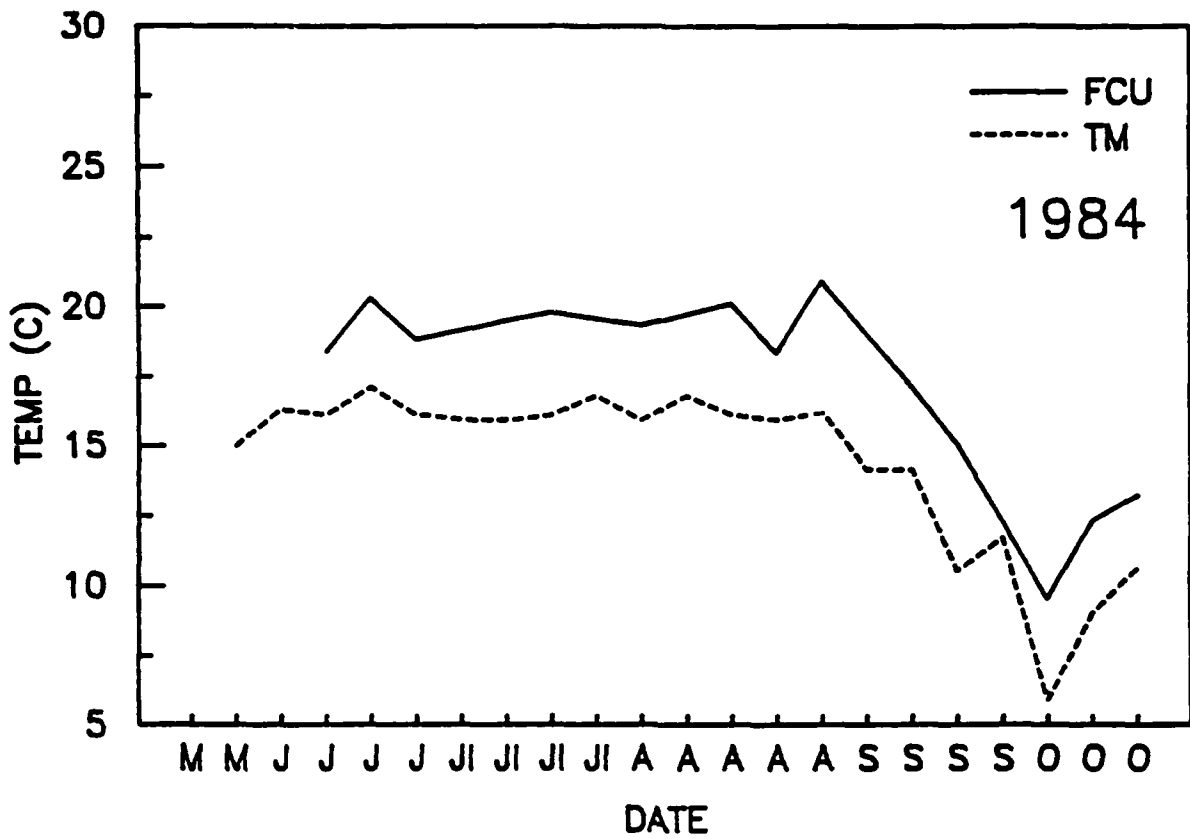
Figure 8.4a. Mean daily water temperature (C) plotted on a weekly basis at TM and FCU from 1984 and 1985.

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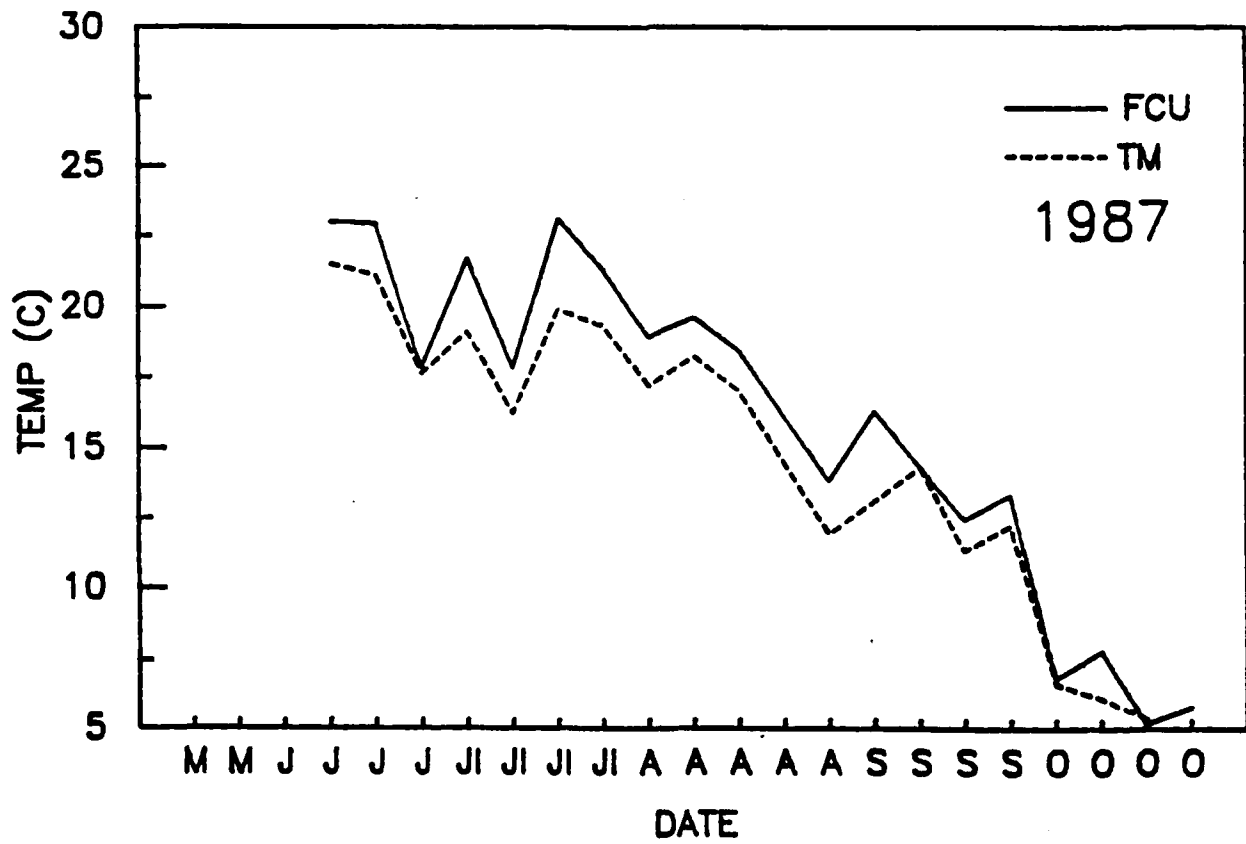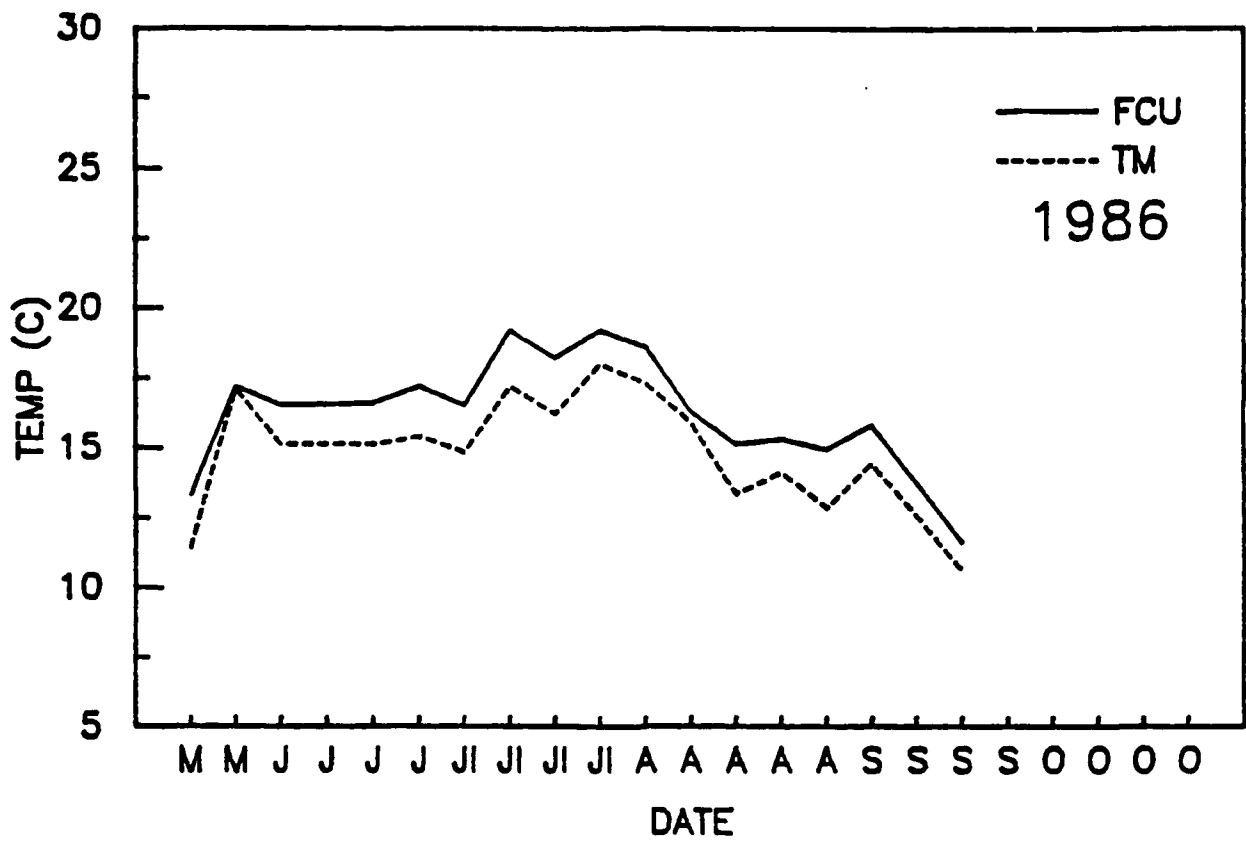
Figure 8.4b. Mean daily water temperature (C) plotted on a weekly basis at TM and FCU from 1986 and 1987.

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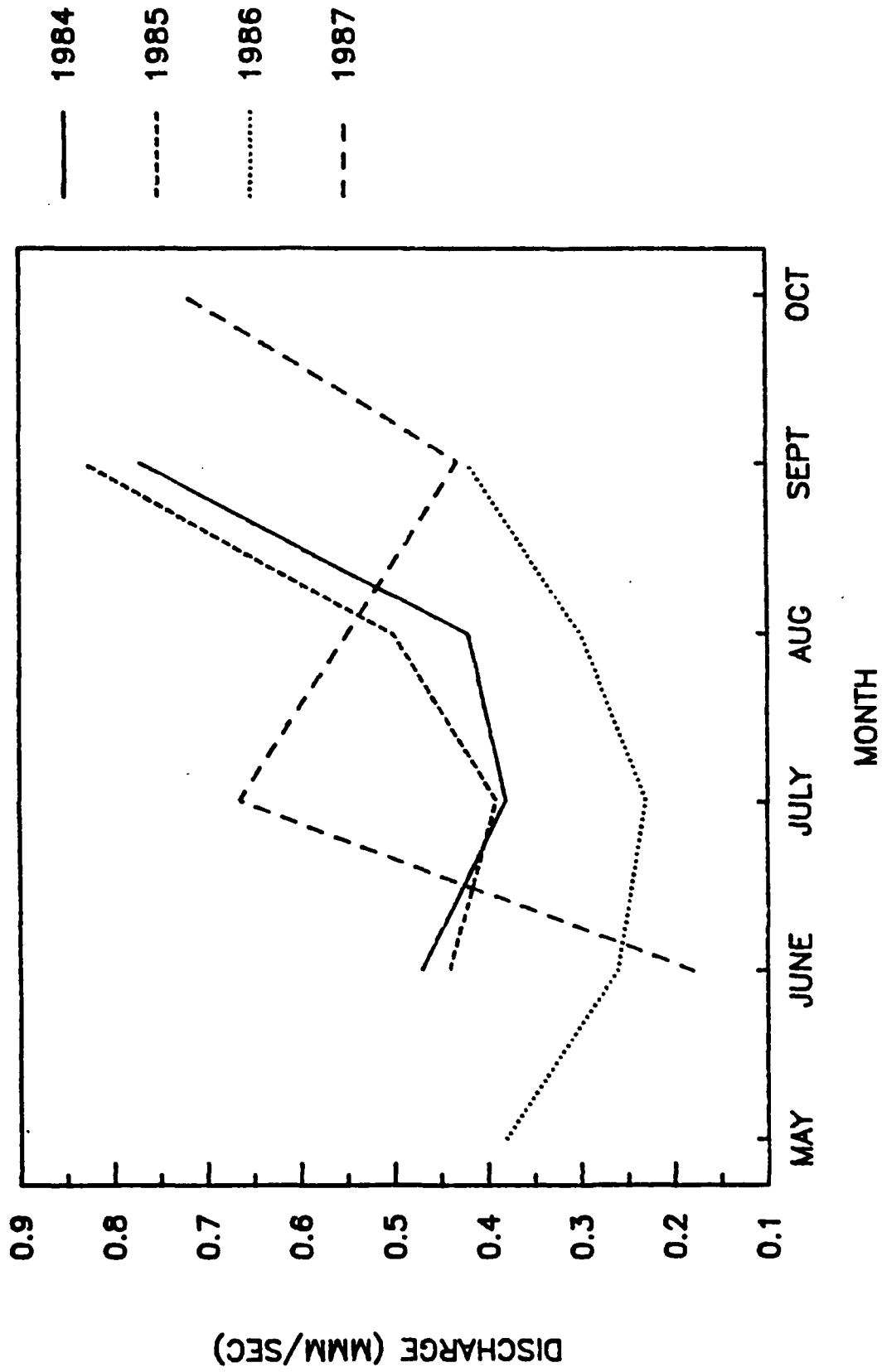
Figure 8.5. Mean monthly discharge (m³/sec) at TM from 1984 to 1987.

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moved at similar rates from 1.4 to 1.8 km/day in 1984, 1985 and 1987. No movement was found between FEX and TM in 1986. Movement from FCD to TM (26.8 km) occurred at different mean rates in 1984 (2.9 km/day) than in 1985 (5.0 km/day). No movement was found between FCD and TM in 1986. Brook trout that were moving between FCD and FEX (14.1 km) also moved at different rates in the first two sampling years with rates of 2.7 km/day in 1984 and 1.2 km/day in 1985. No movement was found between FCD and FEX in 1986. Angler tag return data from throughout the Ford River verified the above trends and indicated that brook trout move at a steady pace (1984 - 2.4 km/day, 1985 - 1.1 km/day and 3.8 km/day in 1987) upstream similar to rates recorded from our sampling gear.

MI DNR Population Analysis. Michigan Department of Natural Resources conducted four brook trout population surveys in 1985 and 1986 using 220 V DC electrofishing gear. Two sites were used in this analysis: 1) Ford Site 1 which is 5 km upstream from FEX; and 2) A site approximately 1 km upstream from FCD. Both sites were approximately 1000 m in length and 1 ha in area. A single Peterson mark-recapture estimate was done at each site to determine trout densities.

Ford Site 1 was found to have 269 ± 47.5 fish per ha on June 25, 1985. The total biomass of this population was estimated from length frequency and length-weight data to be 2.35 kg/ha. The length frequency of this site showed that this area is mainly inhabited by young of the year fish with very low densities of adult and juvenile fish (Figure 8.6a).

Surveys of brook trout populations at the site near FCD showed very low densities of fish. Only 18 fish were caught on the marking run on June 27, 1985, 5 fish on the marking run on August 20, 1985 and 0 fish on the marking run on August 21, 1986. Population estimates were made from the one marking run by assuming that the catch efficiency of each size class was the same at both sites. Densities on June 27, 1985 were estimated at 60.7 fish/ha at FCD with a biomass of 1.28 kg/ha. The length frequency of the catch at this date shows very low densities of YOY and adult fish at the site (Figure 8.6b). The population estimate in the post-movement sampling date of August 20, 1985 was 15.7 fish/ha with a biomass of 0.31 kg/ha. Only a few young of the year remained at this site in August (Figure 8.6b). No fish were captured in August 1986.

These preliminary data indicate that most brook trout move out of the lower site in the summer and are at low densities throughout the river. These densities are very low when compared to literature studies of brook trout populations and are probably indicative of the variable abiotic conditions in the Ford River. These data will be combined with 1988 DNR surveys and all available historical DNR data to provide additional baseline data. This data will also determine what percentage of the population moves in the Ford River.

ELF Population Estimates. ELF study DeLury brook trout
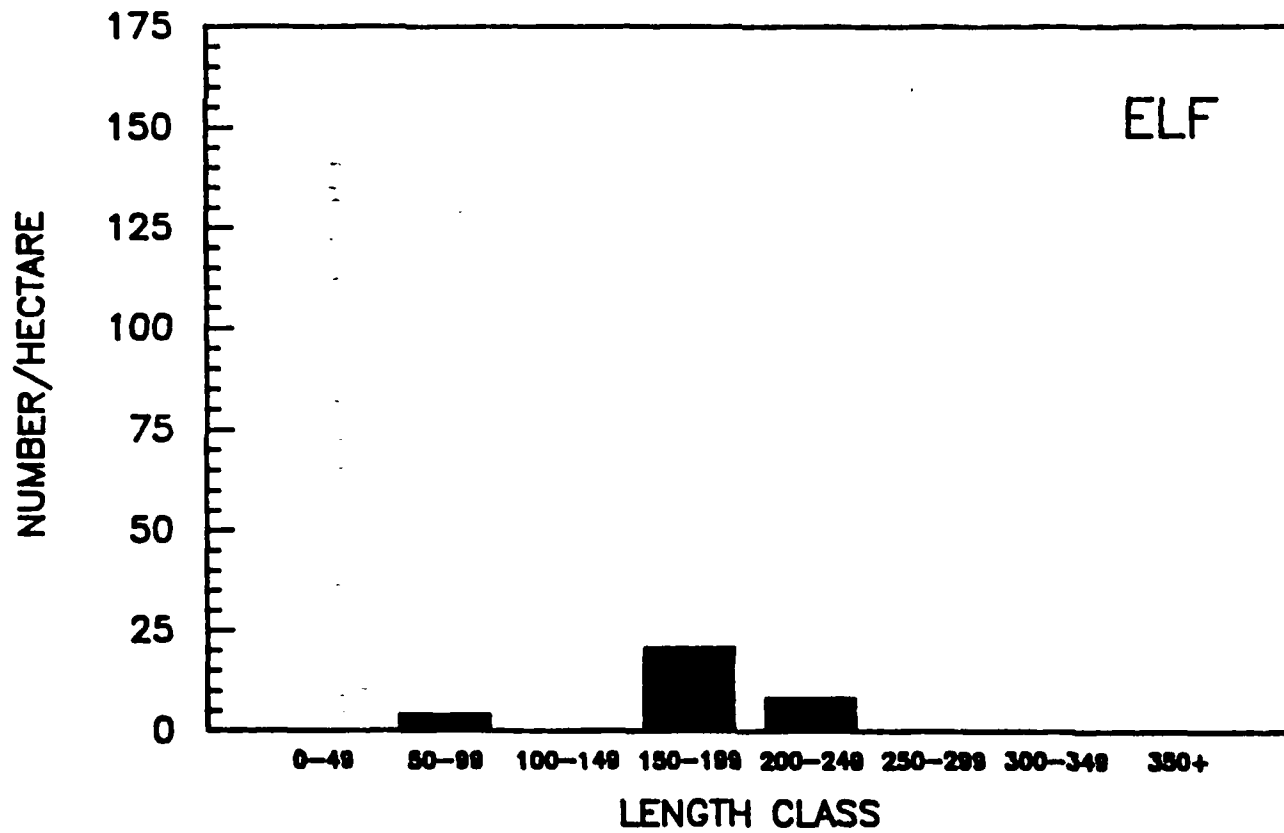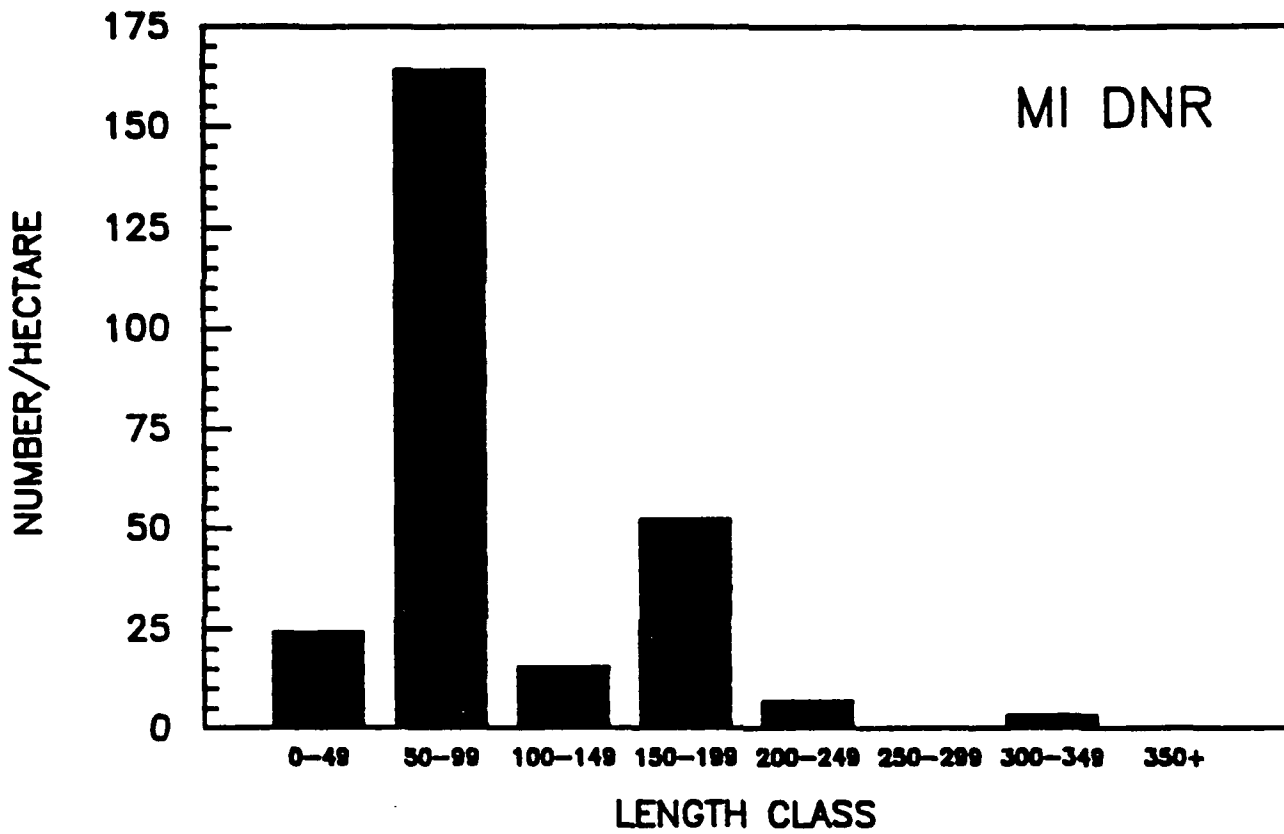
Figure 8.8a. Length frequency of brook trout at FS1 taken by MI DNR on 6-25-85 and MSU ELF personnel on 9-14-87.
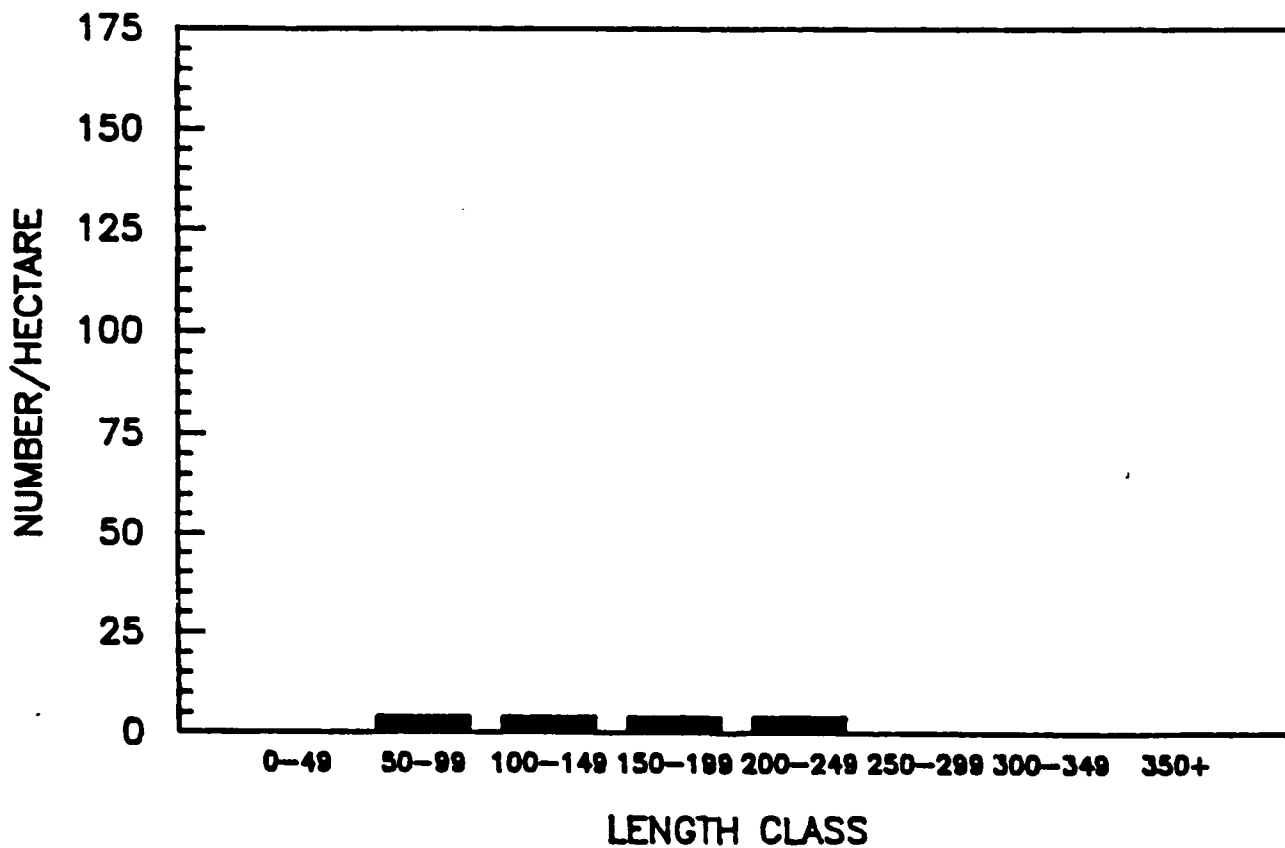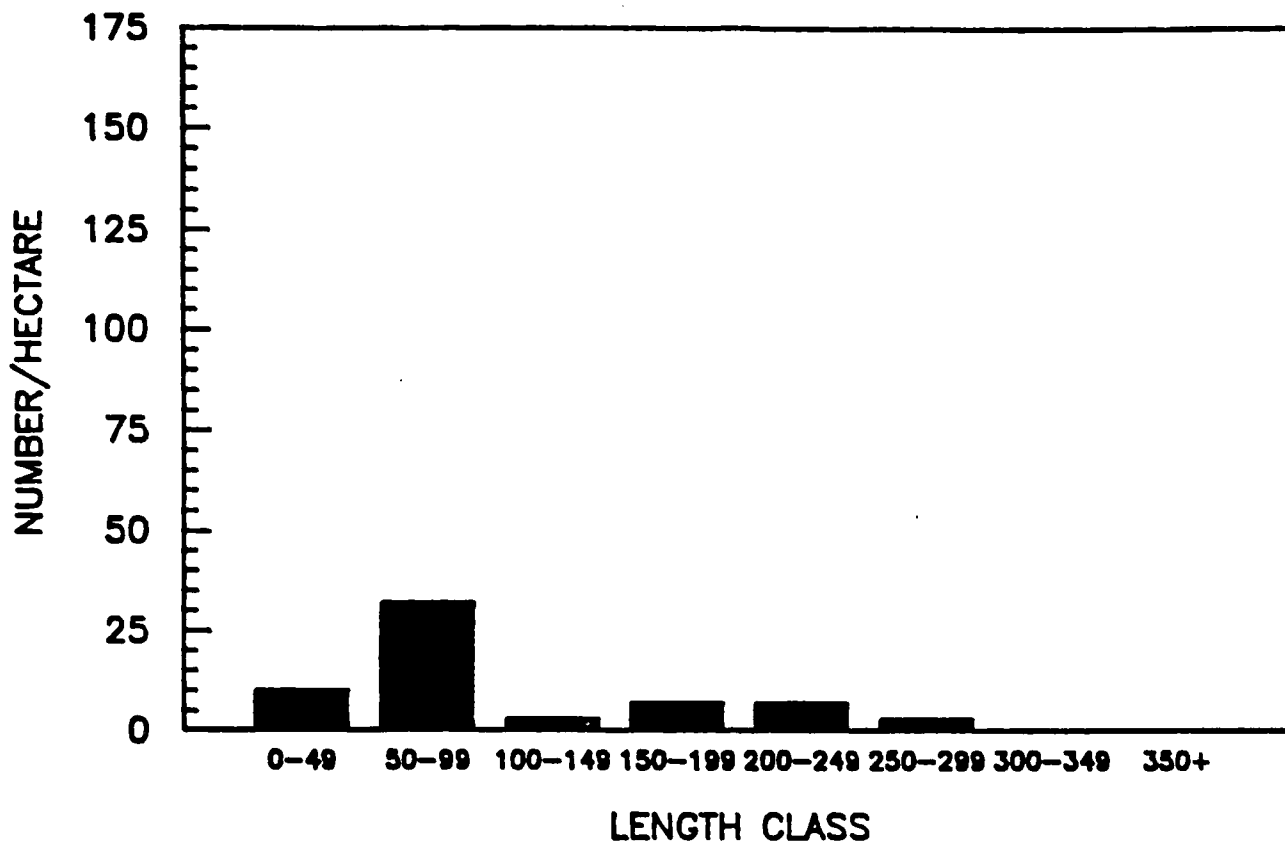
Figure 8.6b. Length frequency of brook trout at FCD taken by MI
DNR on 6—27—85 and 9—19—85 respectively.
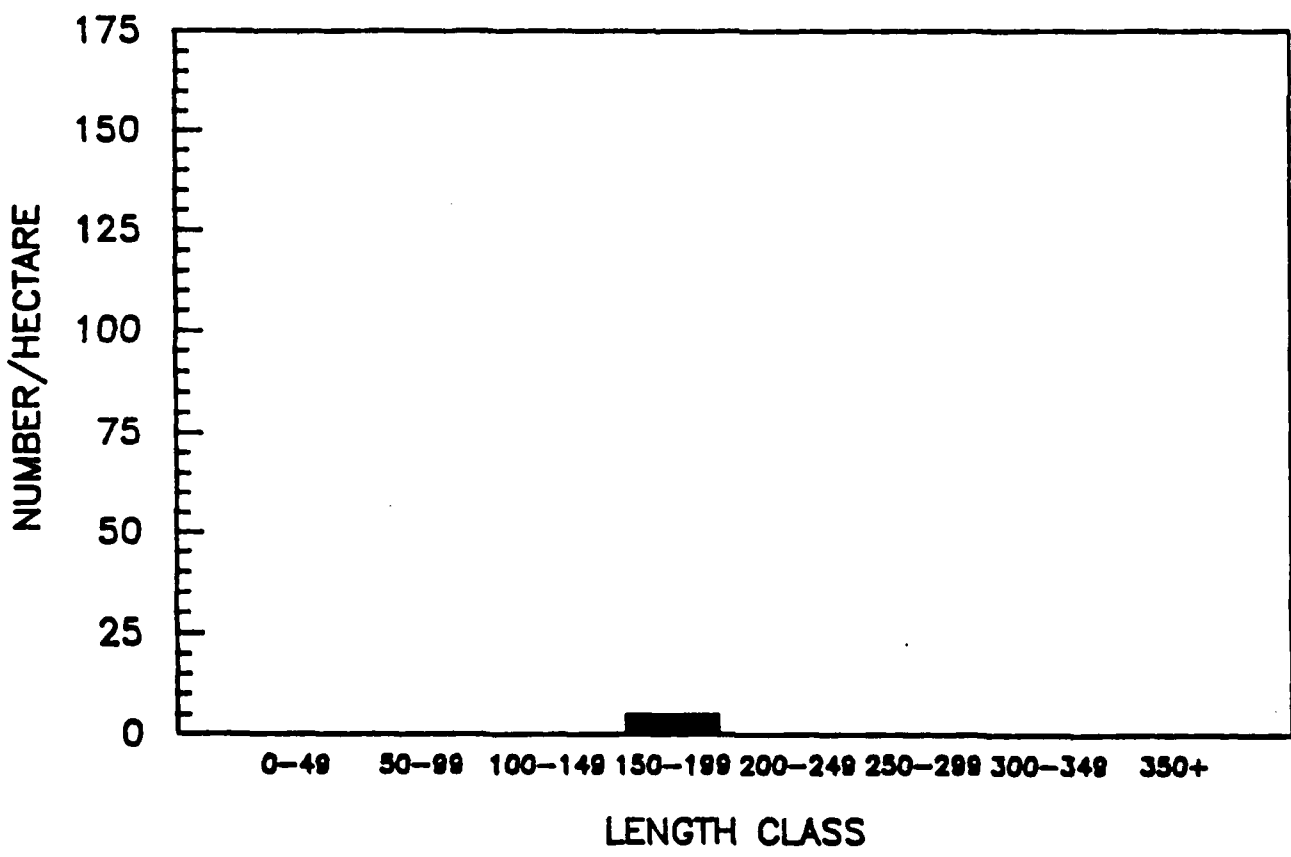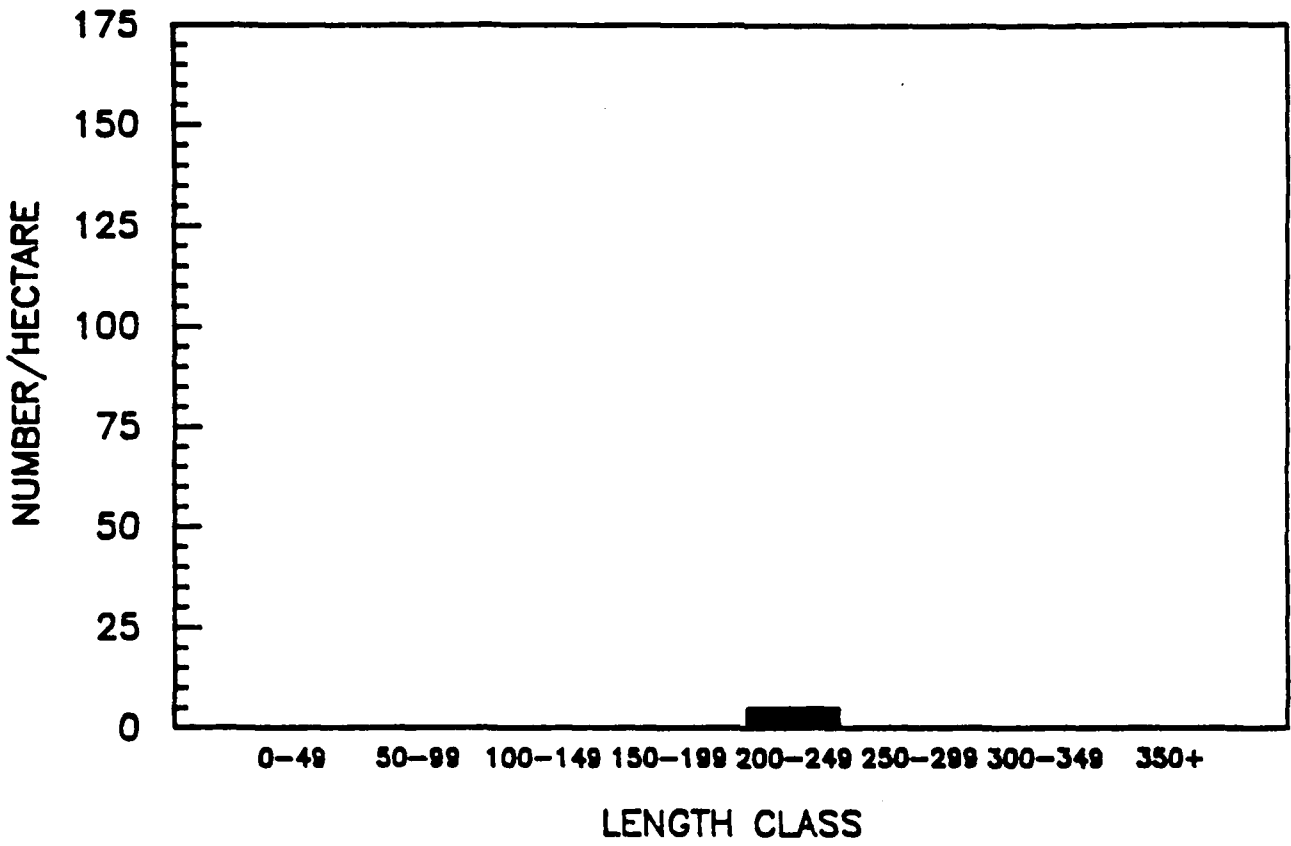
Figure 8.6c. Length frequency of brook trout at FCD taken by MSU
ELF personnel on 7-29-87 and 8-27-87 respectively.
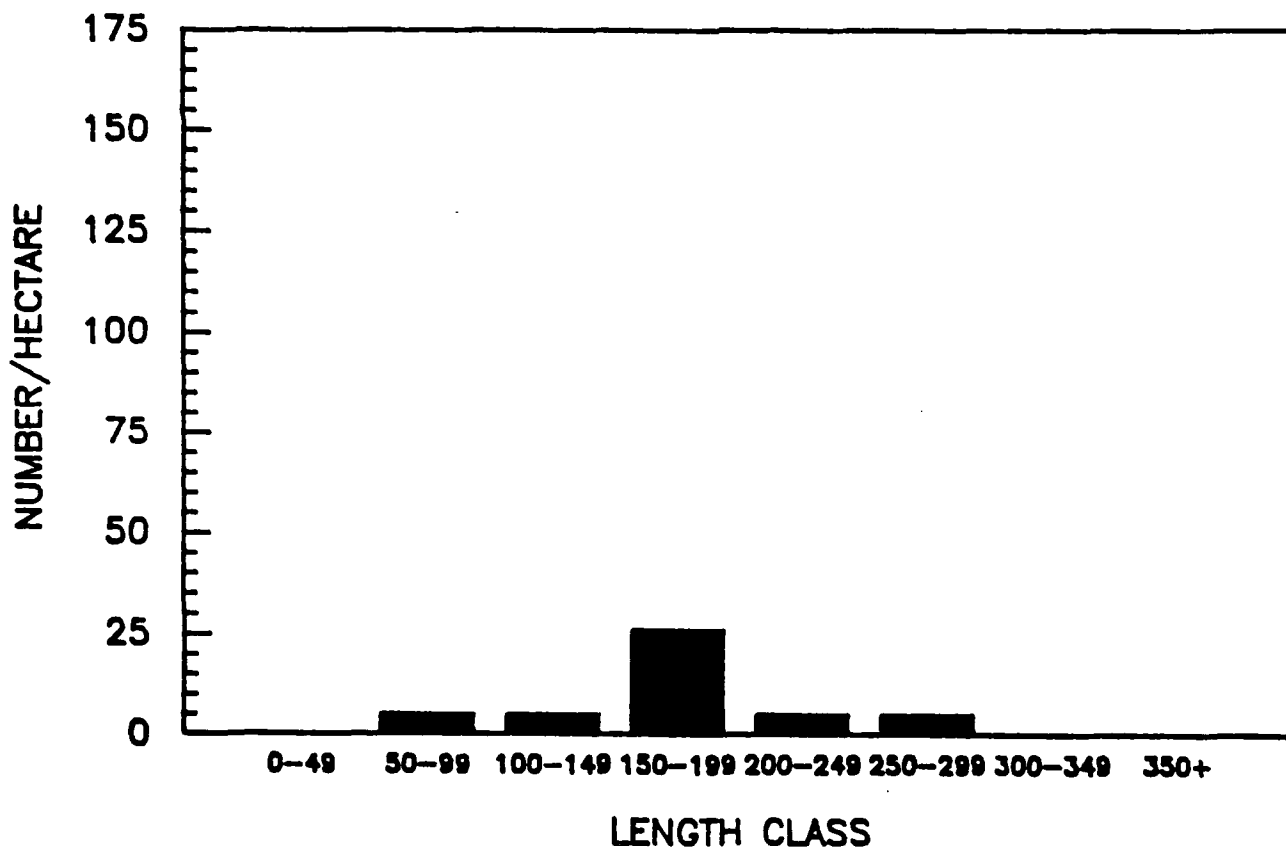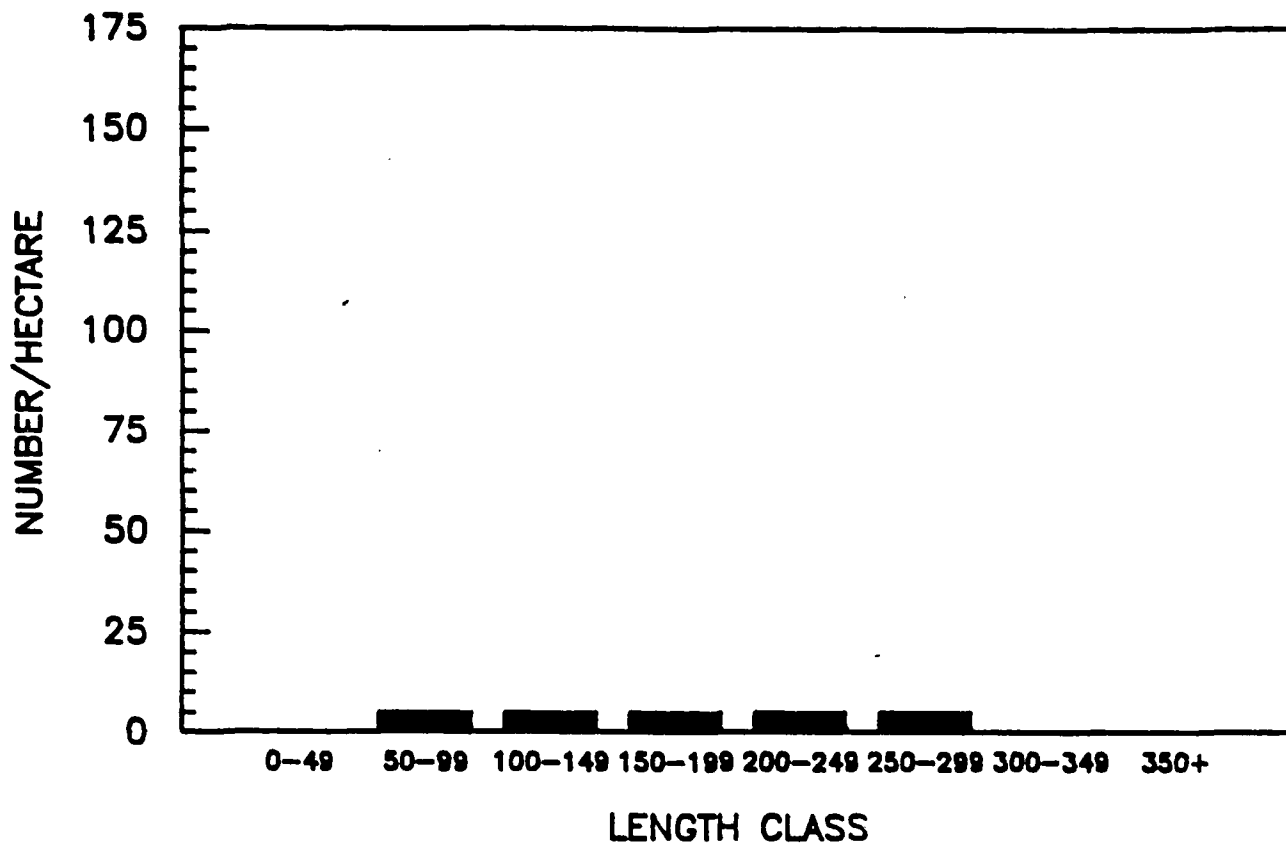
Figure 8.8d. Length frequency of brook trout at FEX taken by MSU
ELF personnel on 7-1-87 and 8-26-87 respectively.
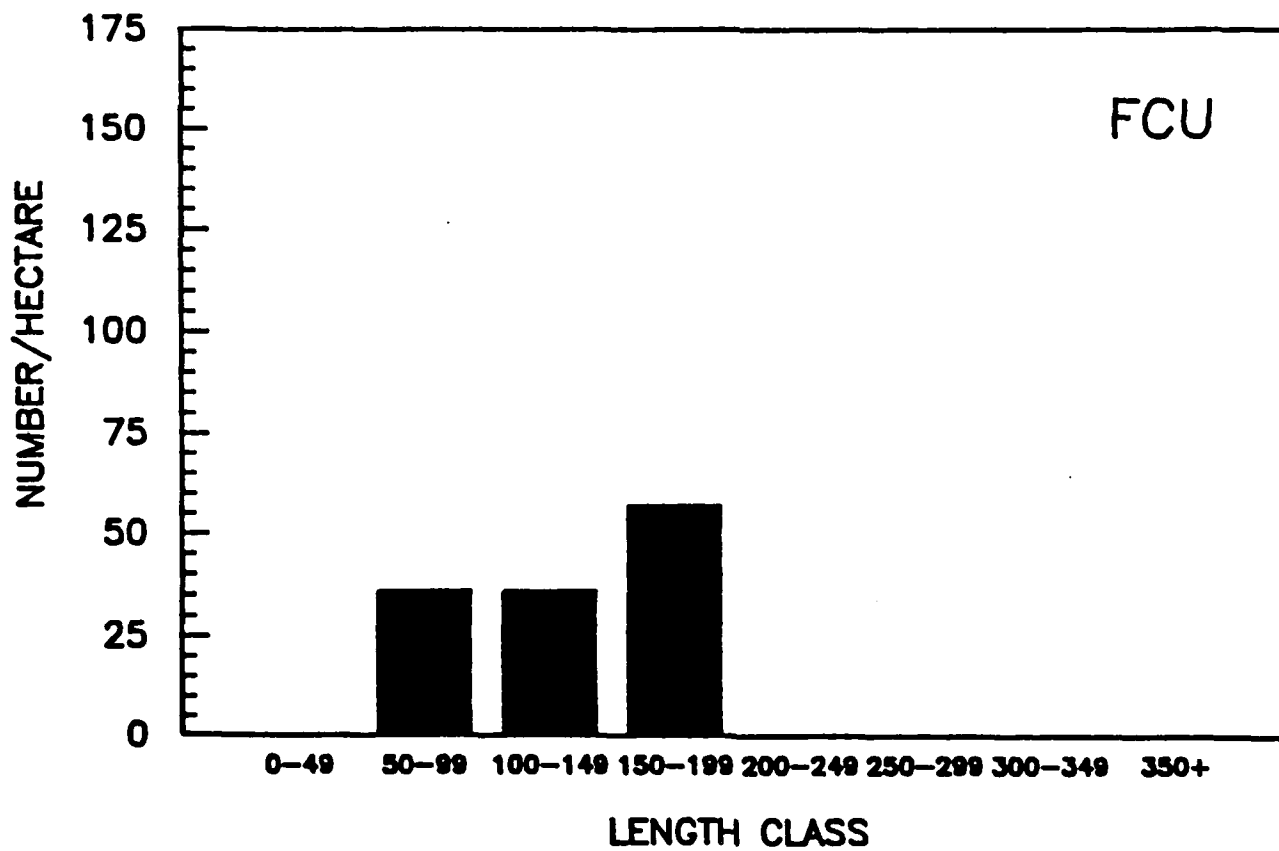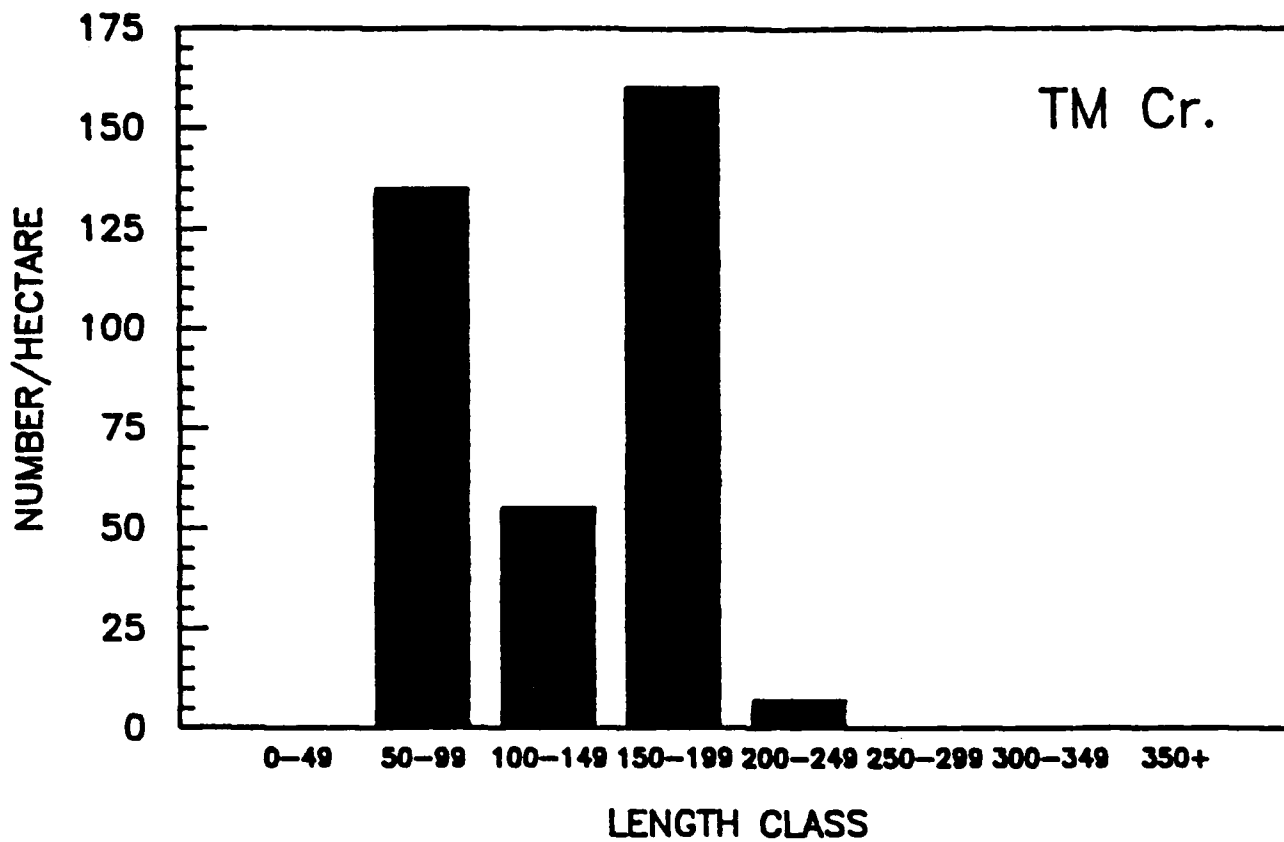
Figure 8.6e. Length frequency of brook trout at TM and FCU taken on 8-17-87 and 8-18-87 respectively by MSU ELF personnel.

estimates ranged from 4.2 fish/HA at FCD to 364.3 fish/HA at TM (Table 8.4). Biomass estimates ranged form 0.3 Kg/HA at FCD to 10.3 Kg/HA at TM. Length frequency values at FCD, FEX, FSI and FCU mirrored MI DNR values and were primarily yearling to adult fish (Figures 8.6a-e) whereas Two Mile Cr. was predominantly YOY and yearling fish (Figure 86e).

The study plan for 1988 calls for spring, movement peak and late summer estimates at each site and when combined with MI DNR data will provide a baseline data set to utilize to test ELF effects. Additional analyses in progress are an examination of mortality rates, length frequencies, and site habitat differences which will be included in a later report.

F. Brook Trout Age and Growth

Age and growth analysis on brook trout was completed using fish captured in the fyke nets and weirs. Data for all sites was pooled because of the high amount of mobility brook trout display in the Ford River. Age determination was done using scales. The body-scale relationship was determined using the technique described in Smale and Taylor (1987). Backcalculations were made using the linear technique described in Bagnenal and Tesch (1978).

Ford River brook trout show excellent growth as seen in Table 8.5 when compared to populations described in Carlander (1969). Size at annulus formation was consistent from 1983-87. Lee's phenomena was not seen in any year. Statistical analysis of yearly differences and comparisons to the literature are in progress and will be included in a future report. Analysis of abiotic and density dependent effects will also be completed at that time.

G. Brook Trout Condition

Examination of brook trout condition was made using the relative weight methodology as described in element 7. The standard weight formula:

$$\log wt = -5.085 + 3.043*\log tl \quad (r=.999)$$

was determined using the 50th percentile equation from 45 literature populations.

Brook trout relative weight ranged from average to slightly below average from 1983 to 1987 compared to values obtained from the above equation (Figure 8.7). Relative weight values declined from 101.6 in 1983 to 89.0 in 1986. Condition improved in 1987 to 92.6 although this value is still below the condition values found from 1983-85. Low water conditions, above optimal temperatures and poor groundwater inputs may have caused the decline from the 1984-1985 values to the lower 1986-87 values. Statistical analysis of yearly and seasonal trends is in progress and will be reported on in an upcoming report.

Table 8.4. DeLury population estimates (density (num/ha), biomass (kilogram/ha)) for brook trout at all sites.

Site	Date	Lower 95% CI	Estimate	Upper 95% CI	Biomass
FCU	870818	97.0	122.2	147.5	4.71
TM	870817	265.0	364.3	463.4	10.30
FS1	870914	32.3	34.4	34.4	1.83
FEX	870701	0.0	16.7	36.3	1.56
	870826	40.8	41.7	42.5	1.73
FCD	870727		4.2		0.32
	870829		4.2		0.28

Table 8.5.   Backcalculated length at annulus data for brook trout
             from 1983-1986.

Age	Backcalculated Length at Annulus		
Class	1	2	3
1	90 + 19.6 (339)		
2	80 + 22.1 (178)	188 + 30.6 (178)	
3	85 + 34.5 (15)	186 + 44.0 (15)	280 + 47.7 (15)
Overall Mean	87 + 21.5 (532)	187 + 31.7 (193)	280 + 47.7 (15)
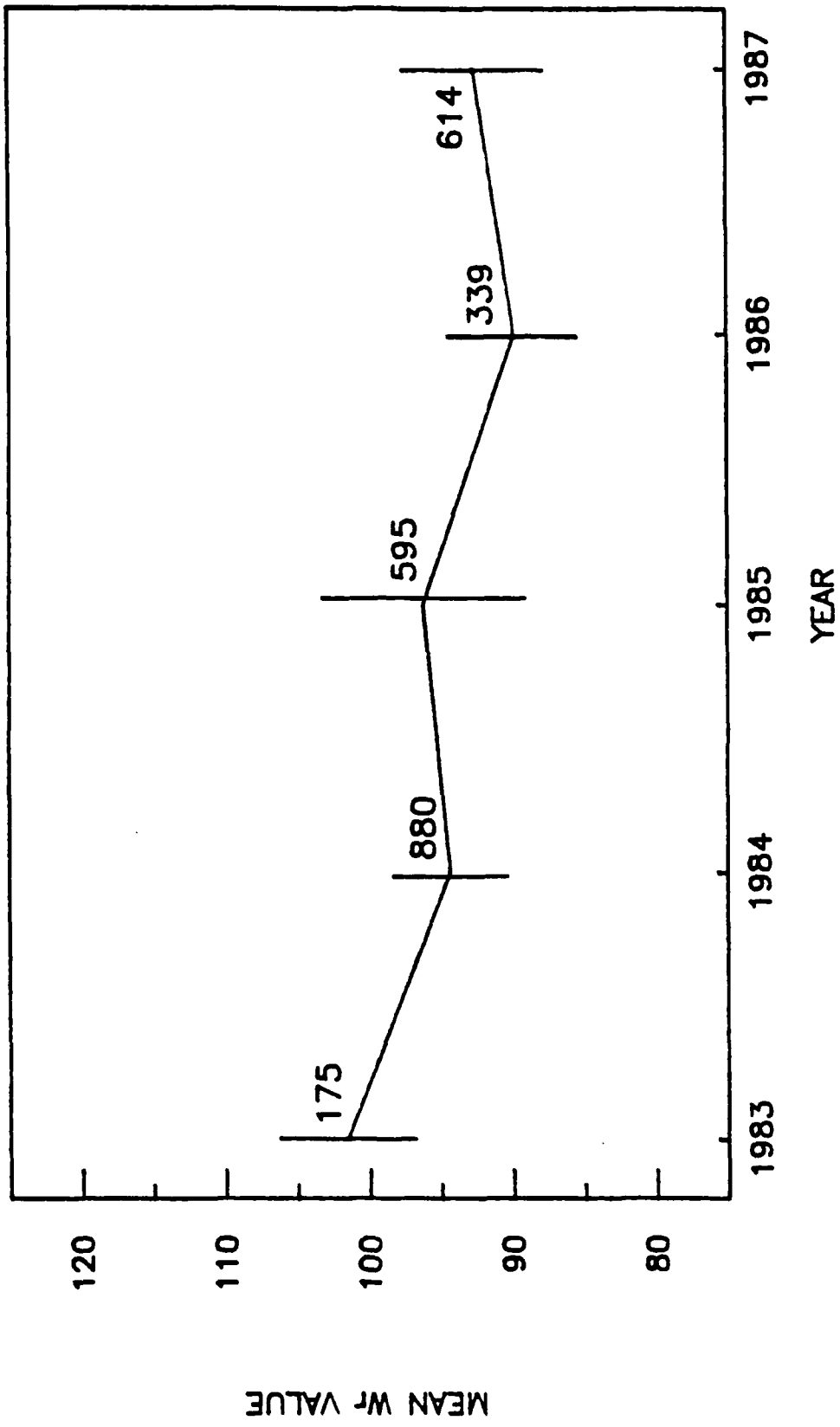
Figure 8.7. Brook trout mean (+/− SD) yearly Wr values from the Ford River. Numbers adjacent to means refer to sample size used in calculation.

Literature Cited

Bagenal, T.B. and F.W. Tesch. 1978. Age and growth. Pages 101-136 in T.B. Bagnenal, editor. Methods for the assessment of fish production in freshwater, 3rd edition. Blackwell Scientific Publications, Oxford, England.

Carlander, K.W. 1969. Handbook of freshwater biology, volume 1. Iowa State University Press, Ames, Iowa, USA.

Meister, A.L. and C.F. Ritzi. 1958. Effects of chloretone and M.S. 222 on eastern brook trout. Progressive Fish Culturist 20:104-110.

Schoettger, R.A. and A.M. Julin. 1967. Efficacy of MS-222 as an anesthetic on four salmonids. United States Bureau of Sport Fisheries and Wildlife Investigations in Fish Control, No. 13, Washington, D.C.

Smale, M. and W.W. Taylor. 1987. Sources of back calculation error in estimating growth of lake whitefish. Pages 189-202 in R.C. Summerfelt and G.E. Hall. The age and growth of fish. Iowa State University Press, Ames, Iowa, USA.

Wydosky, R. and L. Emery. 1983. Tagging and Marking. Pages 215-237 in L.A. Neilson, and D.L. Johnson, editors. Fisheries techniques. American Fisheries Society, Bethesda, Maryland, USA.

Element 9 - Parasite Loads of Selected Fish Species.

This element has been reviewed and it was determined that the database was sufficient for preliminary observation. Additional work may be done after the antenna is 100% operational. As of this writing this element has been postponed indefinitely.

The influence of diet on the growth of *Stenonema vicarium* (Walker) (Ephemeroptera: Heptageniidae)

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Abstract

Laboratory studies compared the growth rate of *Stenonema vicarium* (Walker) nymphs on diets of detritus and natural stream periphyton. In three consecutive runs of the experiment, growth rates were consistently higher on periphyton (mean growth rate = 2.1% wet wt. d^{-1}) than detritus (mean = 1.8% wet wt. d^{-1}). The starting date of each run also significantly influenced growth rates. In each treatment growth rates generally decreased over the course of the 3 runs, and ca. one-half of the nymphs in the last run did not molt or grow. It appeared that growth of *S. vicarium* may be partially controlled by seasonal factors.

Introduction

Food and temperature are among the most influential factors in the life history characteristics of aquatic invertebrates (Sweeney, 1984). Of these, temperature is usually indicated as having the most pronounced effects on growth rates (e.g., Sutcliffe *et al.*, 1981; Merritt *et al.*, 1984; Vannote & Sweeney, 1980, 1986). Food quantity and quality may also play an important role in determining growth rates and other life history parameters (Anderson & Cummins, 1979; Cummins & Klug, 1979; Sweeney & Vannote, 1984). Unfortunately, temperature and food resource availability often covary in natural situations (e.g., changes in riparian vegetation may influence temperature regimes, primary productivity, and detrital inputs). Thus, in the context of the *River Continuum Concept (Vannote et al., 1980)*, it is difficult to determine whether longitudinal differences in growth rates (and productivity) of a given species are primarily attributable to temperature or food (e.g., Hawkins, 1986). Therefore, separation of the effects of these two factors may be possible only under controlled laboratory conditions (Sweeney, 1984; c.f., Sweeney & Vannote, 1986).

This study examined the effect of diet on the growth of nymphs of *Stenonema vicarium* (Walker) (Heptageniidae) under constant temperature conditions in the laboratory. The objective was to determine the relative utilization efficiency of natural stream periphyton vs. leaf detritus by *S. vicarium* nymphs in terms of their growth rate on each food resource. Our specific hypothesis was that growth would be greater on a diet that includes algae than on a diet of leaf detritus because:

1. algae is generally considered to be a superior food resource (Lamberti & Moore, 1984); and/or;
2. members of the Heptageniidae are generally

considered to be grazers or scrapers, and therefore may be "specialized" for feeding on periphyton (Cummins, 1973; Merritt & Cummins, 1984).

Materials and methods

The experiment was conducted in two thermally controlled artificial stream channels (Frigid Units® , Toledo, OH). In each of three runs, *S. vicarium* nymphs in one channel were provided with natural stream periphyton (ALG), while nymphs in the second channel were provided with leaf detritus devoid of algae (DET). Treatments were randomly assigned to channels for Run 1, switched for Run 2, and randomly assigned for Run 3, so that treatment effects could be separated from channel effects (e.g., residual effects from previous usage of the stream channels). At the beginning of each run, both channels were filled with 160 L of water from the Red Cedar River, Meridian Township, Ingham Co., MI. Approximately 1/3 of the water in each channel was replaced every 4 d to prevent nutrient limitation. Each channel was provided with 15 plastic cages (16 × 16 × 10 cm, 1 mm mesh screened sides) for individual growth chambers. Both channels were run at 11 °C (± 1 °C) under a 12:12 h photoperiod during all runs. Channels were thoroughly drained and cleaned between runs. Run 1 began on 29 Sept. 1984, Run 2 on 17 Oct., and Run 3 on 8 Nov.

Treatments were conducted as follows. Natural periphyton growing on stones was provided for food in ALG. Stones of ca. 100 cm² upper surface area were collected from Sloane Creek, a tributary of the Red Cedar River. Stones were replaced every 4 d to prevent food limitation. Care was taken to remove all macroinvertebrates from the stones prior to use. Lighting over ALG was augmented by fluorescent "grow light", also set at a 12:12 photoperiod, and suspended 40 cm over the water's surface. Dried, autumn scenescent White Ash (*Fraxinus americana* L.) leaves were provided for food in DET. Leaves were conditioned in the dark for 14 d prior to each run in aerated Red Cedar River water at 18°C. To stimulate fungal and bac-

terial growth on the leaf surfaces, the culture water was supplemented with 25 g KH_2PO_4, 6.5 g NaCl, 18 g $MgSO_4$, 3 g $CaCl 2(H_2O)$, and 37 g KNO_3 (total volume = 37 L; Lawson *et al.*, 1984). Fungi, bacteria, and protozoa were observed during microscopic examination of leaf surface scrapings cultured in this manner; however, algae was never observed. Each growth chamber was provided with approximately 20 entire leaves, and a stone of approximately the same size as those provided in ALG cages. These stones were collected from a gravel pit and washed prior to their use in each run. Food was provided in excess in both treatments to avoid the effects of food limitation. All water used in DET was filtered through compressed glass wool to remove algae.

Stenonema vicarium nymphs were collected from Sloane Creek on the day preceding the start of each run, and kept without food overnight in the dark at 10°C. At the start of each run, 30 nymphs ranging in size from 3.0–9.0 mm were blotted dry on tissue paper for 5 sec, then weighed to the nearest 0.1 mg on a Sartorius® 1207 MP2 electrobalance. Nymphs were then randomly assigned to cages within each treatment (1 ind./cage). At the end of 14 days, nymphs were removed from their cages, reweighed, and preserved in 70% ethanol. Exuviae in each cage were also preserved as secondary evidence of growth.

Instantaneous growth rate (% wet weight d^{-1}) was calculated for each nymph as per Sutcliffe *et al.* (1981):

$$G = [\ln(W_e/W_b)/t] \times 100\%$$

where W_e = wet weight at the end of the run, W_b = wet weight at the beginning of the run, and t = elapsed time in days.

Growth rate estimates were $\log_{10}$ transformed to correct for heterogeneous variance (Cochran's C; P = 0.053), and analysed using the multivariate model:

$$G_{jkl} = \mu + D_j + F_k + DF_{jk} + e_{jkl}$$

where:

A-2

G_{jkl} = an individual growth rate
μ = overall mean growth rate
D_j = fixed effect of starting date j (j = 1,2,3)
F_k = fixed effect of food source k (k = 1,2)
DF_{jk} = interaction between starting date and food
e_{jkl} = random individual error

Since preliminary analysis indicated that channel effects were not significant (P »0.05), this factor was excluded from the above model.

To confirm that the treatments produced the desired nymphal diets, midgut contents of 3 or 4 nymphs in each treatment group were dissected and mounted on microscope slides using the method of Cummins (1973). Midgut contents were used because the foregut of *S. vicarium* is not large enough to be sampled by this method. Approximate proportions of diatoms and detritus were determined by taking a line transect across each slide using a phase contrast microscope at 400X. The proportion of each particle type was estimated as the total number of ocular micrometer units in 30 fields (300 μm each field) intersected by each particle type, divided by the total micrometer units for both particle types.

Fig. 1. Mean growth rate (±95% CI) of each treatment group. Number at the top of each bar is the number of individuals included in each treatment group mean.

Table 1. Manova table for $\log_{10}$-transformed growth rate data.

Source of variation	Sum squares	df	Mean square	F	P
Constant	5.67154	1	5.67154	338.92681	
Date	0.21993	2	0.10997	6.57156	0.002
Food	0.18133	1	0.18133	10.83605	0.002
Interaction	0.03993	2	0.01997	1.19323	0.310
Error	1.10443	66	0.01673		
Total	7.21716	72			

Results

Only three nymphs died during the course of the experiments. During Run 3, ca. 1/2 of the nymphs in each treatment did not molt or grow substantially (Fig. 1). All other nymphs molted at least once during the experiments. Non-molting individuals were treated separately in the statistical analyses.

The overall effect of diet on growth rates was highly significant (P < 0.01, Table 1), with nymphs in ALG growing an average of 0.22% $^{-1}$d faster than those in DET (Fig. 1). However, only Run 1 was significant when treatment means were compared within each run (P = 0.001, 0.14, 0.09 for Runs 1, 2, and 3 respectively; orthogonal contrasts). The starting date of each run also had a highly significant effect (P < 0.01; Table 1), with growth rates generally decreasing over the course of

the 3 runs (Fig. 1). The overall effect of interaction was not significant (P = 0.31; Table 1), although interaction approached significance (P = 0.06) between Runs 1 and 2.

Inspection of midgut contents of nymphs in each treatment group verified that nymphs in DET did not ingest diatoms (Table 2). Guts of DET nymphs contained primarily amorphous organic material with fragments of fungal hyphae and mineral particles. Guts of ALG nymphs contained diatoms, mineral particles, and amorphous organic material. The proportion of diatoms in gut contents of ALG Run 3 nymphs was much higher than in previous

Table 2. Feeding habits of *S. vicarium* nymphs in each treatment group.

Treatment	Run	n	Percentage in gut	
			Diatoms	Detritus
ALG	1	4	33	67
	2	3	28	72
	3	3	76	24
DET	1	4	0	100
	2	4	0	100
	3	3	0	100

runs (Table 2). Diatoms ingested by ALG nymphs were primarily *Pinnularia, Cocconeis, Gomphonema,* and *Navicula.*

Discussion

Although the overall effect of diet was highly significant, the results only partially support the initial hypothesis that *S. vicarium* grows better on a diet of periphyton than on leaf detritus. Lack of significant differences in growth rates on the two diets during Runs 2 and 3 could have been caused by:

1. contamination by algae in DET Runs 2 and 3 however, examination of gut contents (Table 2) indicated that this was not responsible;

2. changes in the nutritional quality of either diet over the course of the experiment; or

3. a greater consumption rate by DET nymphs. Cummins & Klug (1979) suggested that aquatic consumers may increase their consumption rate to compensate for poor food quality, although this parameter was not considered in the present study.

Since periphyton was collected for ALG during a period of rapid seasonal changes in Sloane Creek, it is possible that changes in nutritional quality occurred over the course of the experiment. Qualitative changes in periphyton during autumn, such as an increase in C:N ratio (McMahon *et al.,* 1974) and decreasing fatty acid content (Moore, 1975), could have had an adverse effect on consumer

growth (Hanson *et al.,* 1983; Cargill *et al.,* 1985). In addition, Hornick *et al.* (1981) showed that an autumnal decline in periphyton productivity in an Appalachian Mountain stream was most highly correlated with changes in lighting, flow, and dissolved organic inputs. In contrast to the susceptibility of ALG to seasonal changes, food for DET was prepared in the laboratory under identical conditions, and therefore was homogeneous across all 3 runs. Thus, over the course of the 3 runs, the nutritional quality of the periphyton may have decreased relative to that of the leaves.

The greater ingestion of diatoms by Run 3 ALG nymphs may also reflect seasonal changes in the periphyton community in Sloane Creek, the source of food for ALG nymphs. Clumps of the filamentous alga *Cladophora* partially covered rocks used in ALG Run 1, but were less prevalent during Run 2 and absent during Run 3. Although *Cladophora* fragments were never observed in gut contents, these clumps may have entrained detritus or hampered the nymphs' ability to scrape diatoms from rock surfaces.

While the general downward trend in growth rates over the course of the 3 runs could have been caused in part by the increase in initial weights of nymphs used in successive runs, the correlation between individual biomass and growth rate was not significant in most treatment groups. Since treatment conditions were identical throughout the experiment, factors external to the experimental conditions, i.e. preconditioning of the nymphs, may have had a significant impact on growth rates. This is supported by the fact that many of the Run 3 nymphs in both treatments failed to molt (Fig. 1). Several workers have concluded that growth of *Stenomena* spp. slows or stops during winter months (Richardson & Tarter, 1976; Barton, 1980; Kreuger & Cook, 1984; K. M. Webb, unpubl. data). Thus, the seasonal pattern of growth rates observed in the laboratory paralleled that commonly observed in the field. This suggests that growth of *S. vicarium* is not controlled entirely by the direct effects of temperature, diet, etc. on metabolism, but may also be controlled endogenously using an environmental timing cue (e.g., temperature or photoperiod). Such mechanisms for the timing of life

history events have been demonstrated in terrestrial insects (Ricklefs, 1973; Chapman, 1982), but unfortunately have not been as carefully examined in aquatic insects (Sweeney, 1984). In view of the rather low net production efficiency (NPE = Growth/Assimilation) reported for *Stenonema pulchellum* (Trama, 1972), slower growth during winter may be necessary for survival of members of this genus. The metabolism of *Stenonema* may be so low during winter that a significant portion of assimilated energy must be channeled into maintenance.

Table 3 compares the methods and results of this study with those of other published studies comparing growth of aquatic insects on diatoms vs. leaf detritus (Cummins *et al.*, 1973; Fuller & Mackay, 1981; Bird & Kaushik, 1984; Sweeney & Vannote, 1984). In all of these studies, growth rates were greater on diatoms than on leaves, but the observed improvement in growth differs markedly between studies (Table 3; % increase). These discrepancies in results may be explained by differences in experimental methods. For example, Bird & Kaushik (1984) may have imposed food limitation in their leaf treatment, since only 15 leaf discs (size and species not given) were provided to groups of 10

"early instar" mayfly nymphs every 4 days. Leaf ratios were much greater in all other studies. Grafius & Anderson (1980) showed that *Lepidostoma unicolor* larvae increase their consumption and growth rates as food availability increases. Therefore, in experiments of this type it is prudent to supply all food resources in excess to remove the confounding effects of limitation; i.e., food resources are best compared by the maximum possible growth rates they produce. If feeding is selective to any degree, then true food availability can only be measured by the food being selected.

The sources of both algal and detrital food resources may also partially explain the differences in results. The ash leaves used in this study were probably of much higher nutritional quality than leaves used in the other studies (Kaushik & Hynes, 1971; Peterson & Cummins, 1974). McCullough *et al.* (1979) found that the assimilation efficiency of *Tricorythodes minutus* was greater on pure diatom cultures (approximated by Fuller & Mackay, 1981; Sweeney & Vannote, 1984) than on mixed cultures (as in Bird & Kaushik, 1984, and this study).

Unfortunately, these variations in experimental technique obscure interspecific differences in resource utilization efficiency. Assessment of such in-

Table 3. Comparison of methods and results with other published feeding studies.

Species	T (°C)	Leaf species	Algal source	Growth rate (% body wt d^{-1})		% increase[*]
				leaves	algae	
Chloeon dipterum[1] (Baetidae)	25	hickory	cultured (diatoms)	23.8	27.1	14
	10			NS[1]	4.7	
Ephemerella subvaria[2] (Ephemerellidae)	15	maple	natural (periphyton)	1.3	5.6	321
Stenonema interpunctatum[3] (& *S. canadense* (Heptageniidae))	5	hickory	cultured (*Ankistrodesmus* sp.)	0.1 – 0.8	not given	–
Stenonema vicarium[4] (Heptageniidae)	11	ash	natural (periphyton)	1.8	2.1	12
Hydropsyche spp.[5] (Hydropsychidae)	11	red maple	natural (diatom mat)	0.2	1.0	400

[1] Sweeney & Vannote (1984); NS = no survivors.

[2] Bird & Kaushik (1984); second study.

[3] Cummins *et al.* (1973).

[4] Present study; Growth rates are means of all 3 runs.

[5] Fuller & Mackay (1981).

[*] % increase = % improvement in growth rate on algae vs. leaves.

terspecific differences may lead to a clearer definition of the importance of various food resources to stream ecosystems. While measurements of assimilation efficiency, protein or lipid content may be more accurate (subject to less variance), the influence of diet on growth and other life history features is ultimately most important to the individual, and consequently to the population and community. However, one drawback to experiments of this type is that the "acceptability" of a resource influences growth rates as well as digestability (Ward & Cummins, 1979). Furthermore, it is still unclear how minute variations in diet influence growth in natural populations. Growth experiments to date generally use diets that are highly artificial, since food resources rarely occur in isolation in nature (e.g., diatoms colonize leaf surfaces). Further refinement in techniques may produce results that are more comparable to natural situations.

Acknowledgements

References

Anderson, N. H. & K. W. Cummins, 1979. Influences of diet on the life histories of aquatic insects. J. Fish. Res. Bd Can. 36: 335–342.

Barton, D. R., 1980. Observations on the life histories and biology of Ephemeroptera and Plecoptera in northeastern Alberta. Aquat. Insects 2: 97–111.

Bird, G. A. & N. K. Kaushik, 1984. Survival and growth of early instar *Ephemerella subvaria* fed various diets. Hydrobiologia 119: 227–233.

Cargill, A. S. II, K. W. Cummins, B. J. Hanson & R. R. Lowry, 1985. The role of lipids, fungi and temperature in the nutrition of a shredder caddisfly, *Clistoronia magnifica*. Freshwat. Invertebr. Biol. 4: 64–78.

Chapman, R. F., 1982. The insects. Structure and function, 3rd

Edition. Harvard Univ. Press, Cambridge, Mass. 919 pp.

Cummins, K. W., 1973. Trophic relations of aquatic insects. Ann. Rev. Ent. 18: 183–206.

Cummins, K. W., R. C. Petersen, F. O. Howard, J. C. Wuycheck & V. I. Holt, 1973. The utilization of leaf litter by stream detritivores. Ecology 54: 336–345.

Cummins, K. W. & M. J. Klug, 1979. Feeding ecology of stream invertebrates. Ann. Rev. Ecol. Syst. 10: 147–172.

Fuller, R. L. & R. J. Mackay, 1981. Effects of food quality on the growth of three *Hydropsyche* species (Trichoptera: Hydropsychidae). Can. J. Zool. 59: 1133–1140.

Grafius, E. & N. H. Anderson, 1980. Population dynamics and role of two species of *Lepidostoma* (Trichoptera: Lepidostomatidae) in an Oregon coniferous forest stream. Ecology 61: 808–816.

Hanson, B. J., K. W. Cummins, A. S. Cargill & R. R. Lowry, 1983. Dietary effects on lipid and fatty acid composition of *Clistoronia magnifica* (Trichoptera: Limnephilidae). Freshwat. Invertebr. Biol. 2: 1–15.

Hawkins, C. P., 1986. Variation in individual growth rates and population densities of Ephemerellid mayflies. Ecology 67: 1384–1395.

Hornick, L. E., J. R. Webster & E. F. Benfield, 1981. Periphyton production in an Appalachian Mountain trout stream. Am. Midl. Nat. 106: 22–36.

Kaushik, N. K. & H. B. N. Hynes, 1971. The fate of dead leaves that fall into streams. Arch. Hydrobiol. 68: 405–515.

Kreuger, C. C. & E. F. Cook, 1984. Life cycles, standing stocks, and drift of some Megaloptera, Ephemeroptera, and Diptera from streams in Minnesota, U.S.A. Aquat. Insects. 6: 101–108.

Lamberti, G. A. & J. W. Moore, 1984. Aquatic insects as primary consumers. In: V. H. Resh and D. M. Rosenberg (eds), The Ecology of Aquatic Insects. Praeger, New York: 164–195.

Lawson, D. L., M. J. Klug & R. W. Merritt, 1984. The influence of the physical, chemical and microbiological characteristics of decomposing leaves on the growth of the detritivore *Tipula abdominalis* (Diptera: Tipulidae). Can. J. Zool. 62: 2339–2343.

McCullough, D. A., G. W. Minshall & C. E. Cushing, 1979. Bioenergetics of a stream "collector" organism, *Tricorythodes minutus* (Insecta: Ephemeroptera). Limnol. Oceanogr. 24: 45–58.

MaMahon, R. F., R. D. Hunter & W. D. Russell-Hunter, 1974. Variation in Aufwuchs at six freshwater habitats in terms of carbon biomass and of carbon: nitrogen ratio. Hydrobiologia 45: 391–404.

Merritt, R. W. & K. W. Cummins (eds), 1984. An introduction to the aquatic insects of North America. Kendall-Hunt, Dubuque, Iowa. 722 pp.

Merritt, R. W., K. W. Cummins & T. M. Burton, 1984. The role of aquatic insects in the processing and cycling of nutrients. In V. H. Resh & D. M. Rosenberg (eds), The Ecology of Aquatic Insects. Praeger, New York: 134–163.

Minshall, G. W., R. C. Petersen, K. W. Cummins, T. L. Bott,

J. R. Sedell, C. E. Cushing & R. L. Vannote, 1983. Interbiome comparison of stream ecosystem dynamics. Ecol. Monogr. 53: 1–25.

Moore, J. W., 1975. Seasonal changes in the proximate and fatty acid composition of some naturally grown freshwater chlorophytes. J. Phycol. 11: 205–211.

Peterson, R. C. & K. W. Cummins, 1974. Leaf processing in a woodland stream. Freshwat. Biol. 4: 343–368.

Richardson, M. Y. & D. C., Tarter, 1976. Life histories of *Stenonema vicarium* (Walker) and *S. tripunctatum* (Banks) in a West Virginia stream (Ephemeroptera: Heptageniidae). Am. Midl. Nat. 95: 1–9.

Ricklefs, R. E., 1973. Ecology. Chiron Press, Portland, OR. 861 pp.

Sutcliffe, D. W., T. R. Carrick & L. G. Willoughby, 1981. Effects of diet, body size, and temperature on growth rates in the amphipod *Gammarus pulex*. Freshwat. Biol. 11: 183–214.

Sweeney, B. W., 1984. Factors influencing life history patterns of aquatic insects. In V. H. Resh & D. M. Rosenberg (eds). The Ecology of Aquatic Insects. Praeger, New York: 56–100.

Sweeney, B. W. & R. L. Vannote, 1984. Influence of food quality and temperature on life history characteristics of the parthenogenetic mayfly, *Cloeon triangulifer*. Freshwat. Biol. 14: 621–630.

Sweeney, B. W. & R. L. Vannote, 1986. Growth and production of a stream stonefly: influences of diet and temperature. Ecology 67: 1396–1410.

Trama, F. B., 1972. Transformation of energy by an aquatic herbivore (*Stenonema pulchellum*) Ephemeroptera. Pol. Arch. Hydrobiol. 19: 113–121.

Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell & C. E. Cushing, 1980. The river continuum concept. Can. J. Fish. Aquat. Sci. 37: 130–137.

Vannote, R. L. & B. W. Sweeney, 1980. Geographic analysis of thermal equilibria: a conceptual model for evaluating the effect of natural and modified thermal regimes or aquatic insect communities. Am. Nat. 115: 667–695.

Ward, G. M. & K. W. Cummins, 1979. Effects of food quality on growth of a stream detritivore, *Paratendipes albimanus* (Meigen) (Diptera: Chironomidae). Ecology 60: 57–64.

Willoughby, L. G. & D. W. Sutcliffe, 1976. Experiments on feeding and growth of the amphipod *Gammarus pulex* (L.) related to its distribution in the River Duddon. Freshwat. Biol. 6: 577–586.

ELF COMMUNICATIONS SYSTEM ECOLOGICAL MONITORING PROGRAM:

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TABLE OF CONTENTS

ABSTRACT

This report summarizes continuing studies that examine potential E.L.F. electromagnetic field effects on peatland ecosystems in northern Wisconsin. For stomatal resistance by Labrador Tea leaves in 1987, we concluded that there were significant differences among E.L.F. treatments in July but not in August; this pattern was similar to that found in 1986. However, differences were between different groups in 1987 than 1986. Nested ANOVA and multiple regression models were contradictory. Statistical analysis of the Labrador Tea decomposition data indicated a significant difference among E.L.F. treatments. This trend was influenced by differences in microenvironment associated with litter bag cover. Multiple regression models which included three E.L.F. electromagnetic fields and environmental data could explain only 32 percent of the variability in weight loss. Foliar nutrient sample size was tripled in 1987 but species were only collected once during the growing season. These samples are being analyzed.

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SUMMARY

This report summarizes the results of field studies and laboratory analyses for 1987. In these studies, we have been investigating the possible effects of ELF electromagnetic fields on eleven bogs in the vicinity of the Wisconsin Test Facility (WTF). Our studies focused on foliar nutrient content, decomposition rate of foliar samples, and stomatal resistance of ericaceous shrub leaves. These are biological variables that might be influenced by ELF electromagnetic fields, because they function at the cell membrane level.

All sites were sampled monthly during the growing season. Environmental parameters were measured and collected monthly from May through September. ELF electromagnetic fields were assumed to be constant throughout the year so they were measured only once during mid-summer. Each of the four ELF treatments was exposed to a unique combination of air, earth, and magnetic fields generated by the WTF antenna. There was also a lesser amount of variability in field strengths between replicate bogs within each treatment.

Stomatal resistance was measured on labrador tea leaves in July and August 1987. As in 1986, significant treatment effects were detected in July but not in August. However, the condition of the antenna during the measurement period in 1986 and 1987 confounded the interpretation of these results. Nested analysis of variance models and multiple regression models provided conflicting statistical conclusions from the data.

Decomposition samples were collected in November, 1987, after twelve months of incubation. Significant treatment effects

were detected with our ANOVA model, but these could be interpreted as resulting from microenvironmental differences associated with bag placement in the different bogs. In addition, multiple regression models using ELF field values and selected environmental parameters accounted for only 32% of the variance in weight loss.

Foliar samples for calcium, magnesium, and potassium analyses were collected once for each plant species during the growing season. Each species was collected at its' physiological peak during the growing season. Instead of increasing the sampling frequency, sample sizes were tripled.

INTRODUCTION

This report outlines recently completed portions of a continuing study of peatlands in northern Wisconsin exposed to E.L.F. electromagnetic fields. The objective is to determine whether long-term exposure to E.L.F. electromagnetic fields significantly influence certain aspects of ecosystem function. Evidence has suggested that the cell membrane would be the site influenced directly by high intensity E.L.F. electromagnetic fields (Miller et al. 1980, 1983, Inoue et al. 1985). We chose variables that would be affected if membrane function were altered and that, if changed, might also influence peatland ecosystem processes. The variables we chose to examine are: leaf decomposition rate, nutrient concentration in foliar tissue of dominant plant species, and stomatal diffusion resistance in Labrador Tea (a dominant peatland shrub).

Our studies continued in the same sites we have used since 1984. We had established eleven transects in ten peatlands that occur along the electromagnetic field gradient around the Wisconsin Test Facility (WTF) (Figure 1). Three sites are located adjacent to the WTF antenna (21,22,40). Three are located at distances far enough away from the antenna that the fields are two orders of magnitude lower than that at the antenna sites and may be considered "background" sites (20, 41, and 50). Another three sites are located at intermediate distances and field strengths between antenna and background (2,7, and 11). The last two sites (101 and 102) are both within one peatland at different distances away from the ground terminus of the north arm of the

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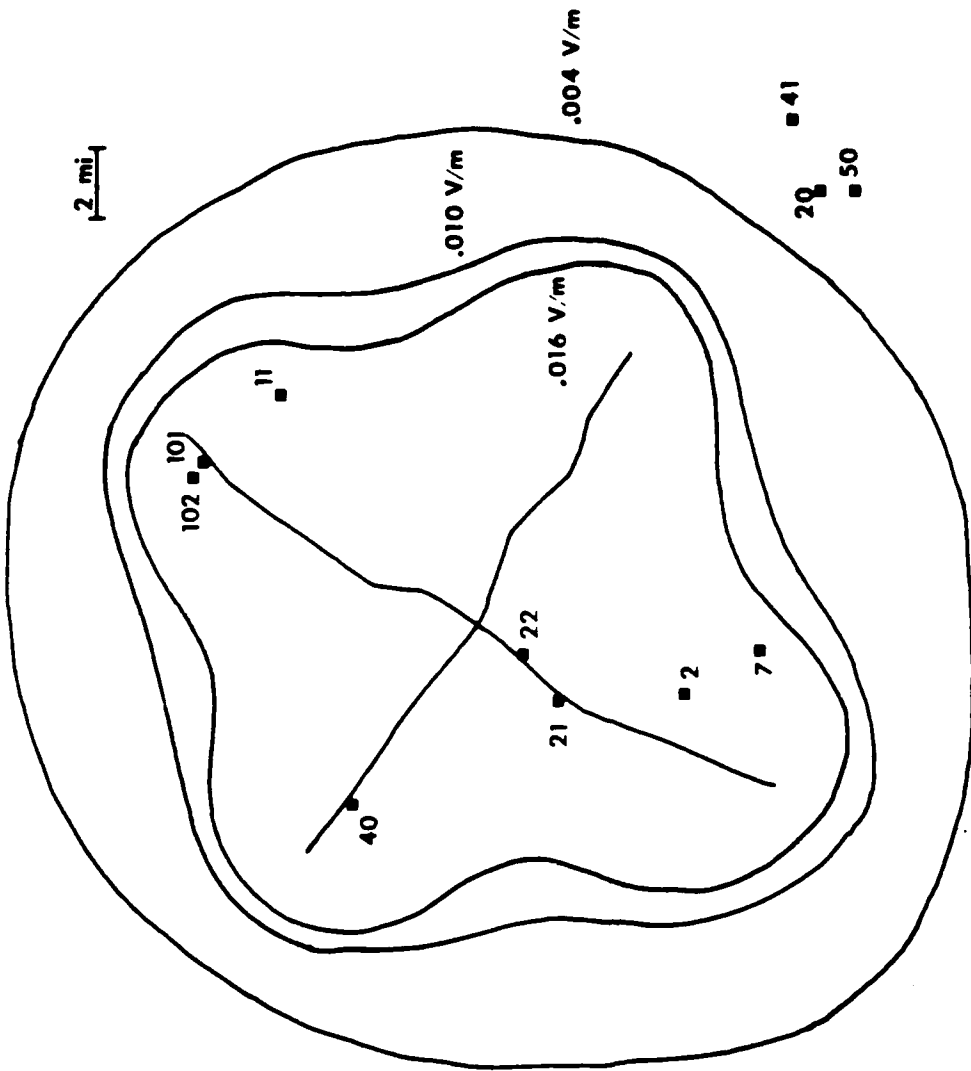
Figure 1. Map showing the location of bog study sites (GROUND = 101,102; ANTENNA = 21,22,40; INTERMEDIATE = 2,7,11; and BACKGROUND = 20,41,50) along the theoretical ELF 76 Hz electromagnetic gradient produced by the Wisconsin Test Facility.

antenna.

These transects were selected because they shared similar
plant species, peat substrate, and groundwater characteristics.
In 1984, the transect in site 21 (ANTENNA) was moved 20 meters
from the original transect (and farther from the WTF antenna) so
it would be located in a portion of the peatland that more
closely resembled the other transects. The new transect had a
lower spruce density than the original and otherwise met our
criteria for species composition and water quality. All of the
other transects were moved 5-10 meters in 1984 and six permanent
wells established in each transect. The six shallow groundwater
wells are located 10 meters apart; all sampling was oriented
around these wells (Figure 2). Since 1984, we have made no other
changes to these transects and oriented all our sampling within
plots surrounding the wells.

During 1987, water samples were collected in the last week
of each month from May to September. Stomatal resistance was
measured on Labrador Tea leaves during July and August when
current year leaves were fully expanded. Decomposition samples
(litter bags) of Labrador Tea leaves were collected in November
after they had been left in the field for twelve months. In 1986
and previous years, foliar samples for nutrient analysis were
collected each month. In 1987, in an effort to reduce the
coefficients of variation, we tripled the number of foliar
samples collected for each species. The large number of samples
involved precluded collecting each species each month. We
determined which month in past years each of the three species

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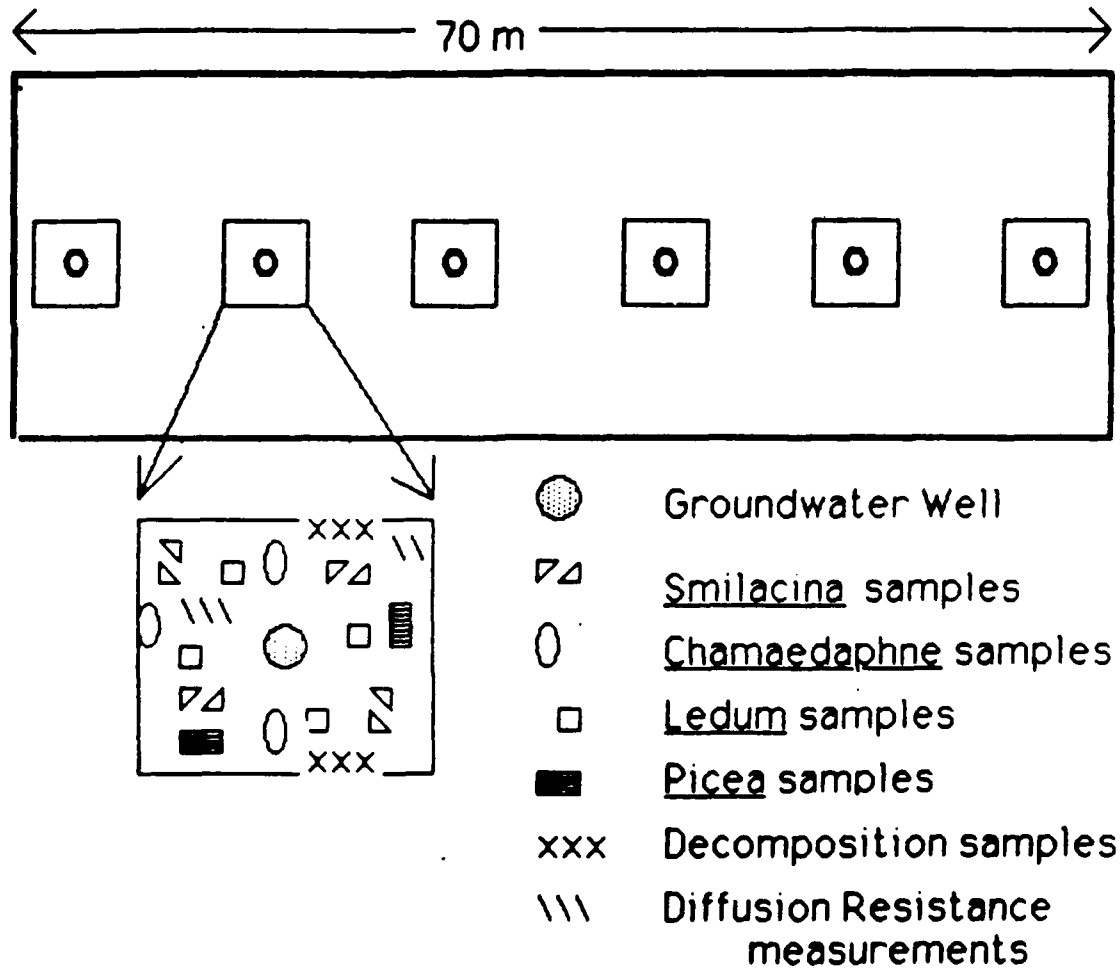
Figure   2.   Diagram of transect design.   Decomposition
samples, diffusion resistance measurements,
and leaf samples were collected within a plot
around each well.   Symbols shown do not reflect
relative number of samples collected.

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had reached their peak condition. as measured by cation content. leaf expansion and flowering phenology. and sampled appropriately. Smilicina was collected in June. leatherleaf in July. and Labrador Tea in August.   In September. we did not increase the sample size for spruce needles and continued to collect samples from the same trees since 1984.

IITRI personnel measured the electromagnetic field strengths.   Three fields: earth. air. and magnetic were measured at each well position in 1987.   ELF field intensities were assumed to be relatively constant and were therefore measured only once each year.

EXPERIMENTAL DESIGN

This study was designed to use linear regression and analysis of variance models to examine the effects of 76hz ELF electromagnetic field exposure on measures of ecosystem function in peatlands surrounding the Wisconsin Test Facility (WTF). ELF electromagnetic fields were measurable in all sites, including those designated as "BACKGROUND". Because the WTF had been operating for several years before we began our research, we could not use a design involving before and after paired plots. Instead, we designed a gradient analysis approach with sites selected at positions along the gradient of 76hz field intensities. The sites also had to meet additional criteria regarding 60hz fields and field strength differences between antenna and background sites as supplied by IITRI. Four categories of sites were selected, based on theoretical ELF field intensities (Table 1). Each category we used is subject to a unique combination of earth, air, and magnetic field exposure. The ANTENNA group includes wetlands within 0.05 km of the antenna system. The INTERMEDIATE sites are located between the antenna arms, the BACKGROUND sites have field intensities at least two orders of magnitude lower than the ANTENNA sites, and the GROUND sites are adjacent to the north ground terminal. Untransformed mean field intensities for 1987 are presented in Figures 3-5. We found that air and earth fields are significantly correlated (Figure 6). ELF field intensity data was log transformed to satisfy the requirements of the models for homogeneity of variance. The WTF antenna is assumed to be on at all times.

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Table 1.   List of sites studied and treatment level (ELF category).   101 and 102 occur within the same bog.

Site	IITRI Category	Treatment Level
20	C2	Background
41	C3	Background
50	C4	Background
2	M2	Intermediate
7	M3	Intermediate
11	M4	Intermediate
21	A4	Antenna
22	A2	Antenna
40	A3	Antenna
101	G1	Ground
102	G2	Ground
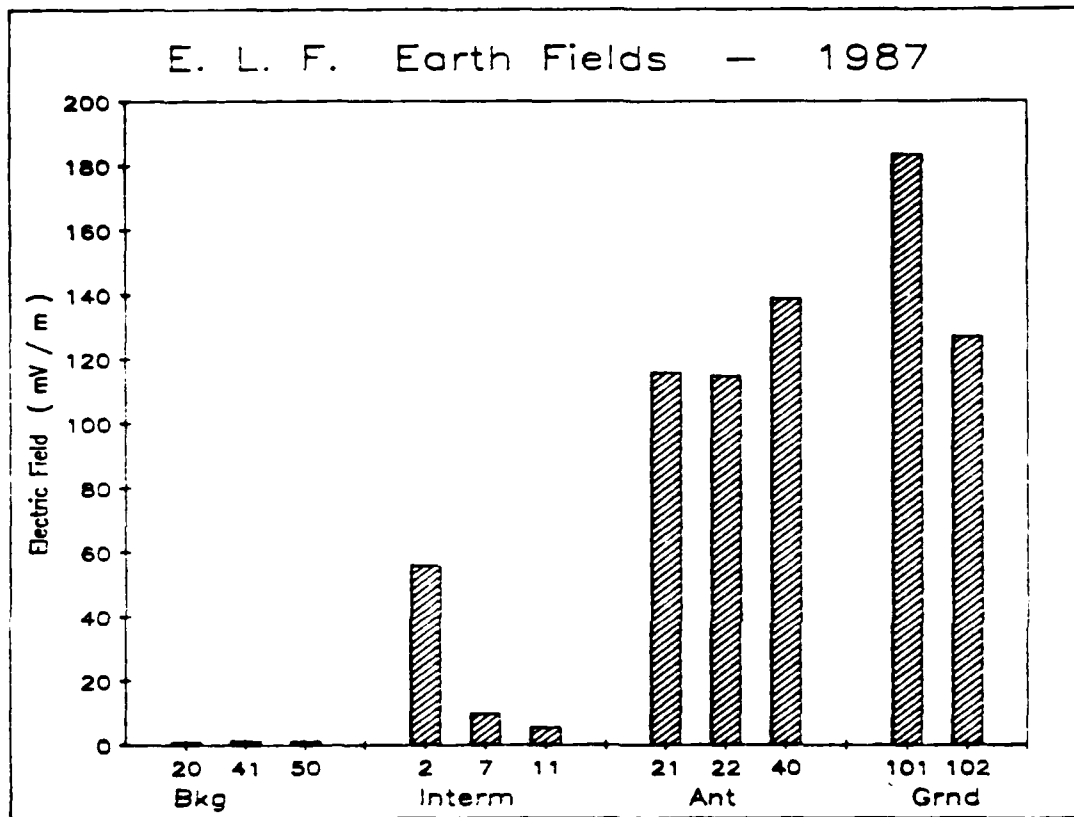
Figure 4. Mean electric field in the earth, measured in August, 1987, at each well site.

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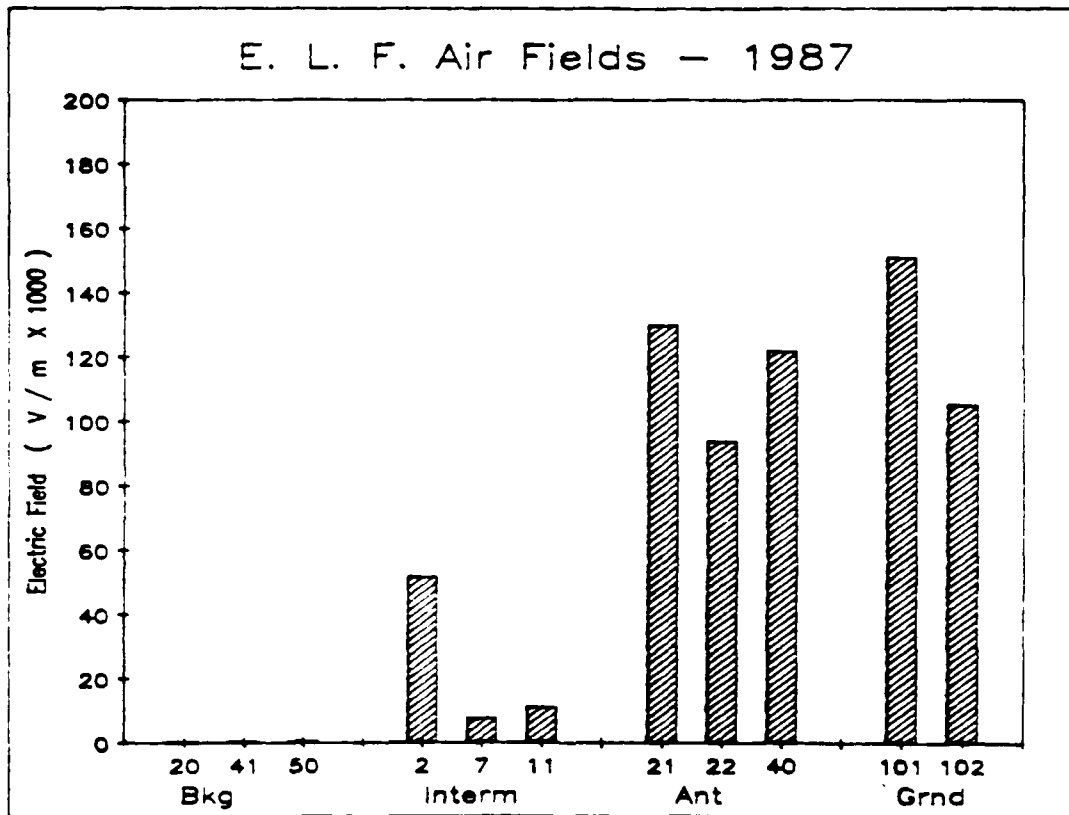
Figure 3.   Mean electric field in air, measured in August, 1987 at each well site.
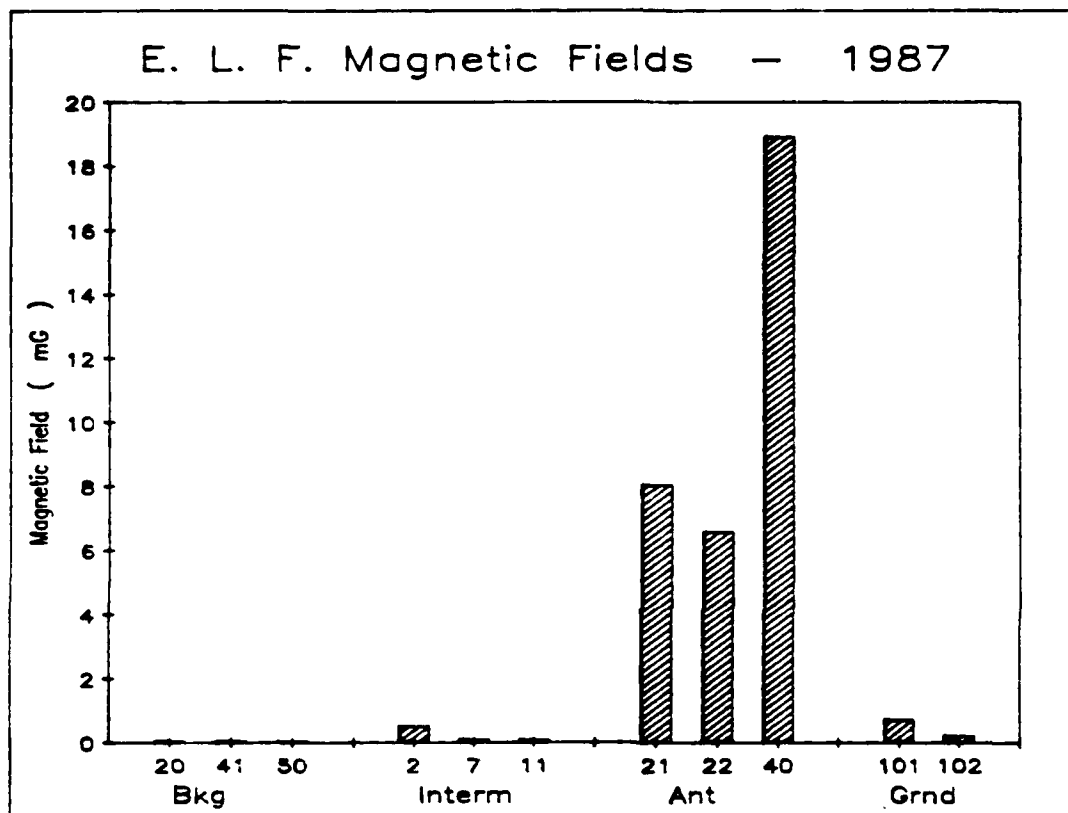
Figure 5.   Mean magnetic field, measured in August, 1987, at each well site.
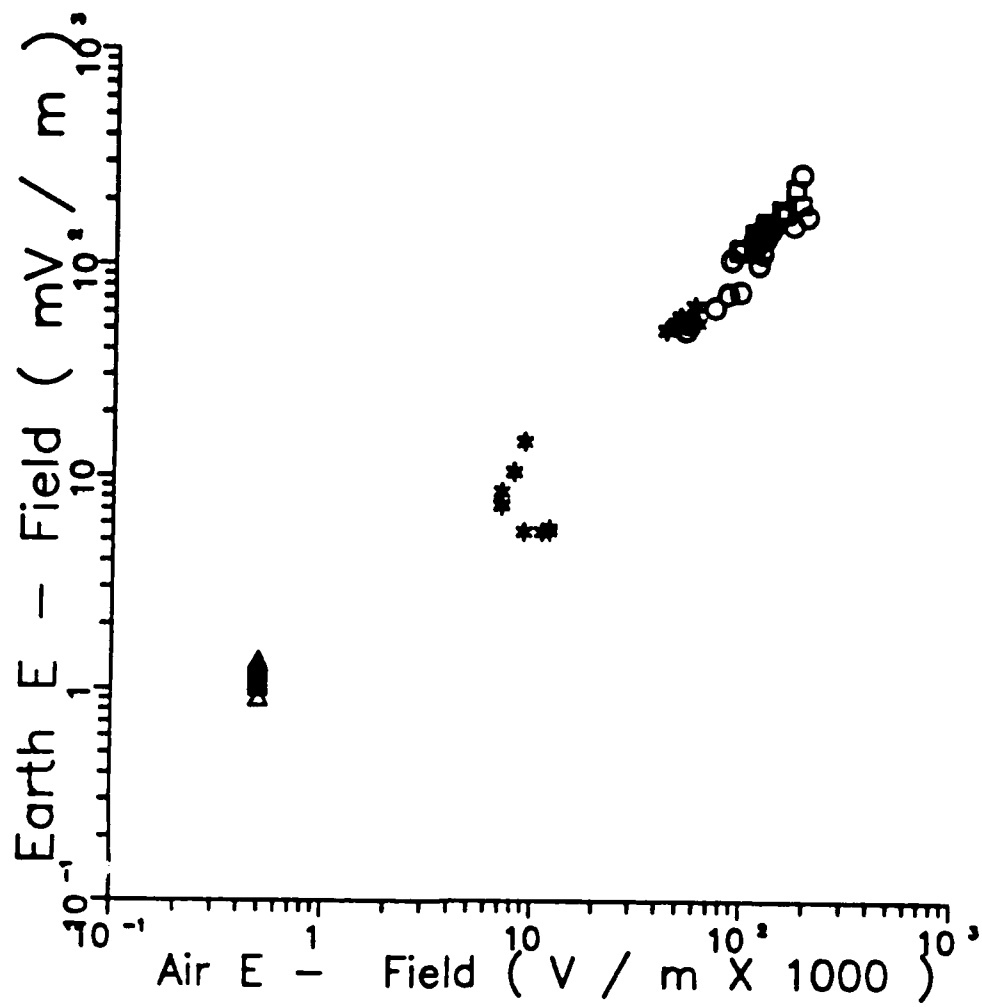
Figure 6. The relationship between electric field in air
and electric field in earth, from measurements
made in 1987 in the bogs. Triangles = Bkg sites,
* = Inter. sites, circles = antenna sites, squares
= Grnd sites. R = 0.99

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Examination of the WTF antenna log sheets provide a check on the antenna on / off status during our sampling trips.

Sokal and Rohlf (1981) served as the primary statistical reference. Data sets were examined for normality using moment statistics and the Kolmogorov-Smirnov test statistic. The Scheffe' - Box log anova test was used to test for homogeneity of variances. In some cases, variables were transformed before further analysis to meet the criteria of normality and homongeity of variances.

In our experimental design, a nested analysis of variance model (below) was used to test for significant effects. Although we chose bogs that were structurally and chemically similar, there was some variation in bog structure and environmental chemistry. The nested design was used to separate variation inherent among replicate bogs from variation which could result from ELF treatment effects.

$$Y_{ijkl} = u - a_i - B_{ij} - C_{ijk} - e_{ijkl} \quad \text{where}$$

Y = dependent variable

u = grand mean

a_i = group (ELF exposure treatment) fixed effect

B_{ij} = subgroup (bog within ELF treatment) random

C_{ijk} = replicate plot within each bog (random)

e_{ijkl} = error term

To test for differences among treatments (ELF levels), the group mean squares were divided by the subgroup mean squares to produce the appropriate F statistic. Likewise, differences among subgroups (bogs) were tested by dividing subgroup mean squares by

plot mean squares. and plots were tested by dividing plot mean squares by the error mean squares to produce the appropriate F statistics.

When significant group (ELF treatment) differences were detected in the nested ANOVA. we conducted "unplanned multiple comparisons of means tests". Potentially significant differences among all combinations of pairs of means were tested using the GT2 method described in Sokal and Rohlf (1981).

Multiple regression techniques were also employed. ELF fields and the environmental parameters had been measured at one point in each plot. So we used the plot means of the measured dependent variables and regressed them against the independent environmental and ELF variables. As discussed later in the section on Environmental Parameters. we used principal components analysis to reduce each set of environmental variables to the two largest principal components. These usually accounted for the largest percentage of variance of all the principal components generated. We then used the component scores and either the earth or air fields and the magnetic field measurements as independent variables. The appropriate model is:

$$Y = a + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 + e$$

B = partial regression coefficient

Y = dependent variable

a = Y - intercept

X = independent variables

e = error term

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From this analysis, the proportion of variance explained by the model (R^2) can be examined. Each regression coefficient (B) was tested to examine whether it was significantly different from 0 (T_{sig}). With this information, the environmental data and ELF fields can be examined for significant trends with each measured dependent variable and help interpret the results of significant nested anovas.

Multiple regression analyses were done using a microcomputer version of SYSTAT (Wilkinson 1986). All other analyses used either SPSS or BIOM (Rohlf 1985) on a Sperry 1100 mainframe.

Several water quality parameters were measured. In 1987, water samples were collected from the centrally located well of each plot and analyzed at monthly intervals from May through September. Electromagnetic field intensities were measured once in August, 1987, at each well by IITRI personnel.

We measured pH, specific conductance, depth from peat surface to ground water, and water temperature. Water samples were collected, filtered, and divided into two aliquots for further analysis. One aliquot was refrigerated and later measured for color. Color was measured spectrophotometrically by absorbance at 320nm. The duplicate aliquot was acidified with nitric acid and later analyzed for cation concentration using atomic absorption spectrometry.

The 1987 data for water temperature, pH, depth, color, dissolved Ca, Mg, and K are graphically presented in Figures 7-13. These data represent the means of six wells per bog. One major difference in 1987 compared to past years appears to be the greater fluctuation in water depth (Fig.9). Depth to groundwater increased drastically over the growing season. The summer of 1987 was generally a dry summer in northwestern Wisconsin. Other groundwater parameters are influenced by the hydrologic cycle although they are also affected by decomposition processes in the peat and by the physiological state of the plant community. For instance, color (an indirect measure of dissolved organic matter) increased in all sites during the sampling period; presumably,
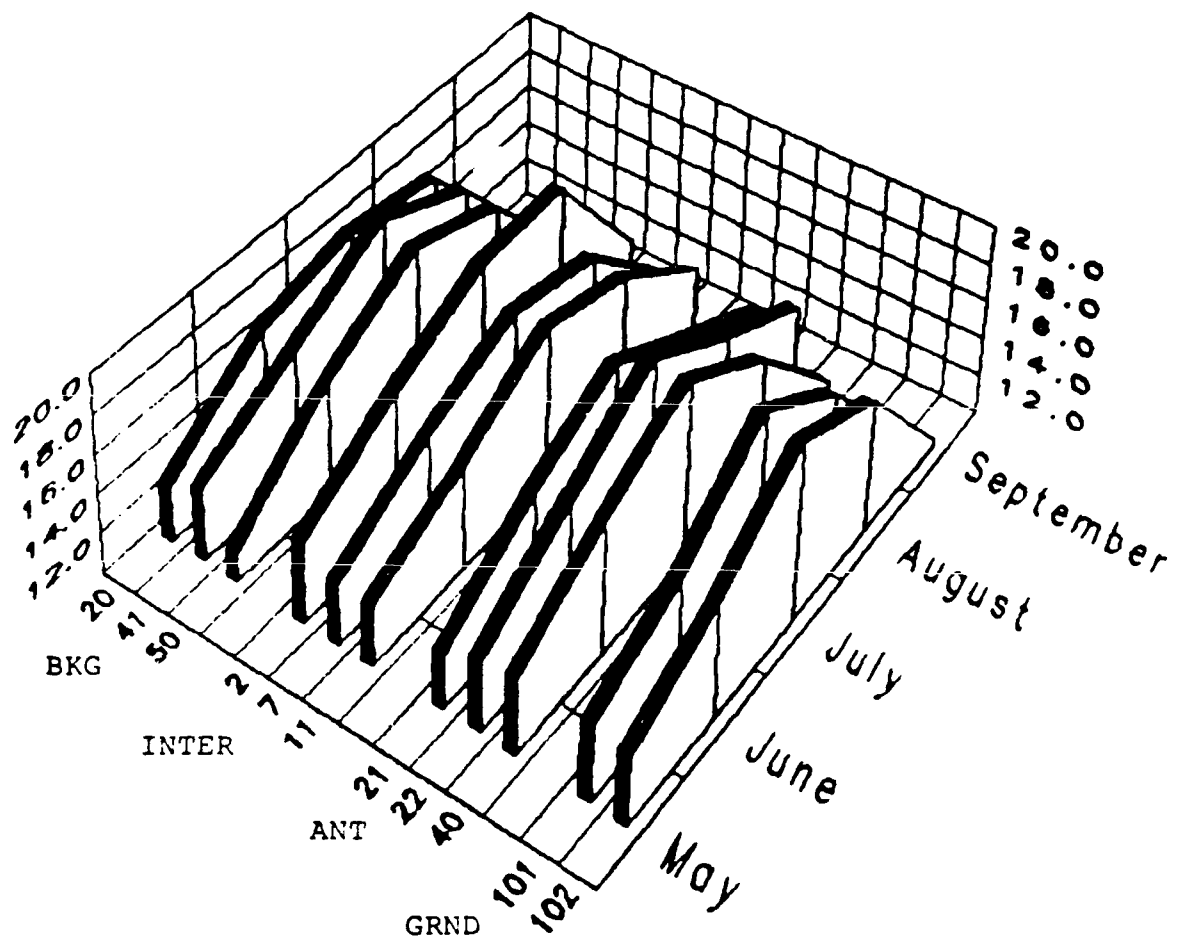
Figure 7. Patterns of groundwater temperature in 1987. Mean temperature, ° C.
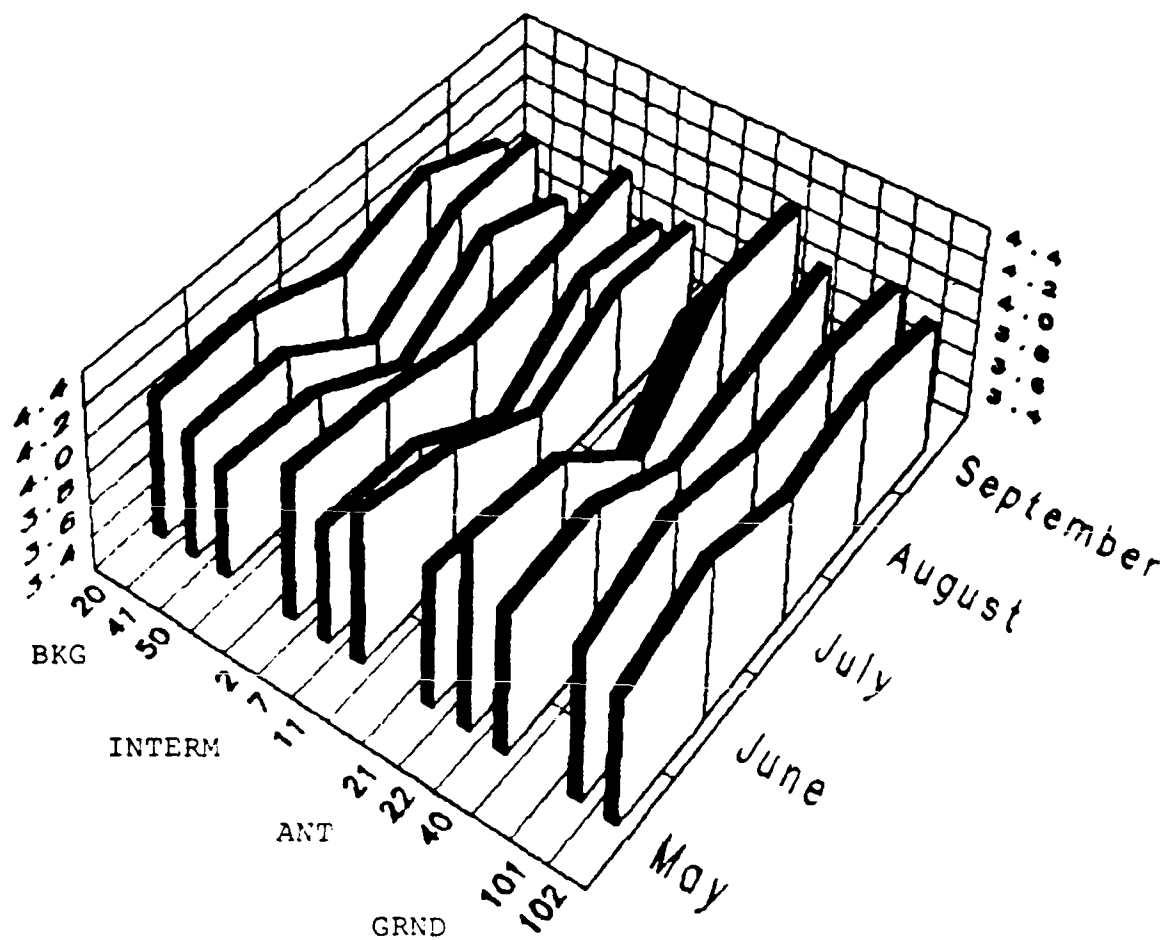
Figure 8. Patterns of groundwater pH in 1987. Mean pH within each transect.
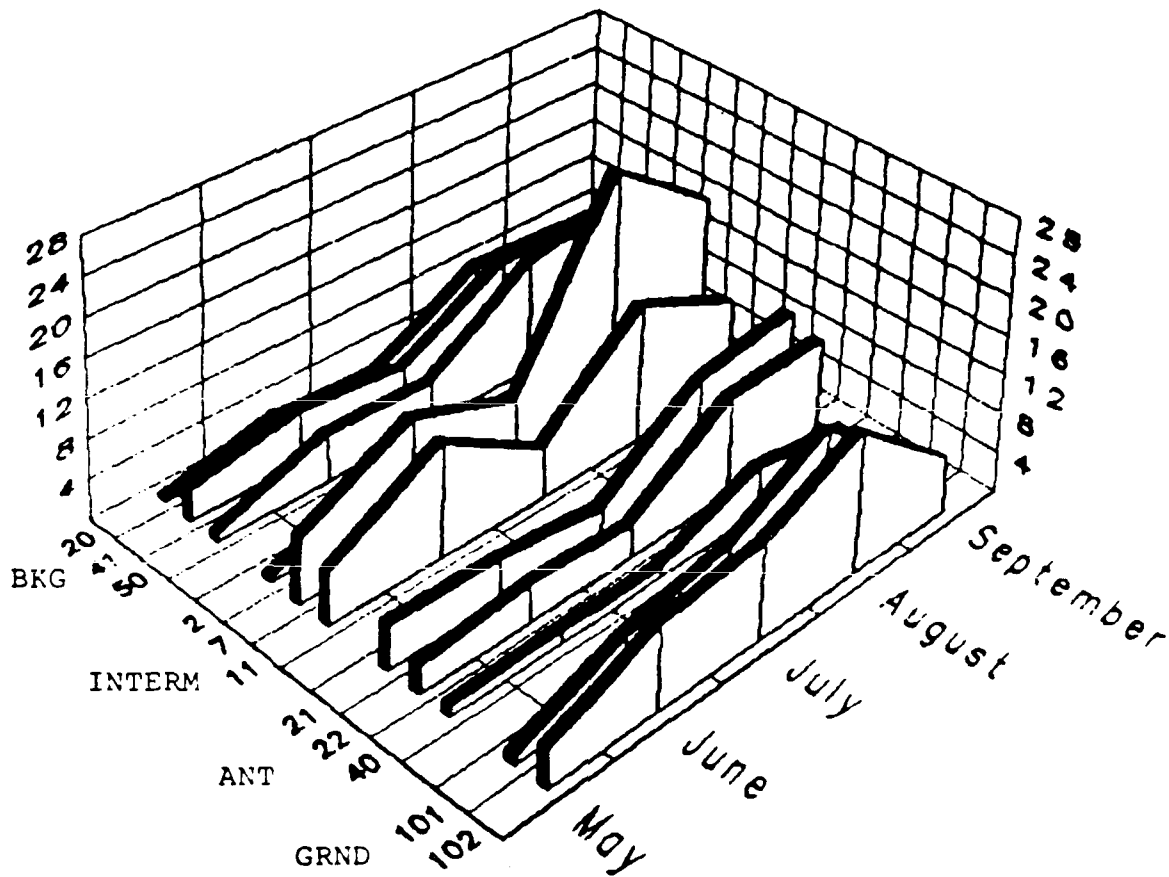
Figure 9. Patterns of groundwater depth below the peat surface, measured in 1987.
Mean depth, cm, within each transect.
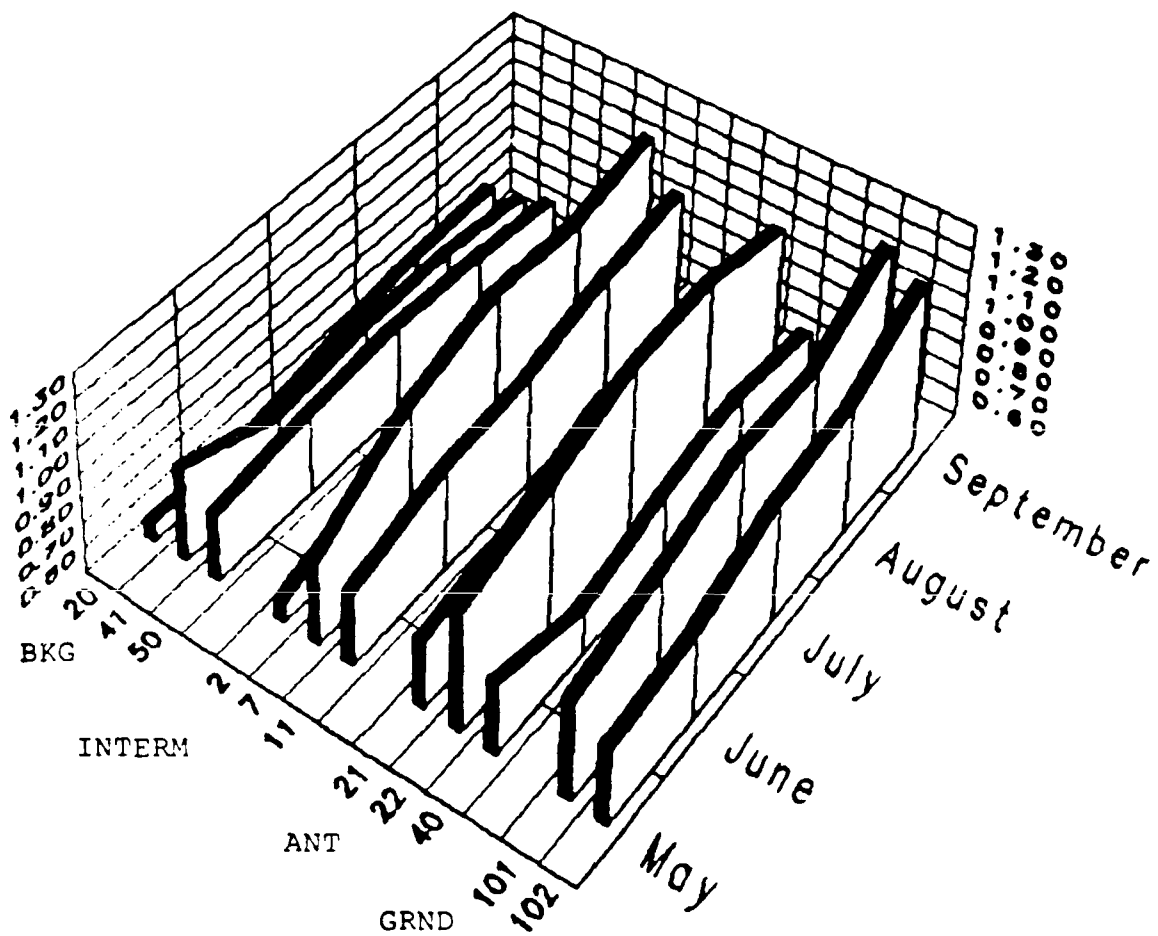
Figure 10. Patterns of groundwater color (Abs. 320 nm)
measured in 1987. Mean color within each
transect.
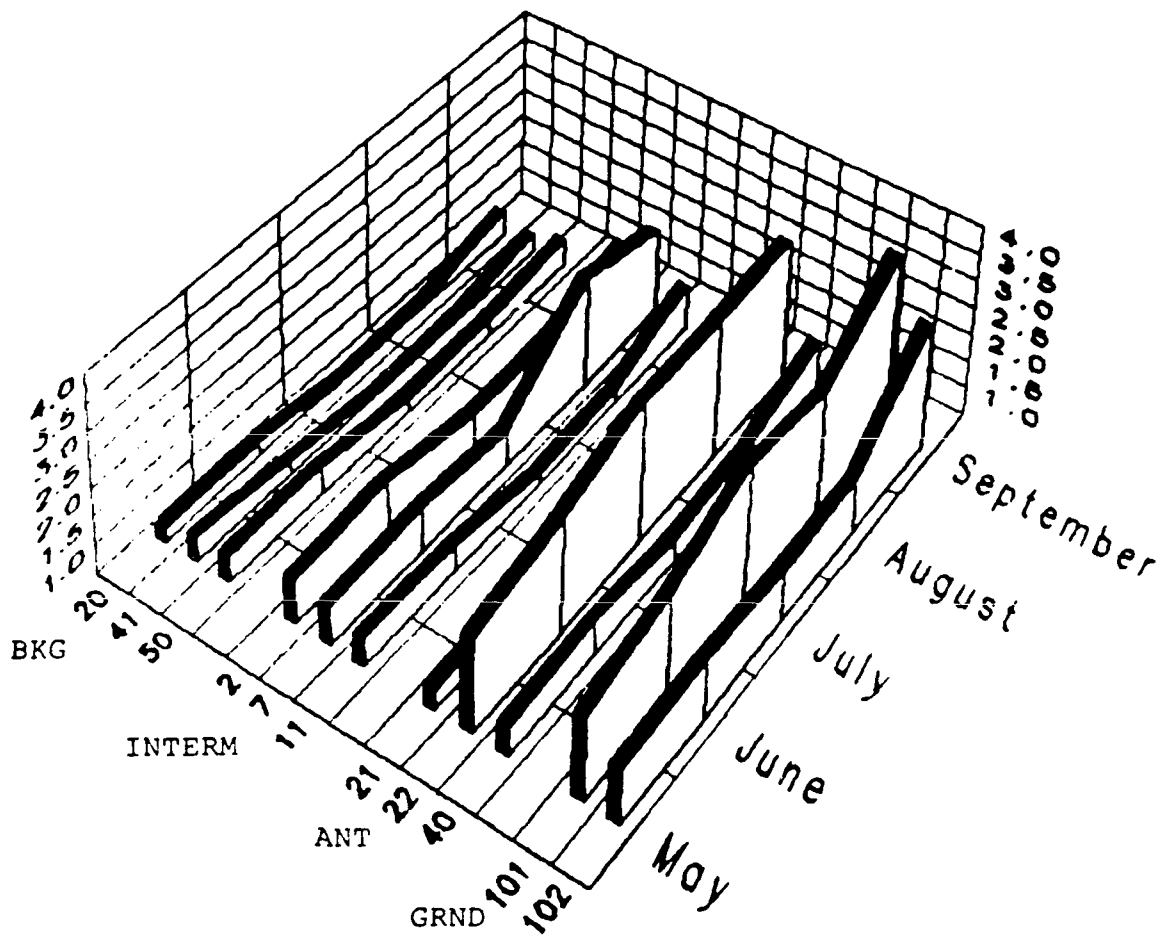
Figure 11. Patterns of groundwater calcium concentration, measured in 1987.
Mean calcium, mg/l, within each transect.
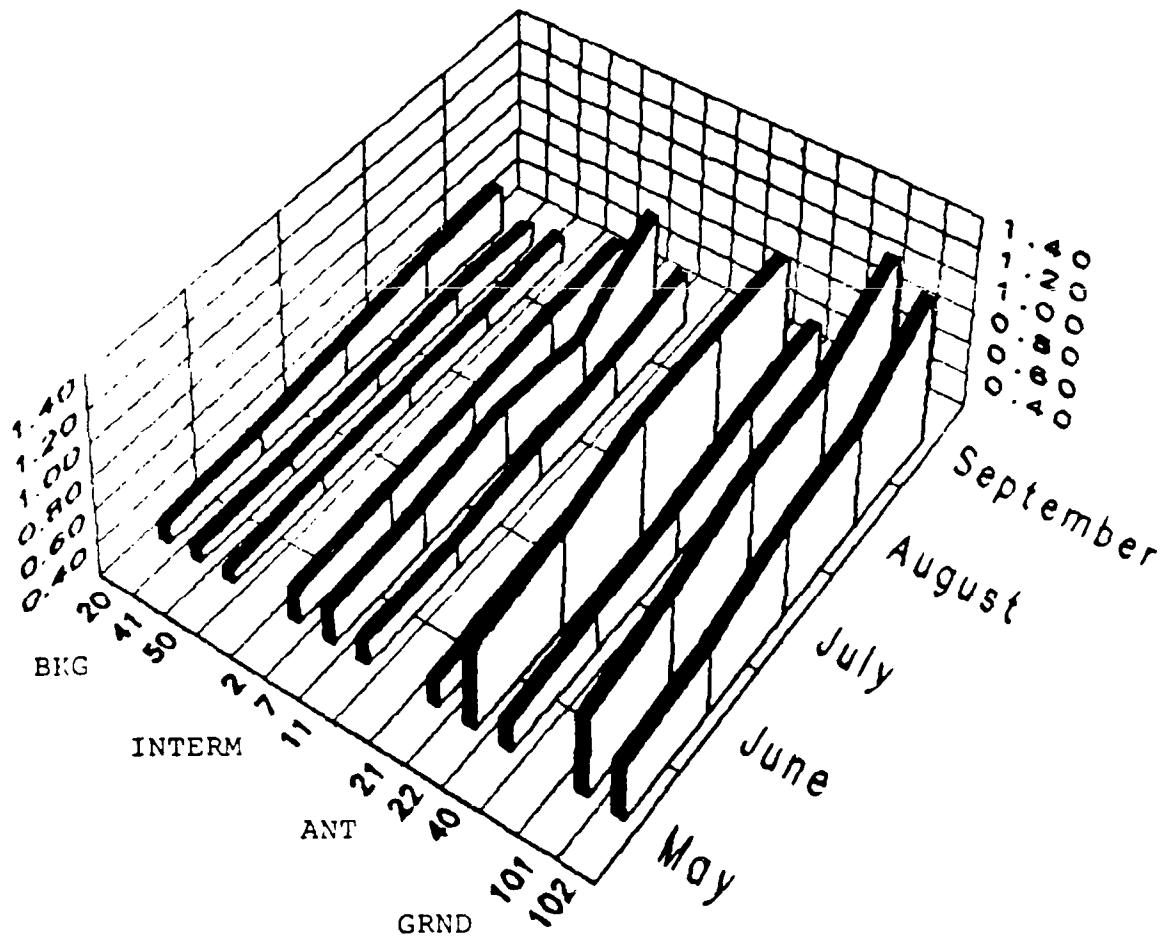
Figure 12. Patterns of groundwater magnesium concentration, measured in 1987.
Mean magnesium, mg/l, within each transect.
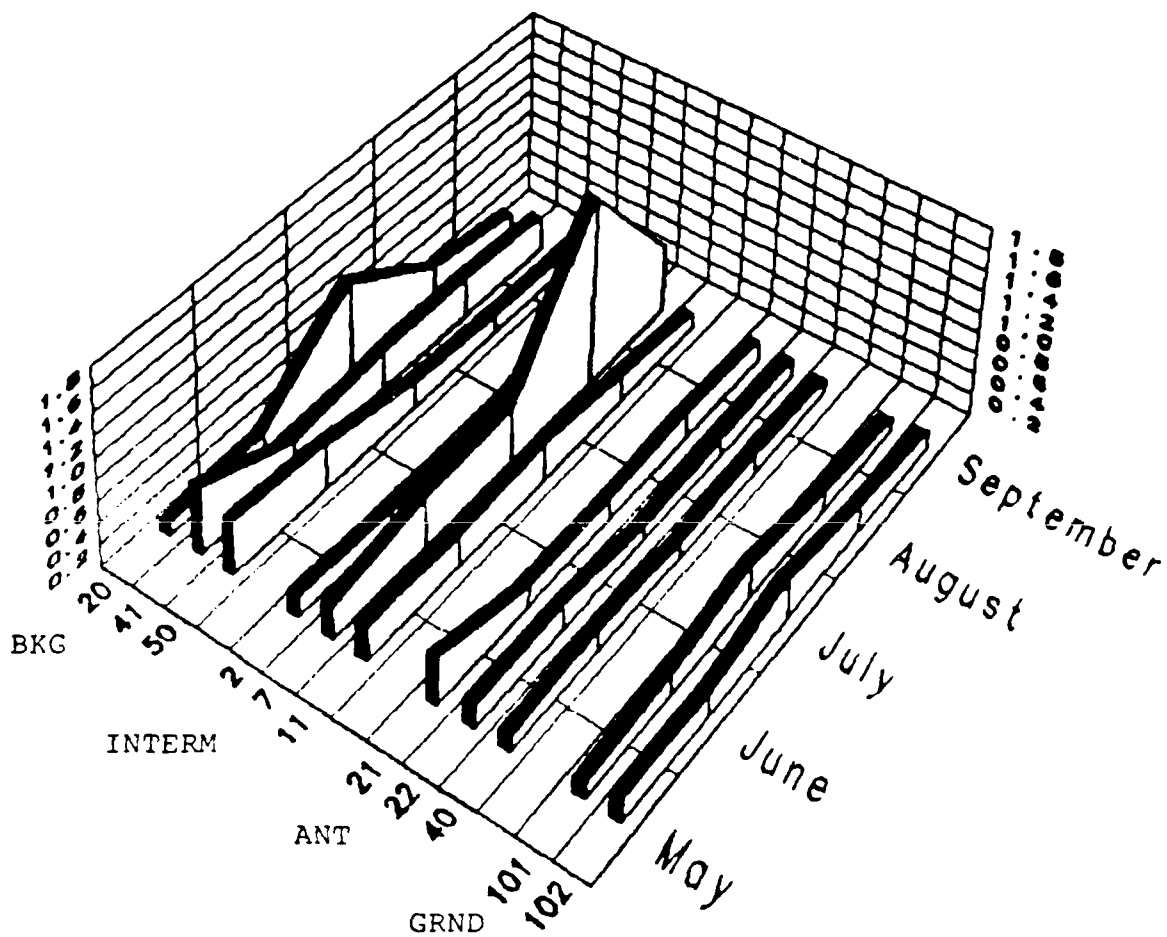
Figure 13.   Patterns of groundwater potassium concentrations,
            measured in 1987.
            Mean potassium, mg/l, within each transect.

suspended organic material was concentrated as the surface groundwater table fell (Fig 10).

All sites exhibited a slight depression in pH during mid summer (Fig 8). Water temperature, however, increased throughout the growing season (Fig 7). Water temperatures decreased late in the growing season due to concurrent seasonal decreases in air temperature. However, some bog-to-bog variation in these trends are evident. For example, Bog 2 (INTERMEDIATE) exhibited a decline in water temperature later than the other bogs.

Dissolved magnesium exhibited increasing concentrations at all sites during the sampling period (Fig 12). Calcium however, showed a somewhat different pattern across the bogs throughout the sampling period (Fig 13). September values were higher in all bogs than the previous month. Potassium concentrations did not exhibit a uniform pattern across the sites (Fig 11). Potassium concentrations peaked in Bog 20 in July and in August for Bog 7 while exhibiting little change over the year in the other nine sites.

In past years, we have found significant correlations between several environmental parameters and thus were restricted to variables that were not autocorrelated in multiple regression models. This year, we used a somewhat different approach for selecting the environmental variables to be used in the multiple regression models with the dependent variables (leaf cation concentration, decomposition rate, stomatal resistance). Principal components analysis was used to examine the relationships among the set of environmental variables. The original measured variables were transformed into a new set of

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uncorrelated variables (principal components). If some of the original variables were correlated then the new set of principal components (which are linear combinations of the original data) could be used to reduce the dimensionality of the data. The principal components were derived so that the first few components explain as much of the variance in the original data set as possible.

Generally, two principal components were chosen that explained a large amount of the variation. As a general rule, we chose principal components whose eigenvalues were greater than one. The variables exhibiting the highest loadings on each of the two principal components usually differed (see Tables 2-4). We used principal components analysis to reduce the dimensionality of the environmental data for the July and August environmental data (to be used with the porometer data) and for the entire May-September data set (to be used with the decomposition data). Principal component scores for each set of components were determined for each of the sixty-six plots in our data set. These scores were then used as independent variables in the multiple regression models.

The principal components chosen had high loadings for related variables. The principal components, however, are independent from one another, permitting us to use all of the environmental data in regression models but avoid problems with collinearity (Johnson 1978, Chatfield and Collins 1980).

The variables that had high loadings on the principal components extracted from the July data were: water color,

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Table 2.   Principal component loadings for environmental (ground water) variables in July , 1987.   * indicates high loading.

Environmental Variable	Components:	Loadings J1	J2
July Temperature		0.181	-0.627
pH		0.142	-0.733*
Water Depth		0.707*	0.239
Specific Conductance		0.236	0.822*
Ca^{--}		0.768*	-0.539
Mg^{--}		0.798*	-0.521
K$^-$		0.017	0.417
Color		0.917*	0.066
Percent of total variance explained		33.60%	30.05%

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Table 3.　Principal component loadings for environmental (ground water) variables in August, 1987.　* indicates high loadings.

Environmental Variable	Components:	Loadings A1	A2
August	Temperature	0.005	-0.280
	pH	-0.401	0.825*
	Water Depth	0.890*	0.146
	Specific Conductance	0.890*	-0.231
	Ca^{++}	0.384	0.836*
	Mg^{++}	-0.072	0.909*
	K^-	0.776	-0.005
	Color	0.621	0.676
Percent of total variance explained		36.07	35.18

Table 4. Principal component loadings for environmental (ground water) variables in 1987 (May, June, July, August, September combined). * indicates high loading.

Environmental Variable	Components:	Loadings 87A	87B
May	Temperature	0.350	-0.229
	pH	0.407	-0.510
	Water Depth	0.144	0.708*
	Specific Conductance	-0.218	0.857*
	Ca--	0.860*	-0.084
	Mg--	0.913*	-0.112
	K-	-0.137	0.267
	Color	0.609	0.298
June	Temperature	0.031	-0.304
	pH	0.636	-0.685
	Water Depth	0.167	0.729*
	Specific Conductance	-0.278	0.877*
	Ca--	0.936*	-0.138
	Mg--	0.953*	-0.168
	k-	-0.038	0.523
	Color	0.729*	0.536
July	Temperature	0.370	-0.273
	pH	0.442	-0.551
	Water Depth	0.462	0.551
	Specific Conductance	-0.157	0.881*
	Ca--	0.933*	-0.144
	Mg--	0.962*	-0.145
	K-	-0.137	0.126
	Color	0.790*	0.490
August	Temperature	-0.157	-0.005
	pH	0.674	-0.520
	Water Depth	0.286	0.855*
	Specific Conductance	-0.048	0.923*
	Ca--	0.845*	0.133
	Mg--	0.920*	-0.209
	K-	0.045	0.562
	Color	0.753*	0.495
September	Temperature	0.077	0.230
	pH	0.659	-0.529
	Water Depth	-0.090	0.836*
	Specific Conductance	0.018	0.679
	Ca--	0.943*	-0.062
	Mg--	0.883*	-0.035
	K-	-0.054	0.363
	Color	0.812*	0.409
Percent of Total Variance Explained		34.06%	25.58%

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calcium, magnesium, and depth (Component J1) and pH and conductance (Component J2). In August, however, depth, conductance, and potassium had high loadings (Component A1) and pH, calcium, and magnesium (Component A2). For each of these two months over 60% of the variance was explained by the first two principal components (Tables 2-3). When all the 1987 environmental data were combined, the first two principal components (87A and 87B) explained 60% of the variation. Principal component 87A had high loadings for Calcium and Magnesium from all months and color values from all months except May. Principal component 87B had high loadings for water depth (all months except July) and conductance (all months except September).

Labrador Tea leaves have been used in the decomposition study since 1984. Although we have seen significant subgroup (BOG) or sub-subgroup (PLOT) effects in past years we have not seen significant treatment (ELF exposure category) effects. In the fall of 1986, we again collected Labrador Tea leaves, brought them back to the laboratory for litter bag preparation, and then placed the nylon mesh litter bags in the field in November.

In 1986, we doubled the number of bags placed in each bog increasing the sample size from 48 to 96 per bog. We calculated that this increase in sample size would allow us to be 80% certain of detecting a 20% difference among sample means at the 0.05 level of significance (Zar 1986). Power analysis revealed that we would need to increase our sample size by an order of magnitude (from 48 to 439 samples per bog) to detect a 10% difference among sample means.

We collected senescent leaves that represented the oldest cohort on the stems of Labrador Tea and which would have entered the litter pool in the fall. It would not be desirable to collect fallen leaves because decomposition begins as soon as leaves fall from the plant. Leaves were air dried at 40 degrees C., and 0.5 g of whole leaves were weighed and placed in 2mm nylon mesh fiberglass bags with a numbered tag. Bags were randomly distributed in 264 groups of 4 bags each and tied together with nylon line.

Four groups of four bags each were placed in hollows in each of the six plots in each bog (Figure 2). We tried to position

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samples to simulate the natural placement of leaves that fall from plants. work their way into the moss layer. and begin to decompose. In the 1985-1986 experiment. the coefficient of variation within a bog averaged 35% but differed greatly between bogs. In 1986. we attempted to refine our choice of microsites in each bog to reduce this variation in weight loss. Bags were collected in November, 1987. after 12 months of incubation. The leaves were removed from the bags. dried to a constant weight. and reweighed to obtain their final weight. Weight loss was. calculated as a proportion of initial weight.

Average weight loss within each bog is presented in Table 5 and Figure 14. Coefficients of variation in 1987 are nearly one half of those in 1986 (16% vs 35%) and are more consistent among sites. Bag positions were checked each time we visited a bog during 1987. and the bags were repositioned if moved by wind. animals. human activity. For instance. bags seemed to attract deer that occasionally tore open or moved bags away from the hollows. However. only four bags were lost due to animal activity.

Based on the results of a nested analysis of variance (Table 6) we concluded that there were ELF and plot effects but no bog effects. Results of an "unplanned multiple comparison of means test" indicated that the ANTENNA treatment had a greater decomposition rate than the other three treatments and that decomposition rates in the BACKGROUND treatment exceeded those in the GROUND treatment.

We also examined the percentage of variation attributable to the different levels of nesting (Table 6). Less than 10% of the

Table 5. Mean proportions of weight loss by Labrador Tea leaves over 12 months (Oct. 1986 - 1987). N = 96 / transect.

Bog	ELF Type	Proportion Weight Lost (Mean +/- 1 S.E.)	
20	Background	0.292	+/- 0.006
41	Background	0.288	+/- 0.006
50	Background	0.287	+/- 0.004
2	Intermediate	0.275	+/- 0.004
7	Intermediate	0.273	+/- 0.005
11	Intermediate	0.285	+/- 0.004
21	Antenna	0.303	+/- 0.006
22	Antenna	0.318	+/- 0.005
40	Antenna	0.300	+/- 0.006
101	Ground	0.273	+/- 0.004
102	Ground	0.269	+/- 0.004

Table 6.   Results of a three level nested analysis of variance for weight loss by decomposing Labrador Tea leaves in 1987.

Source	SS	df	F	Sign.
Treatment (E.L.F. level)	0.1905	3	15.54	P < .05
Bog	0.0286	7	0.75	NS
Plot	0.3014	55	2.72	P < .05
Error	1.9978	990		

Variance Components   (percent of total)

Bog within Treatment	0.4%
Plot within Bog	9.7
Error	89.8

Decomposition of Labrador Tea Leaves, 1987
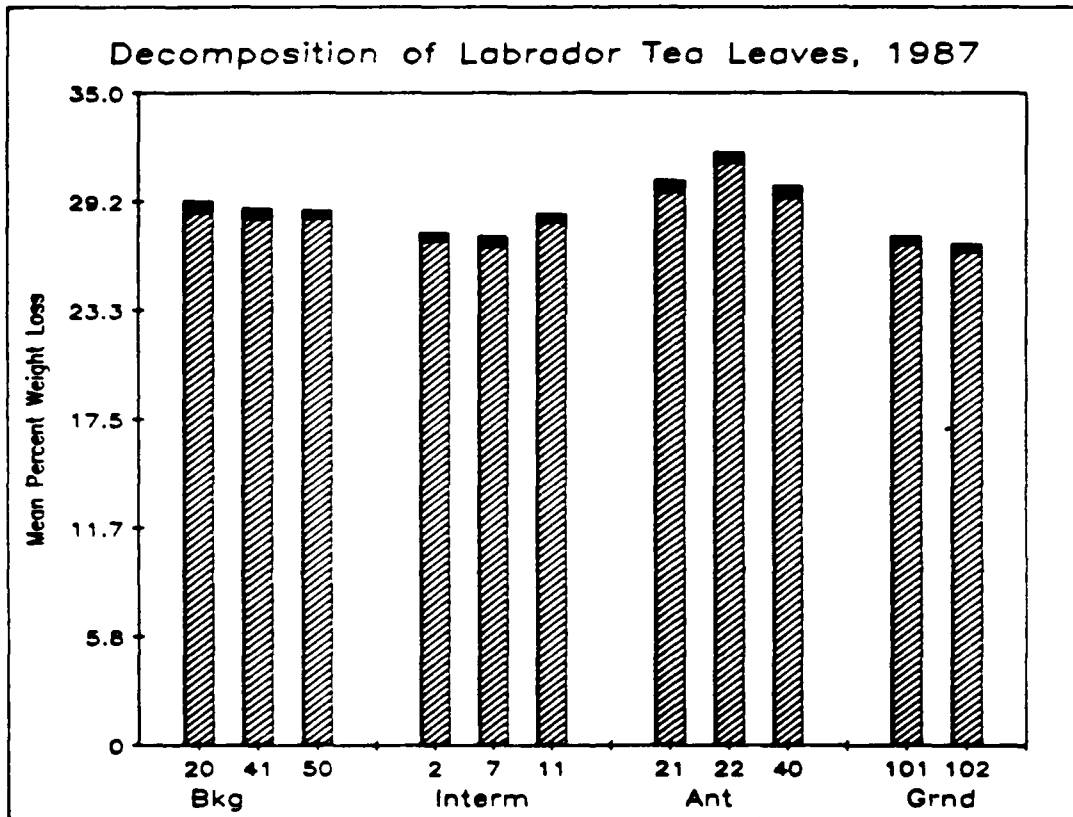
Figure 14.   Decomposition rate of Labrador Tea leaves over
              12 months, Oct. 1986 – Oct. 1987. Tops of the
              bars represent mean percent weight loss. The
              black zone below the top of each bar represents
              1 S.E.

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variation in weight loss could be attributed to 'bog within ELF treatment' or 'plot within bog' effects. However. 80% of the variation is found at the level of the individual replicates. To examine this phenomena. we looked at other data we collected when the litter bags were harvested.

Previous experience had shown that the mosses grew unevenly over the litter bags. Therefore, as in 1986, we quantified the amount of moss cover over each bag using a five point rating system:

    0 - bags lying in standing water

    1 - bags completely covered and under growing moss

    2 - greater than 50% cover by mosses

    3 - less than 50% cover by mosses

    4 - completely uncovered lying on top of the mosses.

The results are summarized in Figure 15. Only 4 out of 1052 bags were in category 0. This category was dropped in subsequent analyses.

We developed a 4 x 4 contingency table and analyzed the data to determine whether the microenvironment experienced by the decomposition sets was independent of ELF exposure type. We found that the microenvironment (expressed as percentage moss cover) was not independent of ELF exposure type (x^2 = 136.33. 9 df. P < 0.05). For instance, 39% of the ANTENNA bags were completely covered by mosses but only 22 and 23% of the INTERMEDIATE and BACKGROUND were covered. Also, 34% of the BACKGROUND bags were uncovered (0% moss cover but only 5% of the Ground bags were. It seems likely that the microenvironment around the decomposition
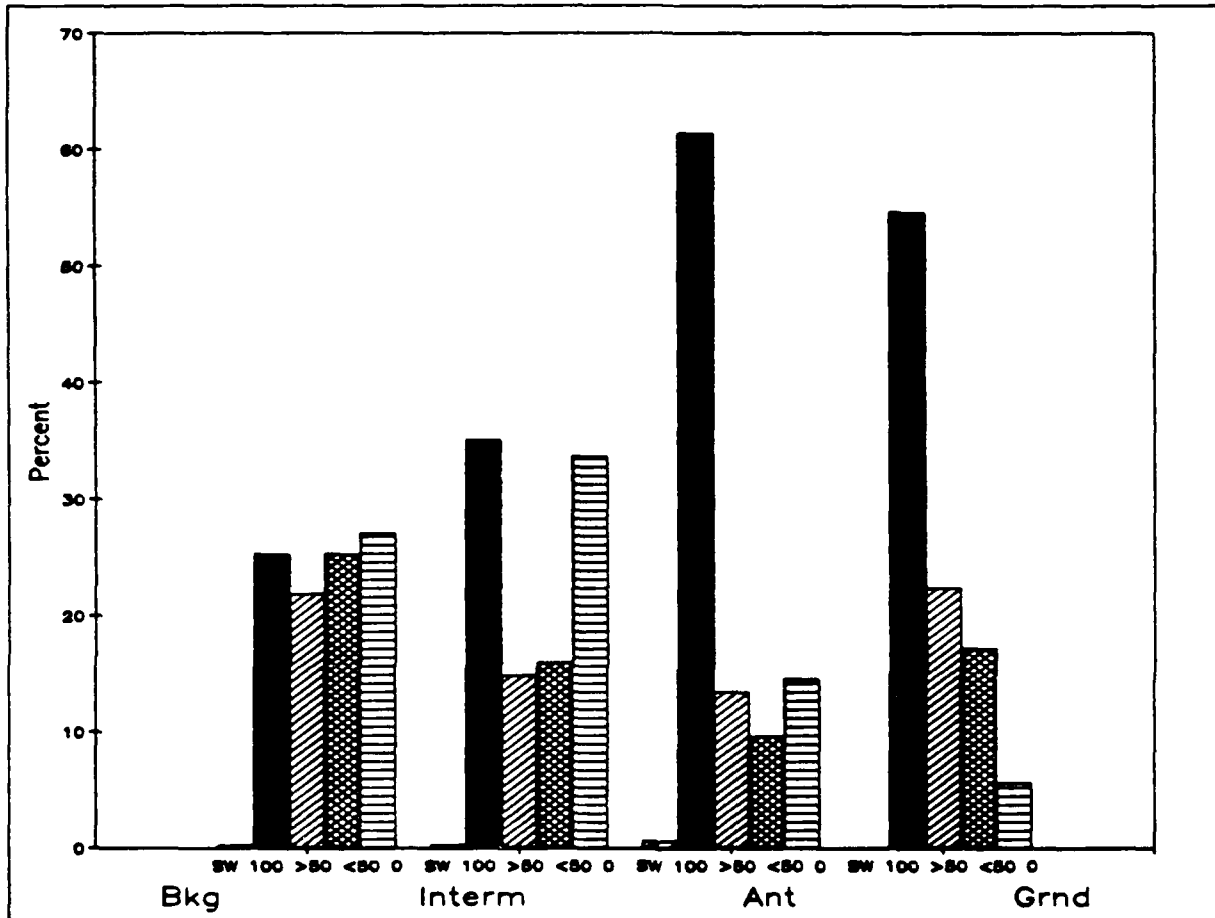
Figure 15. Distribution of placement classes of litter bags
within each ELF treatment type (percent of all bags
within each type). SW = covered by standing
water; moss cover classes = 100%, <50%, >50%, 0%.

bags may have affected weight loss. Since the pattern of microenvironments for litter bags was not the same among treatment groups, this seems related to the significant ELF effects found in the nested analysis of variance.

Nested ANOVA uses the classification assigned to each bog (Background, Antenna, Intermediate, and Ground) as fixed effects in the model. In order to make use of ELF fields as a metric variable and also to use the environmental parameters, we used of multiple regression models. The purpose was to determine the relationship between selected independent variables and the dependent variables of interest.

Two environmental principal components (87A and 87B), earth field, and magnetic field were used as independent variables in multiple regression. The slopes of the relationships between decomposition weight loss and both earth and magnetic field (regression coefficients) were found to be significantly different from zero (Table 7). However, the multiple regression model only explained 32.6% of the variance in the data. However, the standardized partial regression coefficients indicate that the earth and magnetic fields are relatively more important than the environmental factors in this model (Fig 16-17).

The nested analysis of variance model detected significant group effects (ELF exposure types). However, an analysis of the distribution of microenvironmental categories experienced by the decomposition samples indicated that the distribution of decomposition bags in the ELF exposure categories was not independent of the microenvironment. The ANTENNA sites had the

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Table 7.   Results of multiple regression analysis for decomposition rate by Labrador Tea leaves with environmental variables (Components 87A and 87B) and E. L. F. variables (magnetic field and earth electric field).   Decomposition rate is proportion of weight loss over 12 months, between Oct. 1986 - October 1987. $N = 66$, B = regression coefficient, T tests B = 0.

Dependent Variable	Independent Variable	B	T	Sign. T.	Std. B
Decomposition Rate	Constant	0.335			
	87A	0.004	1.290	0.202	0.138
	87B	-0.003	-1.318	0.193	-0.126
	Log Earth Field	-0.012	-4.259	0.0001*	-1.065
	Log Magnetic Field	0.010	5.111	0.0001*	1.139

$R^2 = 0.326$

* = $P < 0.05$

Analysis of Variance

Source	SS	df	MS	F	P
Regression	0.010	4	0.003	7.163	<.05
Residual	0.022	61	0.00042		
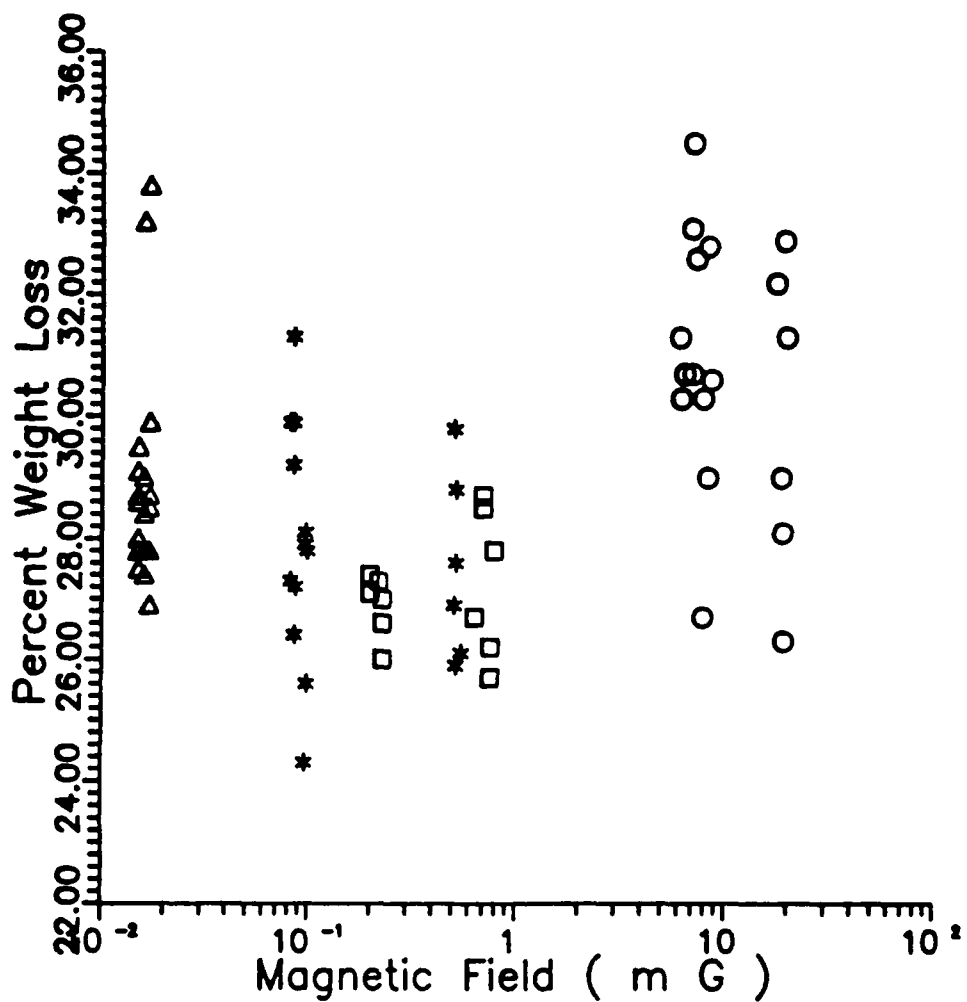
Figure 16. Relationship between percent weight loss
by Labrador Tea leaves and magnetic field.
Triangles = BKG sites, * = INTERM sites,
circles = ANT sites, squares = GRND sites.
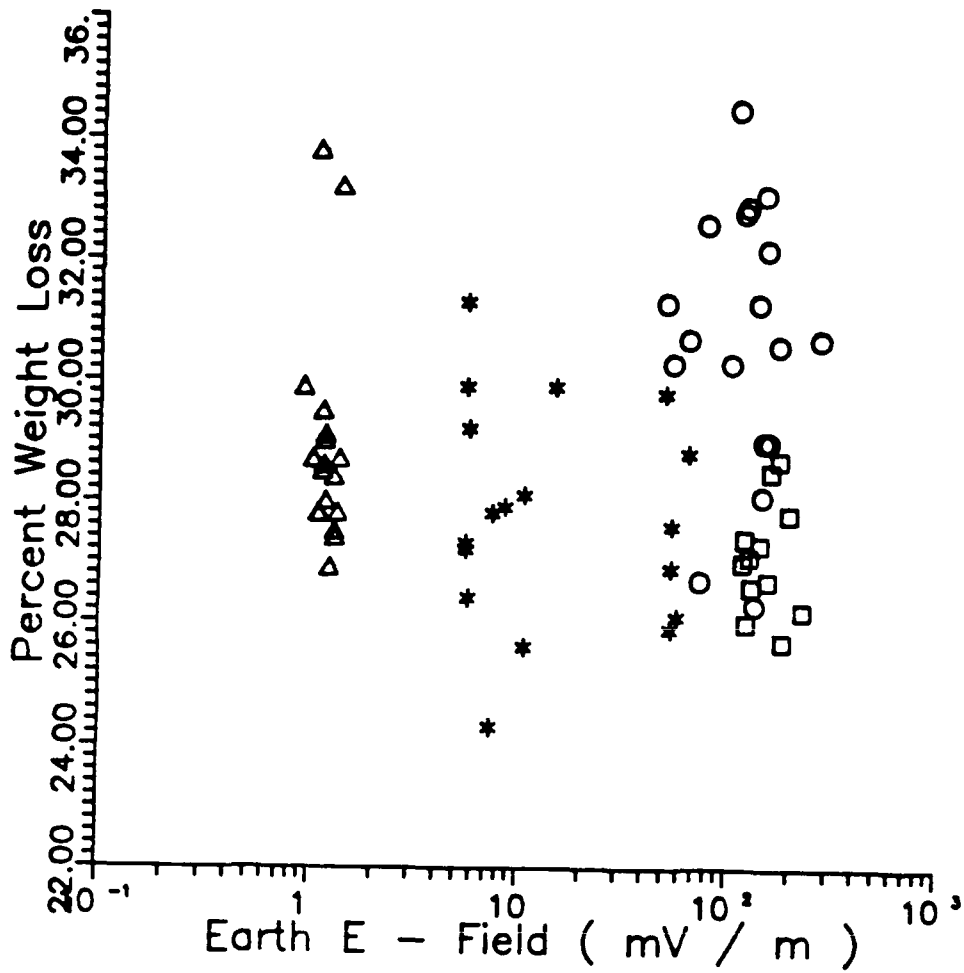
Figure 17. Relationship between percent weight loss by
Labrador Tea leaves and electric field in earth.
Triangles = BKG sites, * = INTERM sites,
circles = ANT sites, squares = GRND sites.

highest frequency of bags covered by mosses. It also had a greater weight loss than the other ELF exposure types indicating that increased moss cover may have been the cause of increased decomposition. The multiple regression model indicates that only 32% of the variation in weight loss is explained by the environment and electromagnetic fields. It is possible that the significant results found this year in this work element are the result of microenvironmental differences associated with bag placement and the growth of mosses over the bags. We plan to explore this data set more extensively for the final summary report.

DIFFUSION RESISTANCE

Stomatal resistance has been examined as a correlate of the physiological status of wetland plants exposed to ELF electromagnetic fields from the Wisconsin Test Facility. Because electromagnetic fields have been hypothesized to operate at the membrane level, it is possible that they may affect the regulation of stomatal opening or closing either directly or indirectly.

Initial analyses using nested ANOVA models in 1986 detected significant differences between levels of electromagnetic exposure. Significant differences were found between the ANTENNA and BACKGROUND exposure types for the July, 1986 measurements. However, use of the same experimental protocol in August, 1986 demonstrated no significant differences between exposure types.

We examined the WTF log to determine the operational status of the antenna (on, off, multiple on and offs during the day, or just partial operation during the day) during the time period we measured in July and August. The WTF antenna was on continuously during the days we measured stomatal resistance in July. However, the antenna was turned on and off several times on a number of days immediately prior to the start of our July measurements. There is some indication, from laboratory experiments, that the multiple on-off episodes have been associated with biological responses. We did not see the same pattern in August, 1986, but it may have been associated with the fact that the WTF antenna was off during part of that measurement period. This was a complication in the experimental design. Thus, the results of

the 1986 measurements were inconsistent. In 1987, we repeated the measurements in July and August. In addition, the sample size was increased from 30 to 60 leaf measurements per bog. We estimated that the increase in sample size would allow us to detect 20% differences in means at the 0.05 level of significance with an 80% probability. However, there is a trade-off between increasing sample size and extending the measurement period. The greater the number of measurements made in each bog, the greater the probability of encountering rain or changing cloud cover and/or variation in temperature, humidity, or irradiance. A sample size of 60 individuals per bog allowed us to complete our measurements in each bog within a reasonably short time (approximately 1 hour) and be able to detect reasonable differences between means.

Because of the large amount of variation attributable among stomatal resistance measurements (60% in 1986), we tried to be more careful in choosing uniform plants and leaves. Labrador Tea leaves were measured while attached to the twig. As in 1986, we measured only fully expanded current-year leaves, because second-year leaves senesce during the summer and are not physiologically uniform. We closely monitored sunlight and took readings only when sunlight levels were above 400 microeinsteins m^{-2} sec^{-1}. Measurements of stomatal resistance (including leaf temperature, air temperature, and a ambient light intensity taken at the same time leaf stomatal resistance was measured) were recorded in each of the eleven transects during July and August. Mean monthly diffusion resistance values for Labrador Tea leaves in each month are presented in Figures 18 and 19.

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We analyzed data sets for each month using nested analysis of variance model (Table 8). Significant (p<.05) differences between types of ELF exposure were identified for July but not for August. Results of an "unplanned multiple comparisons of means" indicated that the INTERMEDIATE exposure category differed from the other three exposure types and that BACKGROUND differed from the GROUND exposure type. We also examined the variation attributable to the nesting levels in the model (Table 8). A high percentage of variation are attributable to replicate readings in July.

In contrast to July, but similiar to the pattern found in 1986, no significant exposure effects were detected in August, 1987. However, there were significant bog and plot effects. We again examined the percentage of variation attributable to the various sub-groups in our model. There was a one third reduction in the variation attributable to replicate readings and increased amounts of variation attributable to electromagnetic field exposure and bogs. This indicates we were more successful in choosing similar plants than in the past. The amount of variation between plots is small in the 1987 data set.

We also examined the WTF logs in 1987. During the July measurement period, there were brief periods of multiple on/off switching occurring during the measurement of some of the sites as in 1986. There was also one day when the antenna was turned off in the afternoon while we were measuring stomatal resistance. In August, the antenna was on at all times we were taking measurements.

Table 8. Results of a three level nested analysis of variance for stomatal resistance in Labrador Tea in 1987.

Source	SS	df	F	Sign.
JULY				
Treatment (E.L.F. level)	11.99	3	7.41	P < .05
Bog	3.78	7	1.68	NS
Plot	17.69	55	4.18	P < .05
Error	45.61	594		
AUGUST				
Treatment (E.L.F. level)	80.06	3	3.14	NS
Bog	59.42	7	19.40	P < .05
Plot	24.07	55	2.45	P < .05
Error	106.07	594		

Variance Components (percent of total)

	July	August
Bog within Treatment	3.5	39.6
Plot within Bog	23.3	7.6
Error	73.2	52.7
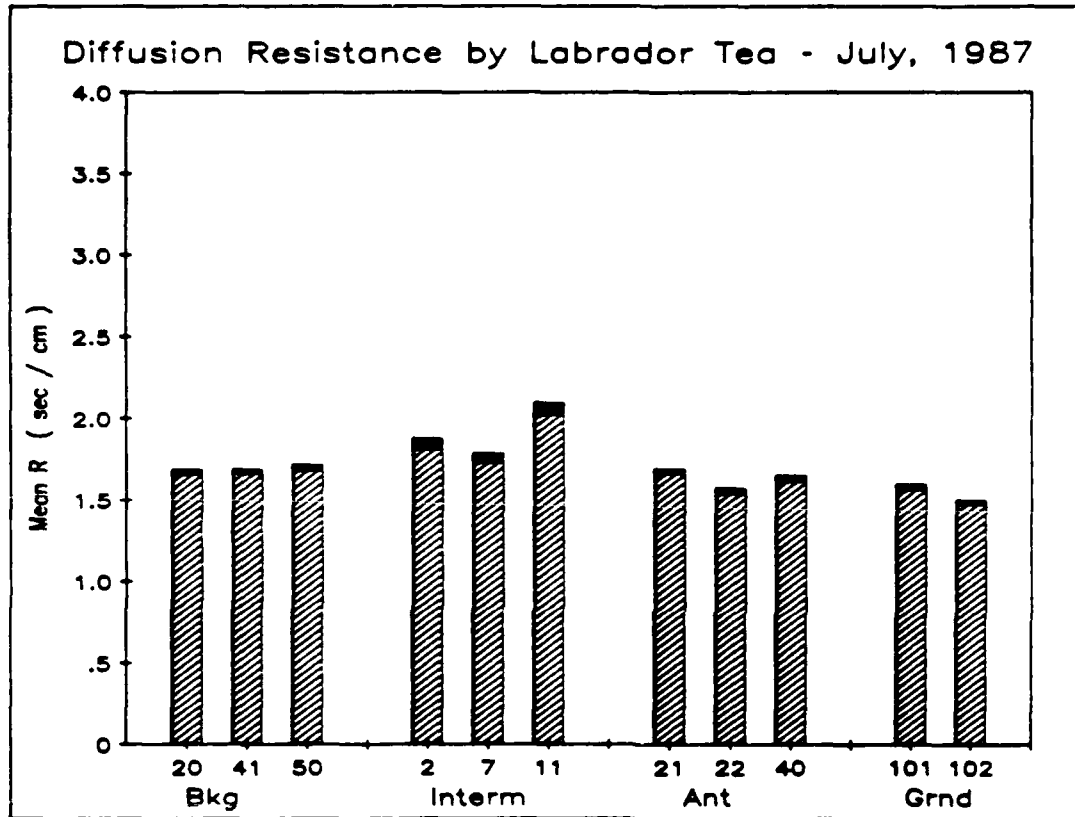
Figure 18.   Diffusion resistance by Labrador Tea leaves,
              measured in July, 1987. Tops of the bars represent
              mean R.   The black zone below the top of each bar
              represents 1 S.E.

Diffusion Resistance by Labrador Tea – August, 1987
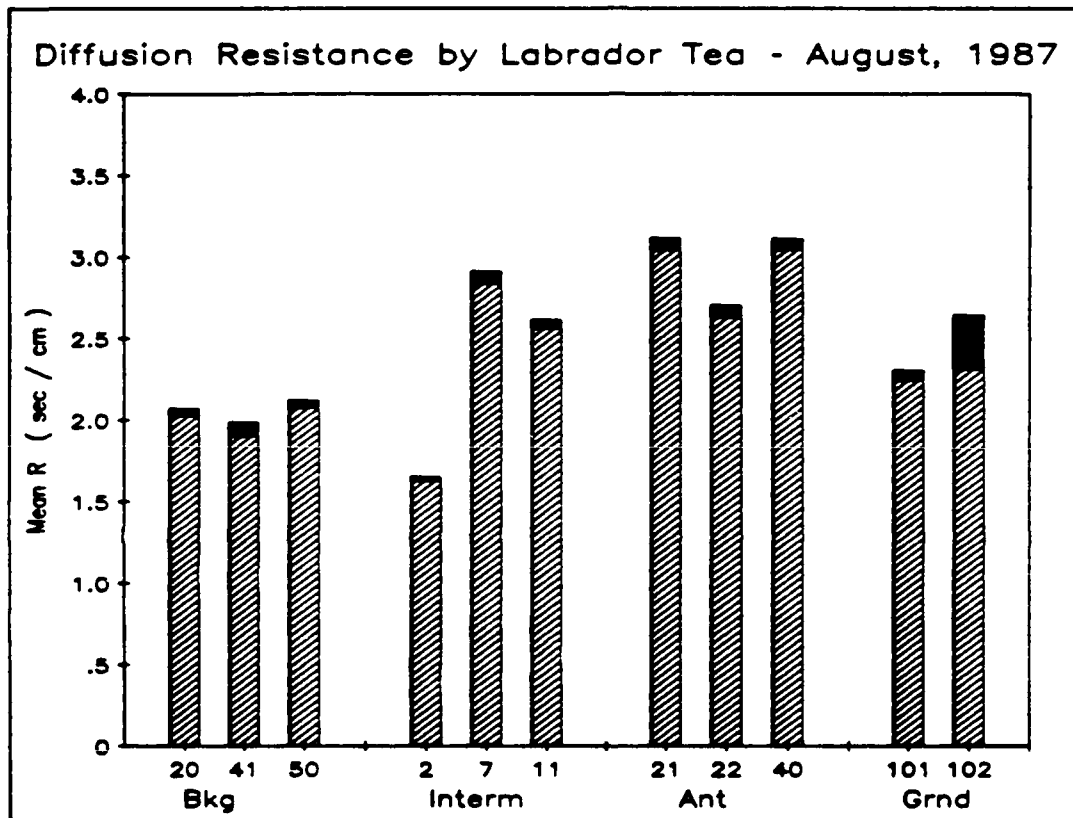
Figure 19. Diffusion resistance by Labrador Tea leaves
measured in August, 1987. Tops of the bars represent
mean R. The black zone below the top of each
bar represents 1 S.E.

We also used multiple regression models to examine the July and August data. The results of the multiple regression using two environmental principal components (J1 and J2), air field, and magnetic field as independent variables and the stomatal resistance measurements for July as the independent variable are presented in Table 9. The slopes of the environmental component J1 was found to be significantly different from zero. The multiple regression model was significant but explained only 14.5 percent of the variance in this data set.

The results of the multiple regressions using the August porometer data are presented in Table 10 and Figures 20-22. The regression coefficients for the environmental component A1 and the magnetic field were significantly different from zero. The multiple regression model was significant and explained 53% of the variance in the data set. The standardized partial regression coefficients indicate that the magnetic field was relatively more important than A1 or the earth field in determining the value of stomatal resistance.

The results of the 1987 analyses are contradictory. Similar to the data from July 1986, the July 1987 results are significant but the differences between the exposure types were not the same in 1986 and 1987. In 1986, the antenna sites were lower than all others. In 1987 the intermediate sites were higher than the others. In addition, the multiple regression model explained only 14.5% of the variation and neither of the ELF electromagnetic fields included in the model had significant regression coefficients.

The August 1987 analysis was not complicated by interruptions

Table 9.   Results of multiple regression analysis for
stomatal diffusion resistance with environmental variables
(Components J1 and J2) and E. L. F. variables (magnetic
field and earth electric field) in July, 1987.   N = 66. B =
regression coefficient.   T tests B = 0.

Dependent Variable	Independent Variable	B	T	Sign. T.	Std. B
Diffusion Resistance	Constant	1.579			
	J1	-0.072	-2.317	0.024*	-0.319
	J2	0.063	1.990	0.051	0.277
	Log Air Field	0.035	1.089	0.280	0.316
	Log Magnetic Field	-0.027	-1.151	0.254	-0.297

R^2 = 0.145

*   = P < 0.05

Analysis of Variance

Source	SS	df	MS	F	P
Regression	0.484	4	0.121	2.581	<.05
Residual	2.861	61	0.047		

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Table 10.   Results of multiple regression analysis for stomatal diffusion resistance with environmental variables (Components A1 and A2) and ELF parameters (magnetic field and earth electric field) in August, 1987.   N = 66, B = regression coefficient, T tests B = 0.

Dependent Variable	Independent Variable	B	T	Sign. T.	Std. B
Diffusion	Constant	3.032			
Resistance	A1	0.198	4.343	0.0001*	0.394
	A2	-0.012	-0.207	0.836	-0.023
	Log Earth Field	-0.112	-2.292	0.025*	-0.456
	Log Magnetic Field	0.216	5.980	0.0001*	1.077

$R^2 = 0.530$

* = $P < 0.05$

Analysis of Variance

Source	SS	df	MS	F	P
Regression	8.665	4	2.166	17.182	<.05
Residual	7.690	61	0.126		
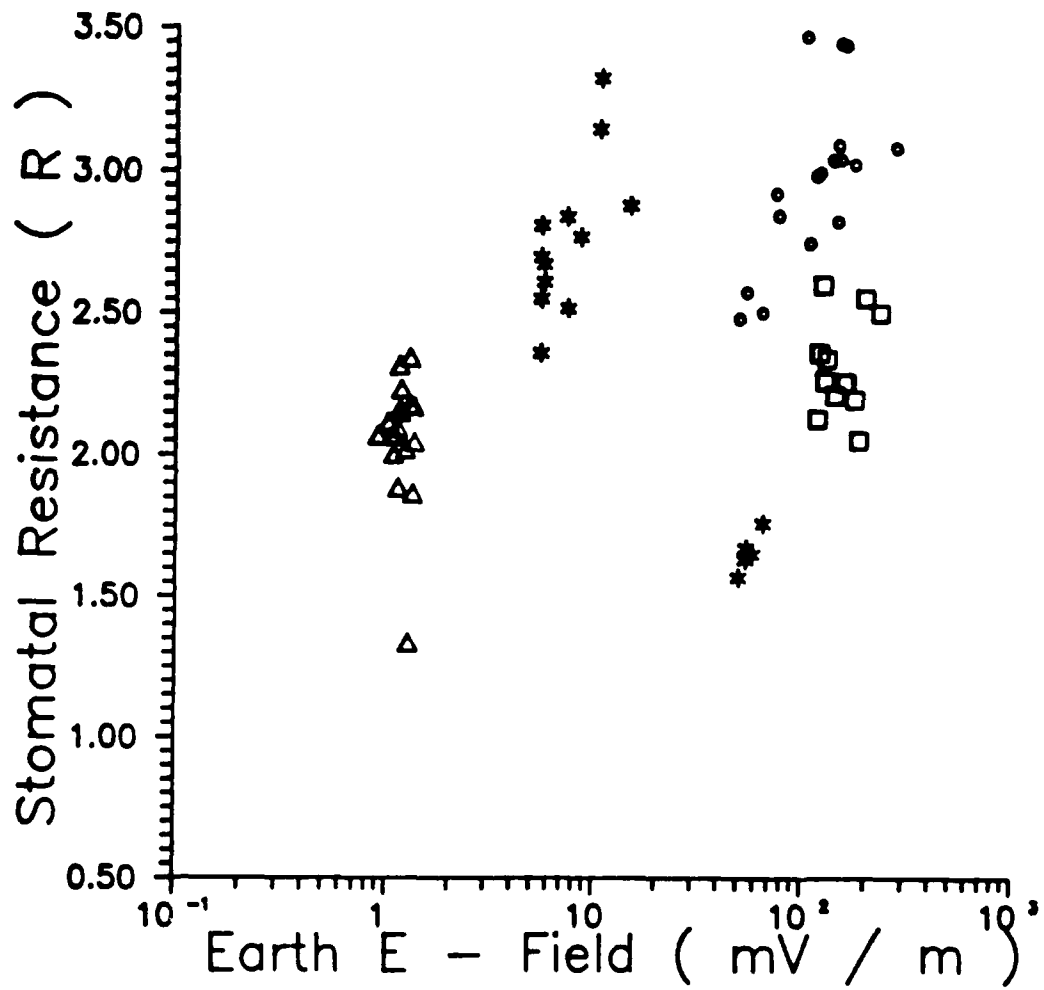
Figure 20. Relationship between Diffusion Resistance
by Labrador Tea leaves measured in August,
1987 and electric field in earth.
Triangles = BKG sites, * = INTERM sites,
circles = ANT sites, squares = GRND sites.
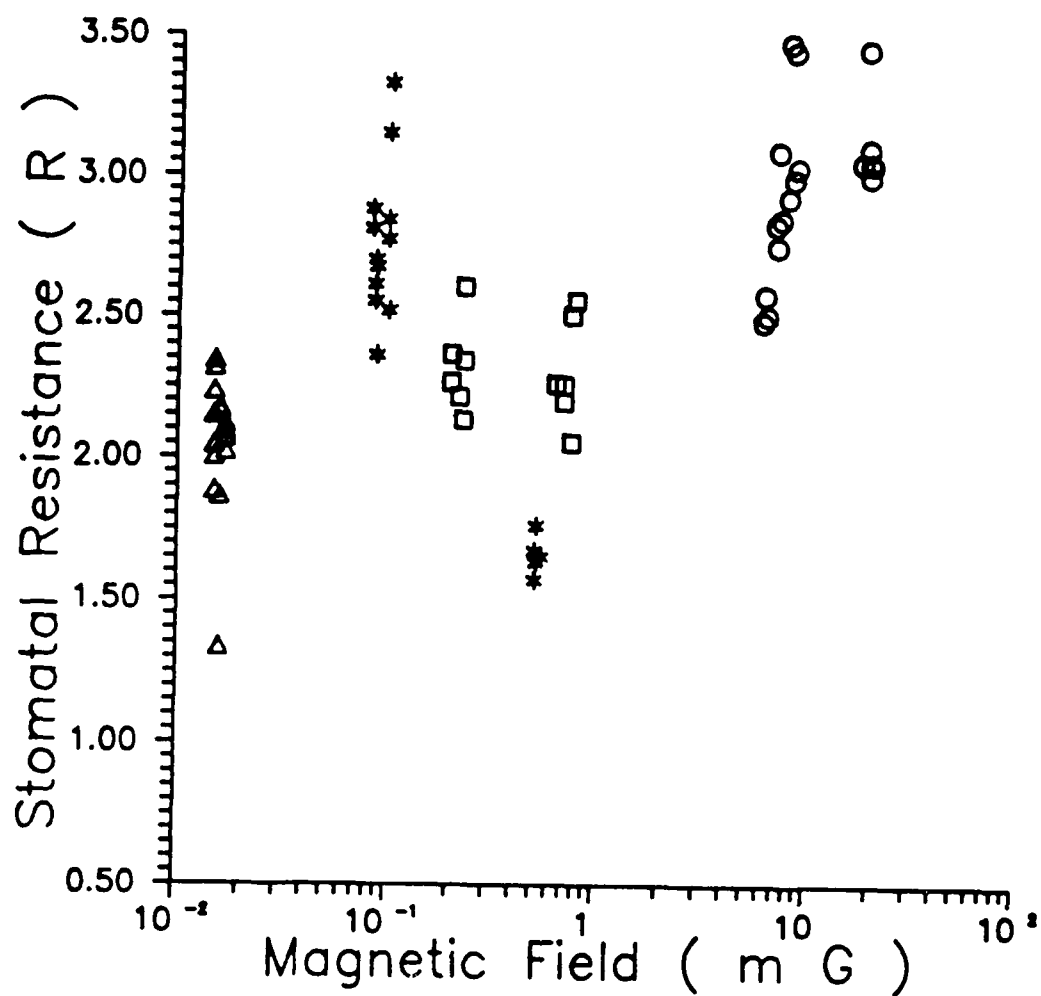
Figure 21. Relationship between Diffusion Resistance by Labrador Tea leaves, measured in August, 1987 and magnetic field.
Triangles = BKG sites, * = INTERM sites, circles = ANT sites, squares = GRND sites.
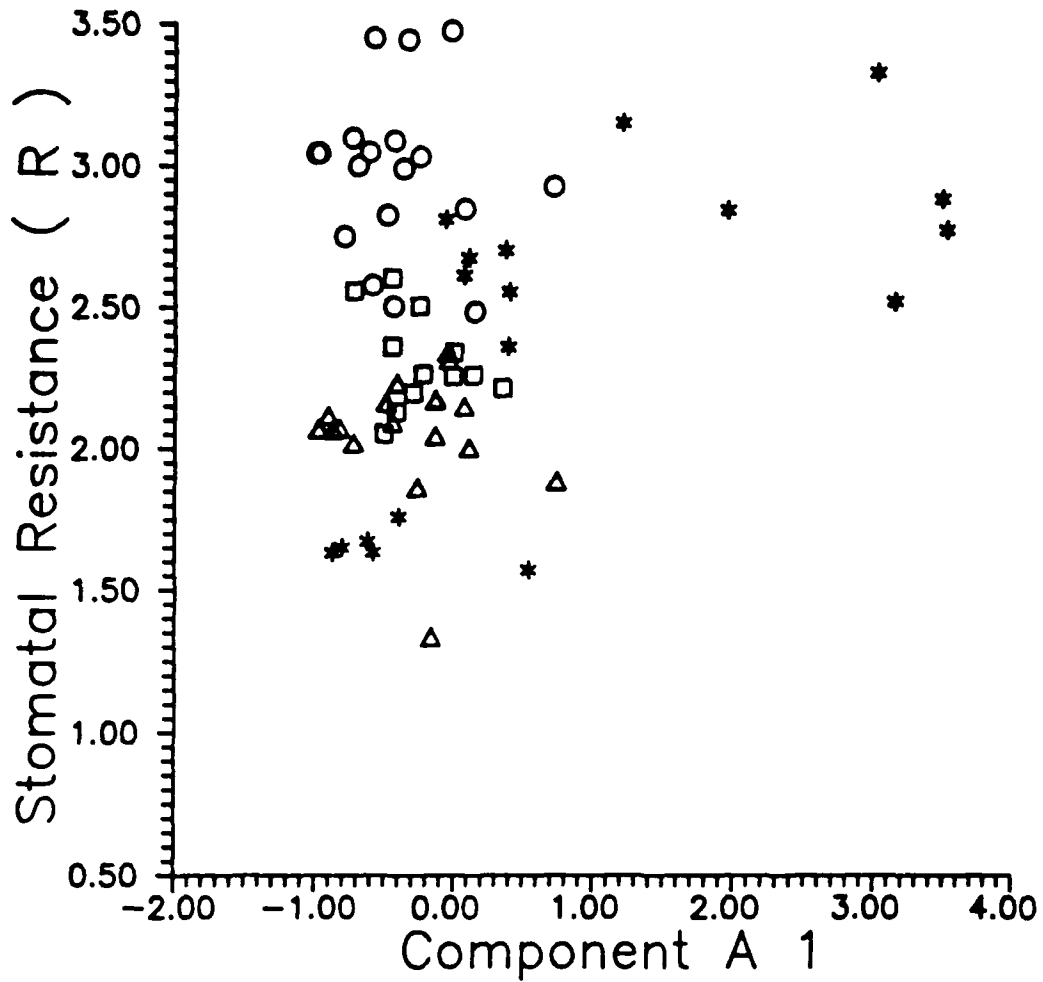
Figure 22. Relationship between Diffusion Resistance by
Labrador Tea leaves, measured in August, 1987
and Principal Component A1.
Triangles = BKG sites, * = INTERM sites,
circles = ANT sites, squares = GRND sites.

in the antenna operation. However. as with the August 1986 data. no significant group effects were detected. The multiple regression model did explain 53% of the variation present.

LEAF CATION CONTENT

Mineral nutrients play important roles in plant physiology and are active constituents of a number of important biochemical reactions. Peatland plants exist in a relatively nutrient poor environment.exist in a relatively nutrient poor environment and tend to conserve mineral nutrients. For instance, Labrador Tea and leatherleaf retain their leaves for two years. Spruce needles remain on the tree for several years before senescing. Smilacina is a herbaceous perennial with strong resorption of foliar nutrients from old leaves and translocation to new leaves. We choose to analyze current year foliar tissue of the major plant species in our sites for three major cations. Calcium, potassium, and magnesium represent important constituents of plant tissue whose uptake and concentration in a plant may be affected by exposure to ELF electromagnetic fields.

Analysis of previous years data with nested analysis of variance models detected no significant differences among ELF treatments. Therefore, we decided to increase the number of foliar samples from each bog in 1987. Instead of collecting 36 samples per species three times a year, we decided to collect three times the number of samples for a given species, but only sample that species once in 1987. Analysis of previous data suggests that at this sample size our nested ANOVA models will at best be able to detect a 20% difference in potassium means at the 0.05% level with 80% probability. Hence, 120 samples per bog (20 per plot) of leatherleaf, Labrador Tea, and Smilacina were collected once in 1987. Leaves were collected from each species

when it had reached its' physiological peak, as measured by leaf expansion, flowering phenology, and cation content. Smilacina leaves were collected in late June, leatherleaf in late July, and Labrador Tea in late August.

We did not increase the number of spruce needle samples because, to obtain thirty-six samples (six per plot), nearly all the appropriate sized trees within our transects had to be sampled. Increasing the number of spruce trees sampled would have meant collecting from a large number of trees outside of our sampling area. We have been following the nutrient status of the same marked trees since 1985 and decided it would be worthwhile to continue to sample those same individuals in 1987.

Last year, we presented initial results from a pilot study designed to examine variability in nutrient content on a leaf area, as well as dry weight, basis. Leatherleaf leaf area, weight, and number of leaves per sample were recorded for August and September samples. The nutrient content of samples was calculated on a leaf area basis last year. We also calculated nutrient content as mg nutrient/cm^2/leaf. The data were standardized by weight and area and expressed on a per leaf basis. The coefficients of variation for these two techniques are presented in Table 11. The variability in our data was not reduced by expressing nutrient content in this standardized manner. In fact, coefficients of variation were as much as two times greater than when nutrient content was expressed on a percent dry weight basis. However, examination of the coefficients of variation are in themselves useful. For instance, examination of the September, 1986, calcium values indicated that

Table 11. Coefficient of variation for cation concentration in Leatherleaf foliar tissue in August and September, 1986. Cation concentration calculated as a) percent dry weight, and b) mg/cm2/leaf.

Cation:	K		Ca		Mg	
	C.V. (a)	C.V. (b)	C.V. (a)	C.V. (b)	C.V. (a)	C.V. (b)

AUGUST

Bog

20	12	28	18	34	13	34
41	8	23	25	32	13	26
50	14	22	17	31	14	19
2	10	25	13	29	13	29
7	16	26	18	31	18	20
11	10	16	18	24	17	27
21	10	27	15	35	13	31
22	13	26	21	38	13	34
40	10	35	17	48	15	36
101	13	31	21	31	14	34

SEPTEMBER

Bog

20	9	20	19	31	17	28
41	14	32	30	40	16	32
50	9	34	19	45	19	40
2	10	30	19	34	18	32
7	14	27	19	32	18	29
11	6	16	16	23	13	19
21	11	26	18	27	14	28
22	12	17	17	28	16	24
40	10	29	18	39	18	34
101	11	29	23	35	15	30
102	10	19	20	27	19	22

Bog 41 was more variable than the other bogs. We examined mean leaf number, area, and weight and found no major differences between Bog 41 and the other ten. We hypothesized that there might have been some contamination of those samples or some operator or machine error associated with the measurement of calcium. Samples from Bog 41 were re-analyzed for calcium, but found to be no different than the original run. We concluded that the variation is real and as yet unexplainable. Results of the analyses for the 1987 cation concentrations in foliar samples of leatherleaf, labrador tea, spruce, and Smilacina will be included in the final report.

References

Chatfield, C. and A. J. Collins. 1980. Introduction to multivariate analysis. Chapman and Hall, New York. 246 pp.

Hsiao, T. C. 1975. Variables affecting stomatal opening - complicating effects. pp. 28-31. In: Measurements of stomatal aperture and diffusive resistance. Washington State Univ. Research Center Publ. Bull. 809.

Hull, C. H. and N. H. Nie. 1981. SPSS Update 7-9. McGraw-Hill Book Co. New York.

Inoue, M., M. W. Miller, C. Cox, and E. L. Carstesen. 1985. Growth rate and mitotic index analysis of Vicia fava L. roots exposed to 60 Hz electric fields. Bioelectromagnetics 6:293 - 303.

Johnston, R. J. 1978. Multivariate statistical analysis in geography. Longman, New York. 280 pp.

Miller, M. W., e. L. Carstensen, D. Robertson, and S. Z. Child. 1980. 60 Hz electric field parameters associated with the perturbation of a eukaryotic cell system. Radiation Environ. Biophys. 18:289 - 300.

Miller, M. W., D. A. Dooley, C. Cox, and E. L. Carstensen. 1983. On the mechanism of 60 Hz electric field induced effects in Psium sativum L. roots' vertical field exposure. Radiation Environ. Biophys. 22:293 - 302.

Sokal, R. R. and F. J. Rohlf. 1981. Biometry. W. H. Freeman and Co., San Fransisco. CA.

Stearns, F., G. Guntenspergen, J. Keough and D. Wikum. 1984. ELF communications system monitoring program: wetland studies. Annual Report 1983.

Stearns, F., G. Guntenspergen, J. Keough and D. Wikum. 1985. ELF communication system monitoring program: wetland studies. Annual Report 1984.

Stearns, F., G. Guntenspergen, J. Keough and D. Wikum. 1986. ELF communication system monitoring program: wetland studies. Annual Report 1985.

Stearns, F., G. Guntenspergen, and J. Keough. 1987. ELF communication system monitoring program: wetland studies. Annual Report 1986.

Wilkinson, L. 1986. SYSTAT: the system for statistics. Systat. Inc., Evanston, IL.

Zar, J. H. 1984. Biostatistical analysis. Prentice-Hall, Inc. Englewood Cliffs, N. J. 718 pp.

ELF COMMUNICATIONS SYSTEM ECOLOGICAL MONITORING PROGRAM:

BIRD SPECIES AND COMMUNITIES

ANNUAL REPORT: 1987

SUBCONTRACT NUMBER: EO6549-84-011

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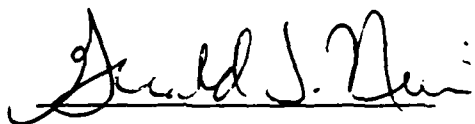
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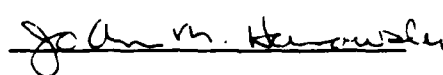
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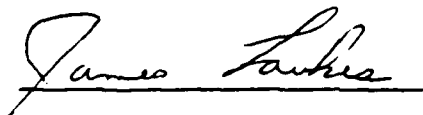
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ABSTRACT

This investigation was designed to isolate effects of electromagnetic 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 (based on habitat, diet, migration strategy, and nesting behavior).

This report summarizes 1987 research activities for studies to identify potential effects of ELF electromagnetic fields on bird species and communities in Wisconsin and Michigan. Our monitoring program included bird censuses over a five month period from May to September. In addition, we completed a detailed habitat assessment of all control and treatment segments in Wisconsin that was initiated in 1986. These data will allow us to pair control and treatment segments on the basis of habitat, thereby enabling us to assess effects of the ELF antenna, even though there are no pre-impact data available from Wisconsin. The Michigan transmitter operated intermittently at low levels during 1987. We are therefore considering 1987 a transitional year in terms of EM exposures.

Principal components (PCA) and Bray-Curtis analyses of vegetation on Wisconsin segments revealed differences between treatment and control segments. Qualitative assessments of habitat types in Michigan also revealed differences between segment types. The most

important difference in relation to birds relates to distribution of coniferous and deciduous habitats. Treatment segments support more coniferous and lowland habitats than do control areas in both states.

Logging affected the vegetation on four treatment segments in Michigan and four treatment and one control segment in Wisconsin. In Michigan, clear-cutting along several treatment segments resulted in a significant difference between treatment and control segments in the amount of early successional habitat, with more now present on treatment sites. Logging was less severe in Wisconsin but did result in significant changes in some habitat variables for the affected segments. We omitted all segments affected by logging in our between year comparisons of bird communities.

Five segments sampled for vegetation in Wisconsin in 1986 were resampled in 1987. Between year differences were noted for seven variables, especially ground cover, canopy cover, and overall height of the vegetation. Measurement of these variables involves some qualitative estimations and between year differences may be due to sampling effects. These variables were not included in PCA.

Bird abundance and species diversity were highest in June and July in Michigan and in May and June in Wisconsin. Observations reached a low in September in Michigan but increased from August to September in Wisconsin. Differences between treatment and control segments in total number of individuals and species were not consistent across seasons in either state. Species richness was higher on control than on treatment segments in Michigan in May; no other differences in community level parameters were significant in either state. Considerable annual variation in numbers of individuals

and species was noted, particularly in Michigan, where significant year effects occurred in four of five sample periods. Annual differences were not, however, consistent among seasons in Michigan.

Particularly abundant species (all seasons included) included the Nashville Warbler, Ovenbird, White-throated Sparrow, Red-eyed Vireo, Black-capped Chickadee, Golden-crowned Kinglet, and Red-breasted Nuthatch. 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), seven comparisons (over all seasons) revealed a significant difference between treatment and control segments in Michigan; five indicated a greater abundance on treatment segments. Three comparisons indicated a higher abundance on treatment segments in Wisconsin and two on controls. Twelve comparisons in Michigan and eight in Wisconsin showed significant annual variation in abundance.

Twenty-one comparisons of common species (based on prominence values) between treatment and control segments in Michigan and 14 in Wisconsin were significant. Values were higher on control segments in Michigan in all but two cases; 9 of 14 were more abundant on control 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, particularly in Michigan where the antenna was operated periodically, are most likely due to habitat differences.

Species were classified into guilds on the basis of migratory strategy, nest site preference, diet and foraging location, and preferred breeding habitat. Abundances of different guild types on

treatment and control segments were compared for June 1985, 1986, and 1987, the primary breeding season. Few significant differences were found between treatment and control segments and most were not consistent among years. Differences were most consistent for habitat categories, suggesting that habitat differences between treatment and control segments may be responsible for many of the observed differences in bird distribution patterns.

We repeated tests for differences in abilities of observers to detect birds, for differences in spring arrival times of several different groups of birds, and for potential edge effects on distribution patterns of birds. Few significant differences emerged.

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). Birds use the earth's magnetic fields to aid in their navigation during migration (Emlen 1975; Beason and Brennan 1986) and magnetic fields produced by the ELF communications system may affect their navigation abilities. Some investigations have reported that orientation of Ring-billed Gull (Larus delawarensis) chicks (Southern 1972; 1975) and migrating birds (Larkin and Sutherland 1977) were disrupted by the ELF antenna in Wisconsin. However, Williams and Williams (1976) found no evidence of attraction to or repulsion from the antenna by migrating birds during any mode of operation. Behavioral and physiological effects of domestic birds exposed to ELF fields have been studied in the laboratory (Krueger et al. 1972; Durfee et al. 1976) and environmental studies of a native bird species are currently underway at the Navy's ELF antenna site in Michigan (Beaver et al. 1985).

Several investigators have studied effects of transmission lines on bird communities, in contrast to studies that have focused on individuals of one or a few species. Most have analyzed combined effects of habitat alteration and EM fields on bird communities (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). Other studies have focused on effects of the right-of-way (ROW) edge (Chasko and Gates 1982; Kroodsma 1982), collison 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 (based on habitat, diet, migration strategy, and nesting behavior).

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 1987, our fourth year of participation in the ELF ecological monitoring program. This is the second 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 and, thus, may be little affected by EM fields. Conversely, breeding birds remain on territories for substantial periods of time, 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. Because our study was initiated in Michigan before the antenna began operation, we can conduct a before-and-after investigation in that state. The antenna was operated for 6 to 8 hours on weekdays from June to October 1987, but well below its full strength (15 amps versus 150 amps). Tests were started on 1 June, after most birds were on territories.

EM fields measured at study areas during test periods (15 amps) indicate that 76 Hz transverse and longitudinal electric field intensities and 76 Hz magnetic flux densities were all an order of magnitude lower on control than on treatment sites (J. R. Gauger report to Principal Investigators; November 1987). Because the EM field ratios between control and treatment sites meet or exceed the criteria originally extablished, we consider 1987 to be a transitional year. However, data are analysed in the same manner regardless of EM field impacts. Thus, in future years we can look at 1987 data in a different light in terms of EM field effects.

Future operational plans are uncertain. IITRI anticipates that intermittent operation of the Michigan antenna at 75 amperes will begin in November 1987. Full operation at 150 amperes will begin in the fall of 1989.

The antenna has been operating in Wisconsin periodically since 1969 and on a near continuous basis for the past two years but no pre-impact data are available. Thus, we cannot assume that the antenna system has not already had an affect on the bird communities in this area. Consequently, we cannot compare transect segments based on similarities in bird species communities. We can, however, account for habitat differences in our analyses and, potentially,

pair control and treatment segments on the basis of habitat features. 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 fact 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 1977; 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 furthur 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 linear transects 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 1986 and are described in Appendix 1. Five transect segments (500 m each or a total of 2500 m) in Wisconsin and four in Michigan (2000 m) were partially or completely logged. Additional areas are likely to be affected before the project is completed (Table A2). Vegetation was

resampled on logged areas in Wisconsin (see below) and our analyses
of bird distribution patterns between years omit logged segments.

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 (Emlen 1971,
1977, Jarvinen and Vaisanen 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 one
half hour before to 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. A third observer was used in Wisconsin in June to allow
two observers to simultaneously census one transect in order to
document observer variation.

Eight transect segments were censused by each observer daily.
Each observer walked at a rate of 16.7 m/min 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. A hierarchical classification scheme was used if a species occurred in more than one category per guild, but analyses reported here are based only on the primary classification for each species. Guilds were used in analyses of the effects of the ELF antenna. These analyses were not done in previous years but were calculated for all years and reported here.

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. To assess inter-year variation in vegetation, five 500 m segments (105 points) sampled in 1986 were randomly selected to be resampled in 1987. In addition, 35 points within 5 segments where logging had occurred were resampled to allow determination of the impact of logging on the vegetation.

STATISTICAL ANALYSES

VARIABLE SELECTION AND WITHIN SEASON ANALYSES

We used the same criteria for selecti.g 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. Variables used in parametric statistical tests were examined for normality (Wilks-Shapiro test; skewness and kurtosis) and homoscedasticity 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, Sokal and Rohlf 1981) were used for variables that did not meet assumptions, even after transformation.

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 the previous report (Hanowski et
al. 1987). Briefly, results based on prominence values are
intermediate between those based either on total individuals or
number of segments the species occurred on. Fewer significant
differences are achieved than when comparisons are based on
individuals but more than when frequency of occurrence is used.

ANNUAL DIFFERENCES IN BIRD NUMBERS

Annual differences were examined by season for number of
species and individuals and for abundant species. A two-way ANOVA
was computed to test for year and treatment effects. Because some
segments were affected by logging after the initial census in 1985,
we excluded logged segments in all analyses of annual variation.

Calculation of prominence values for common species is based in
part on the total number of individuals observed. If logged
segments are unevenly distributed between control and treatment
segments, then a higher total number of individuals is likely to be
recorded on treatment or controls (whichever has received less
logging). Consequently, prominence values would not be directly
comparable. In all but one case (in Wisconsin), logging occurred on
treatment segments. Therefore, to make comparisons between
treatment and control segments valid, we adjusted the total number

of individuals observed on control segments to reflect differences in number of logged segments.

OBSERVER VARIATION

A paired t-test was used to assess observer variation for data gathered almost simultaneously ($\pm$ 10 minutes) by two observers on eight segments during June in Wisconsin. In this census, observer two (Hanowski) started 10 minutes after observer one (Blake) to control for potential effect of observers on each other. This order of observers reverses that used in 1986. We tested for differences between observers for number of individuals, number of species, and for abundant species.

SPRING ARRIVAL DATES

We tabulated the number of species observed first on control and the number observed first on treatment transects in each state during May and tested the frequency of occurence (first versus second) with a goodness of fit G-test. Separate tests were computed for: (1) all species, (2) permanent residents, (3) short-distance migrants, (4) long-distance migrants, and (5) vireo and warbler species, for each state. For these tests, a species could be included in more than one category.

EDGE EFFECT

We designed our treatment transects to reduce edge effects by not including the ROW and the 25 m adjacent to the ROW in our census belt. It is possible that the effect of the edge penetrates beyond the 25 m we allowed for in our study design. Previous analyses (Hanowski et al. 1987) demonstrated no consistent edge effect on distribution of species. To further address this question, we

analyzed distribution patterns in relation to the ROW of eleven species that typically require large expanses of forest habitat for breeding (Hairy and Pileated Woodpeckers, Red- and White-breasted Nuthatches, Brown Creeper, Winter Wren, Golden-crowned Kinglet, Hermit Thrush, Black-throated Green Warbler, Ovenbird, and Scarlet Tanager). If the edge affects the distribution of such species, we would expect forest species to be more abundant on control than treatment transects and to be more abundant in the area of treatment transects that is farthest from the antenna. A goodness-of-fit G-test was used to test for differences in the total number of observations on the right or left side of the transect center line for control segments or between number of observations adjacent to versus opposite the transect center line from the ROW for treatment segments. For more abundant species, each observation was classified into 25 m intervals (4 on each side). The distribution in corresponding belts on either side of the transect center line was compared with a chi-square 2 x 4 contingency table test. This test was used when there were at least five individuals observed within each cell.

VEGETATION

Number of points (habitat assessed at 25 m intervals) characterized within 19 habitat types were tabulated for treatment and control segments in Michigan during 1986. Habitat type was reassessed during 1987 on all points that had been logged. Changes in number of points characterized by a particular vegetation type that occurred as a result of logging were then incorporated into comparisons for 1987. We used a goodness-of-fit G-test to compare differences between treatment and control segments.

Mean values of habitat variables used to characterize Wisconsin segments were compared between treatment and controls with one-way ANOVA. All variables were examined for normality and homogeneity of variances as described in the bird section. Transformations were used when appropriate. Between year differences in habitat variables (also transformed when appropriate) within resampled segments were compared with paired t-tests. We used paired t-tests to compare habitat variables in segments before and after logging.

We used a principal components analysis (correlation matrix) to further examine differences in habitat structure among treatment and control segments; variables were log transformed (natural) before the analysis. We used a Bray-Curtis analysis (Beals 1984) to analyze distribution patterns of tree species among treatment and control segments. Importance values (IV) were calculated for each tree species (IV = relative frequency + relative density + relative dominance) but only the 20 most common species were used in the analyses. These species comprised a majority of all tree species (80%) and individuals (>95%) recorded. Prior to the analysis, we relativized the data by rows (IV's) (Greig-Smith 1983, page 248) so that contribution of a tree species was expressed as a proportion of the total IV of tree species in that segment (see Beals 1984 for a thorough discussion of these procedures).

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

VEGETATION

MICHIGAN

We identified 19 habitat types in Michigan. Most types (14 of 19) differed in frequency of occurrence on treatment and control segments (goodness-of-fit G-test) when comparisons were based on number of points (Table 1). Parts of four treatment segments were logged in 1987 and number of points characterized as "newly logged" therefore increased (Table 1). Occurrence of seven types decreased; number of points characterized as "lowland mixed habitat" decreased the most (Table 1). Differences between treatment and control segments were less pronounced when habitat types were lumped (Table 1). Treatment areas had more coniferous and early successional habitats than control segments (Table 1). The difference in percent of early successional habitat occurred only after the treatment segments were logged in 1987.

WISCONSIN

Habitat variables

Mean values for all habitat variables are presented for each segment in Appendix 5; species of trees, shrubs, and forbs recorded on all segments are in Appendix 6. Three of 16 variables differed between control and treatment segments (Table 2); Wisconsin treatment segments had taller shrubs, fewer deciduous trees, and more canopy cover than control segments. Differences in relative abundance of deciduous versus coniferous trees are likely to be the most meaningful biologically. As was true in Michigan, treatment segments had a greater percentage of coniferous habitat.

Five segments were sampled in 1986 and resampled in 1987 (Table 3). Three variables (shrub and fallen log densities, and shrub

Table 1. Number and percentage of points identified for each habitat type within Michigan control (C) and treatment (TR) segments (N = 840 for controls and for treatments. Results for 1987 are indicated for treatment segments only if number of points changed; results for control segments are assumed to be the same in 1986 and 1987. Significance of differences between treatment and control segments (goodness-of-fit G-test) is indicated.

Habitat Type	Control		TR - 1986		TR - 1987		C vs. TR	
	Pts.	%	Pts.	%	Pts.	%	1986	1987
Upland conifer (1)	6	1	49	6	47	6	***	***
Lowland conifer (2)	62	7	174	21	168	20	***	***
Upland deciduous (3)	62	7	121	14			***	
Maple (4)	105	12	33	4			***	
Lowland deciduous (5)	15	2	1	< 1			***	
Upland mixed (6)	191	23	139	17	101	12	**	***
Lowland mixed (7)	84	10	34	4	31	4	***	***
Cedar (8)	90	11	15	2			***	
Wet shrub (9)	16	2	13	2	8	1		
Tree shrub (10)	25	3	50	6			**	
New cut (11)	0	0	23	3	56	7	***	***
Young cut (12)	8	1	36	4			***	
Young mix (13)	28	3	3	< 1			***	
Short aspen (14)	68	8	88	10				
Short mix (15)	46	5	15	2			***	
Open (16)	22	3	43	5	42	5	**	*
Sedge (17)	6	1	3	< 1	2	< 1		
Pond (18)	4	1	0	0				
Cattail (19)	2	< 1	0	0				
Upland (1,3,4,6)	344	41	342	41	302	36		
Lowland (2,5,7,8)	251	30	224	27	215	26		
Coniferous (1,2,8)	158	19	238	28	230	27	***	***
Deciduous (3,4,5)	167	20	155	18	155	18		
Early succ. (11-15)	150	18	165	20	198	24		*

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

Table 2. Means and coefficients of variation (CV) per segment of
vegetation variables sampled in Wisconsin. Differences between control
and treatment segments (one-way ANOVA) are indicated. "+" = value < 0.5
but > 0.0.

Habitat variable	Control (N=40)			Treatment (N=40)	
	Mean	CV %		Mean	CV %
grass, sedge density per m²	195	107.7		311	118.2
forb density per m²	74	90.5		70	44.7
shrub density per m²	66	40.9		69	65.1
tree density per 100 m²	17	49.4		21	41.0
log density per 100 m²	105	100.7		79	76.3
ground cover (%)	29	69.8		31	66.3
water cover (%)	4	221.1		2	325.1
water depth (cm)	1	265.7		+	287.4
canopy cover (%)	19	83.0	*	26	65.7
shrub height (dm)	10	24.3	*	11	22.9
tree height (m)	10	27.6		9	31.1
overall height (m)	14	25.0		13	29.1
number of tree species	10	24.4		9	25.4
number of shrub species	13	22.1		12	19.2
number of forb species	17	20.1		17	23.3
deciduous trees (%)	69	29.4	***	43	47.3

* P < 0.05; *** P < 0.001

Table 3. Means per segment of vegetation variables for five Wisconsin segments measured in 1986 and 1987.

		Segment								
	1		25		33		57		73	
Variable	86	87	86	87	86	87	86	87	86	87
grass-sedge density per m2	37.0	204.4	105.7	77.4	235.7	263.5	731.9	142.8	202.2	325.5
forb density per m2	162.9	171.8	52.5***	130.3	73.8	38.7	123.8	110.8	43.5**	97.1
shrub density per m2	104.7	79.0	37.8 *	39.6	68.1	77.3	95.4	47.0	104.7	78.1
tree density per 100 m2	24.9	26.5	25.2	25.2	10.1	11.0	25.3	26.5	17.9	19.4
log density per 100 m2	44.3	29.3	39.0	21.5	139.2	**55.3	13.6	13.4	130.0	51.2
% ground cover	20.6	**28.3	63.2***	48.2	4.5***	12.5	65.5	63.5	67.8	65.8
% water cover	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	0.0
water depth, cm	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0
% canopy cover	6.0	***9.8	19.2	17.9	7.3***	11.4	50.0 *	43.7	26.7 *	23.4
shrub height, dm	10.9	11.4	10.1	11.5	8.7	9.3	9.4	11.3	9.2***	12.4
tree height, m	9.6	10.4	10.6	11.0	15.7	15.9	7.4	7.5	8.5	8.1
overall height, m	14.6	14.7	13.7	14.3	20.6	21.1	8.6***	11.7	9.9***	13.3

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

height) differed between years only on one segment. Shrub height increased on all segments between years although the increase was significant only on one (Table 3). The consistency of the pattern, however, suggests that the observed changes were real. In contrast, it is likely that some of the differences between years were due to slight differences in location of sample points. Markers sometimes were lost over the winter and small differences (50-100 cm) in point location could result in relatively large changes in values for shrub density and forb density. Forb density differed significantly between years on two segments (Table 3). Tree density should be less affected by small changes in sample location and, in fact, tree density values were very similar between years.

Overall height (estimate of average height of vegetation in 25 m^2 surrounding center point) and percent ground cover differed between years on three of the five segments sampled; canopy cover differed on three. All three variables involve some qualitative estimation by observers and it is not clear whether between year differences reflect actual changes in vegetation or simply sampling effects. For example, ground cover decreased significantly on one segment (25) where forb density almost tripled (Table 3). Overall height is highly correlated (r=0.86) with tree height; canopy cover is negatively correlated (r=-0.66) with tree height. Tree height is measured rather than estimated and thus is likely to be more accurately sampled by different observers.

To examine the relationships of habitat structure among treatment and control segments, we performed a principal components analysis (PCA) on 12 habitat variables (ln transformed). We omitted

canopy cover, ground cover, and overall height because of the between year differences mentioned above. We also omitted water depth because it was highly correlated (r=0.95) with water cover.

The first component of the PCA explained about 21% of total variation in habitat among the 80 segments (Table 4, Fig. 1). Segments are arranged on a gradient from sites with diverse, tall trees to sites with tall shrubs and greater densities of grasses and forbs (Table 4; Fig. 2). The second component accounted for 17% of the variation and contrasted areas with dense trees to those with more water and shrubs (Table 4). Treatment and control segments showed a great deal of overlap along the first two components (Fig. 1). Species richness of trees, shrubs, and forbs contributed to the third component (Table 4, Fig. 1).

Tree species

We used a Bray-Curtis analysis to examine relationships among control and treatment segments (Table 5, Fig. 3) using importance values for the 20 most important tree species (Appendix 7). The first axis separates segments dominated by balsam fir from those dominated by sugar maple (Table 5; Fig. 4). Treatment and control segments were separated somewhat on this axis, with control segments more heavily dominated by sugar maple and treatment segments by balsam fir. These results confirm the significant difference that we found in percent occurrence of deciduous versus coniferous trees on control and treatment segments (Table 2). The second axis (Table 5) primarily reflects a gradient from lowland areas dominated by black ash and cedar to upland sites supporting quaking and large-toothed aspen. Similarly, the third axis separates lowland areas with black spruce and tamarack from upland areas with red maple

Table 4. Results of a principal components analysis on 12 habitat variables (see Appendix 3 for a description). Correlations between the original variables and the first three factors are shown if correlations are significant.

Habitat variable	Factor 1	Factor 2	Factor 3
Water cover		0.56	
Grass density	0.51	0.35	
Forb density	0.53	-0.41	
Shrub density		0.64	
Log density	-0.35	0.47	-0.37
Tree density		-0.57	
Shrub height	0.56		0.36
Tree height	-0.79		
Tree species	-0.54		0.54
Shrub species	-0.24	-0.32	0.65
Forb species	0.38	0.44	0.58
Deciduous trees (%)	-0.56	0.44	0.34
% variance accounted for	21	17	13

$r > 0.22$, $P < 0.05$; $r > 0.29$, $P < 0.01$; $r > 0.36$, $P < 0.001$
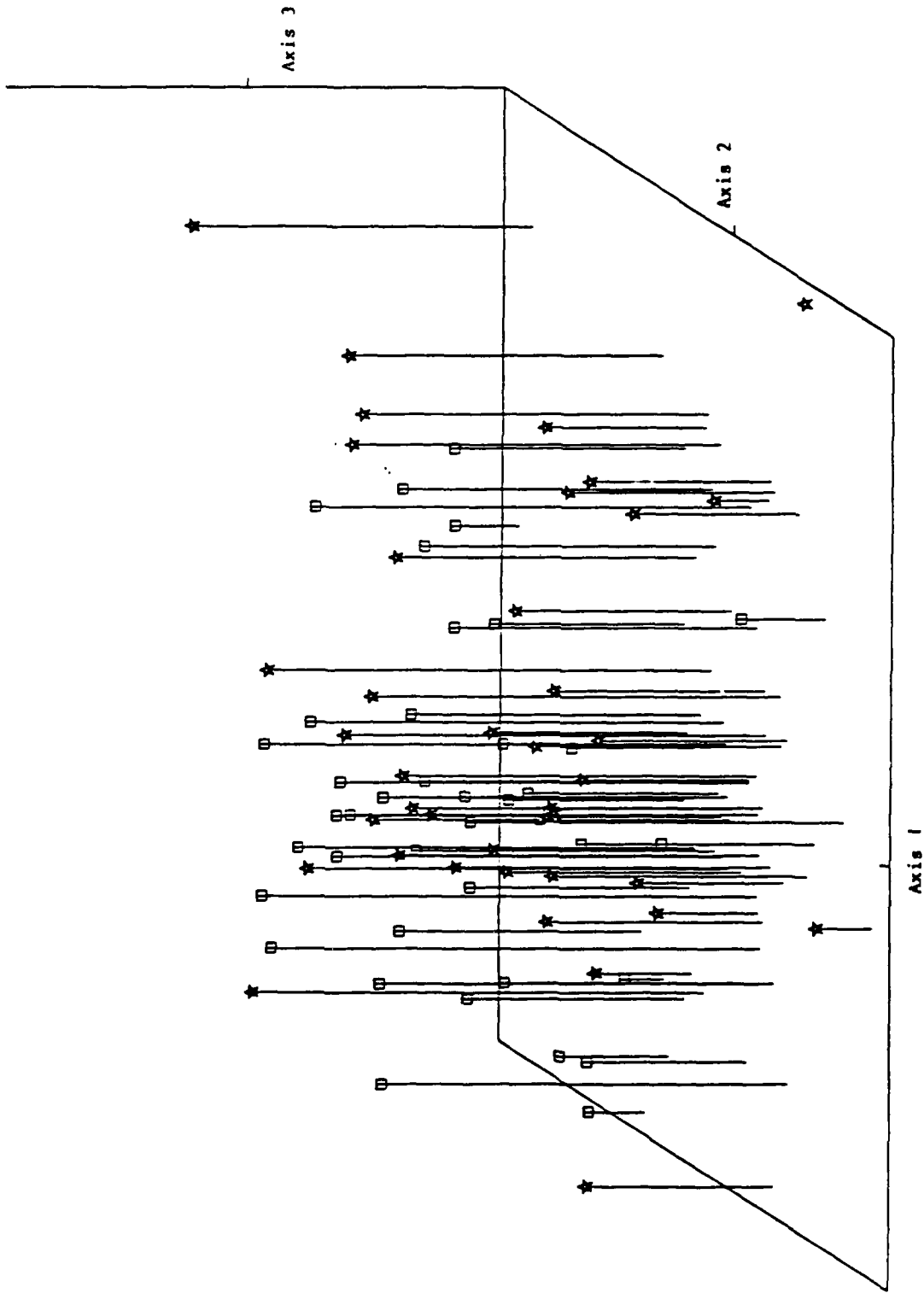
Figure 1. Distribution of control (☆) and treatment (☐) segments in a three-dimensional space defined by the first three components of a principal components analysis (PCA) of 12 (ln transformed) habitat variables (see Table 4).

20

(A) Tree Height

(B) Shrub Height

Axis 1

Axis 1

Axis 2
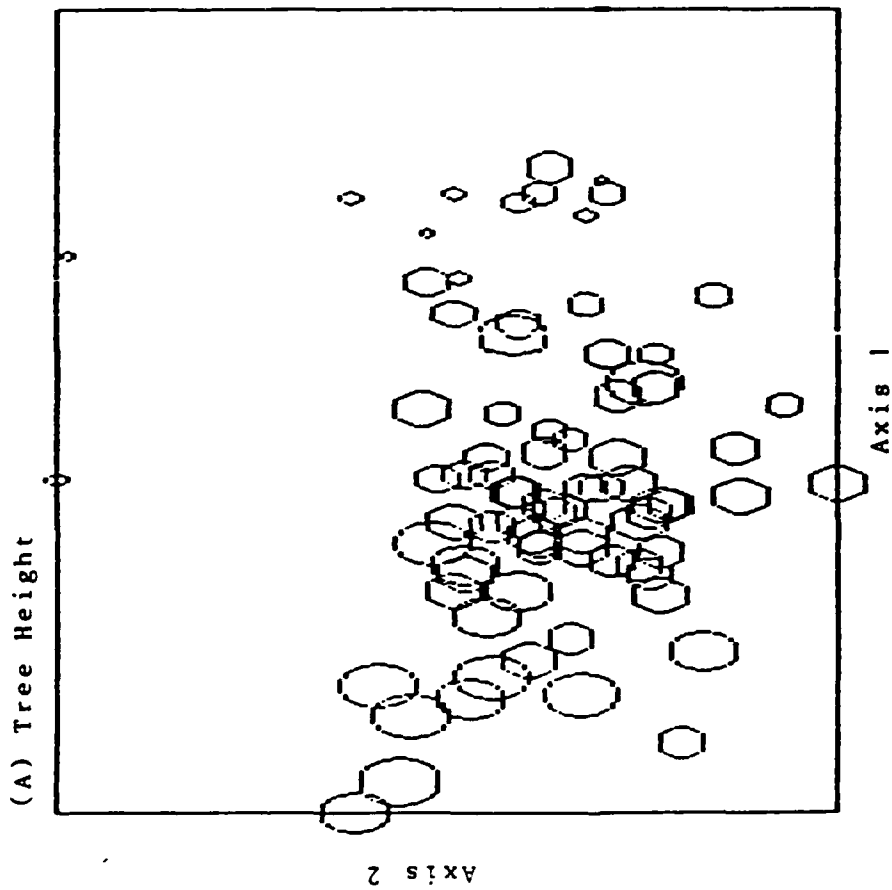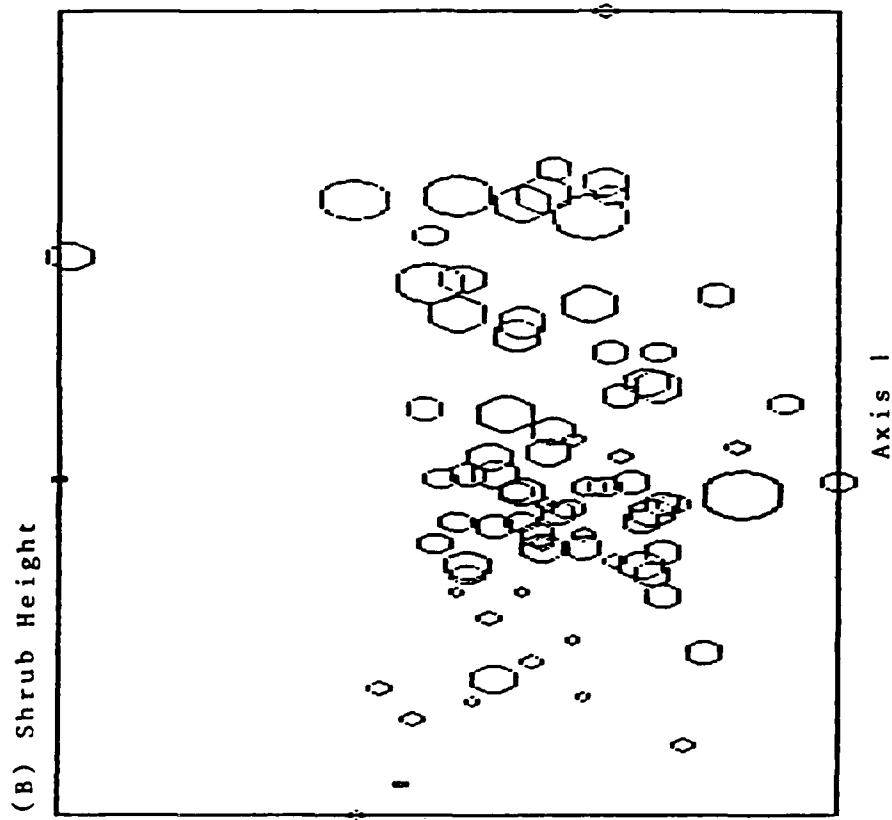
Figure 2.   Distribution of control and treatment segments along the first two PCA axes (see Figure 1) showing relative values (indicated by size of circles) for (A) tree height and (B) shrub height, the variables that correlated most strongly with the first component

Table 5. Results of a Bray-Curtis analysis based on importance values of 20 tree species. Correlations between the original variables and the first three axes are shown if correlations are significant. Scientific names are in Appendix 6.

Tree Species	Axis 1	Axis 2	Axis 3
White pine			
Red pine			0.49
Tamarack	0.23	0.46	0.53
Balsam fir	0.61	-0.44	
Hemlock		-0.36	
White spruce			
Black spruce	0.31	0.42	0.56
Northern white cedar		-0.54	
Aspen (two species)	0.42	0.67	-0.28
Ironwood	-0.46		
Paper birch			
Yellow birch	-0.26	-0.44	-0.43
Red oak	-0.27		
Black cherry			
Red maple			-0.61
Sugar maple	-0.93		
Basswood	-0.58		
Green ash	-0.50		
Black ash		-0.66	
Dead trees			
% information extracted	25	19	14

r > 0.22, P < 0.05; r > 0.29, P < 0.01; r > 0.36, P < 0.001
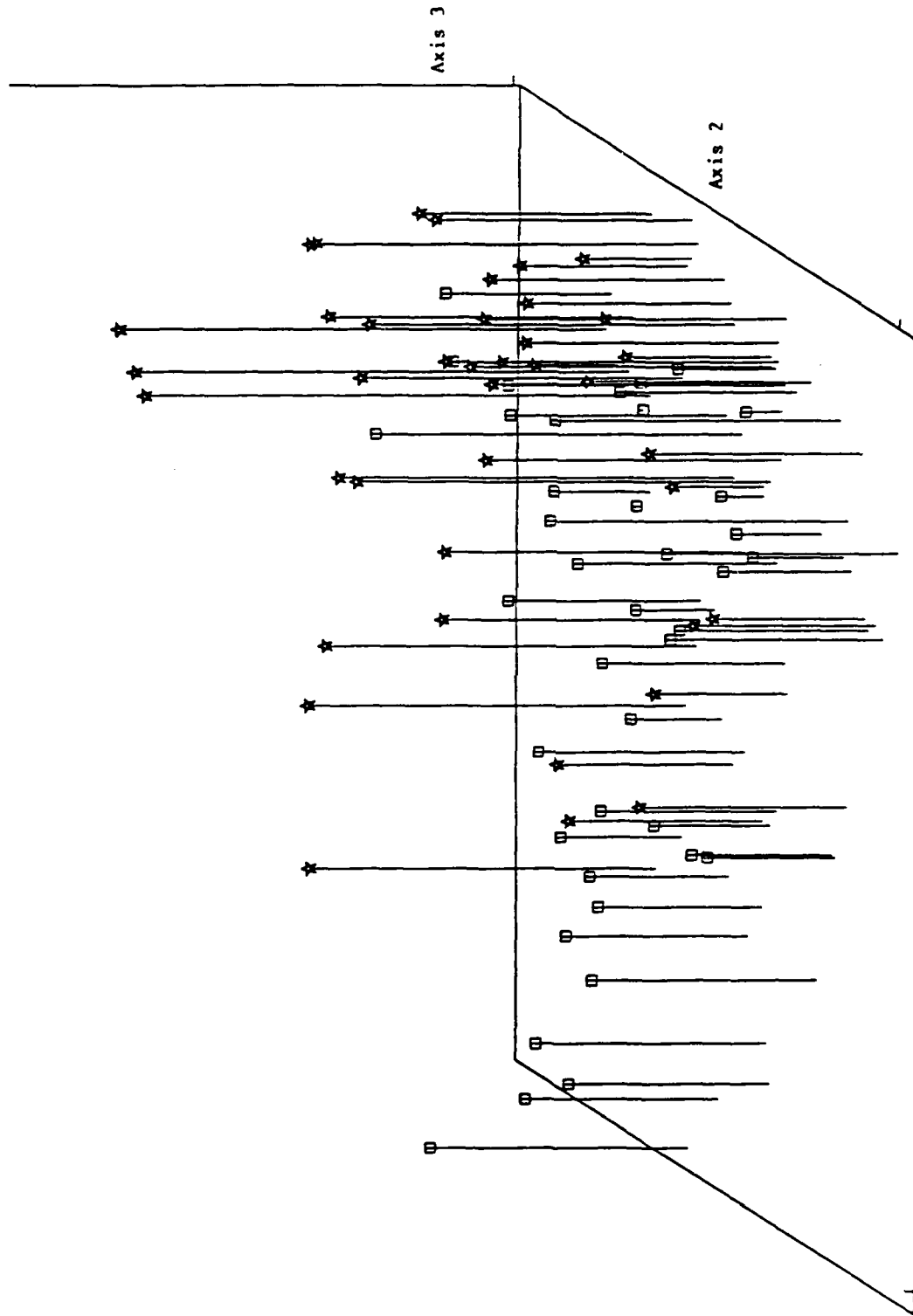
Figure 3. Distribution of control (□) and treatment (☆) segments in a three-dimensional space defined by the first three axes of a Bray-Curtis analysis (BCA) based on the (relativized) importance values of 20 common tree species (see Table 5).

22

23
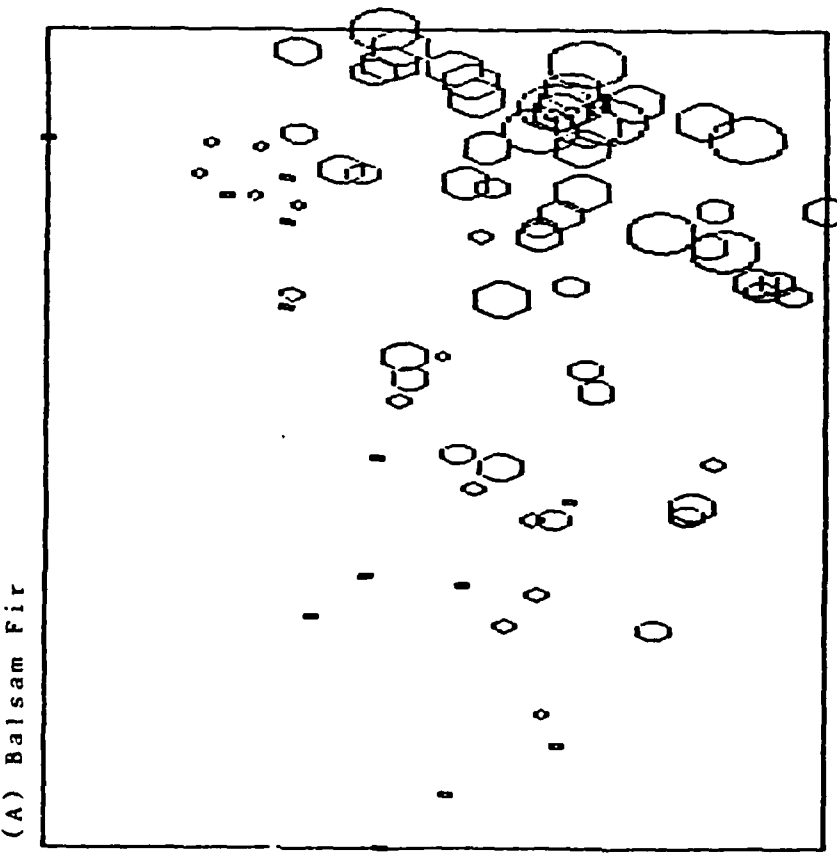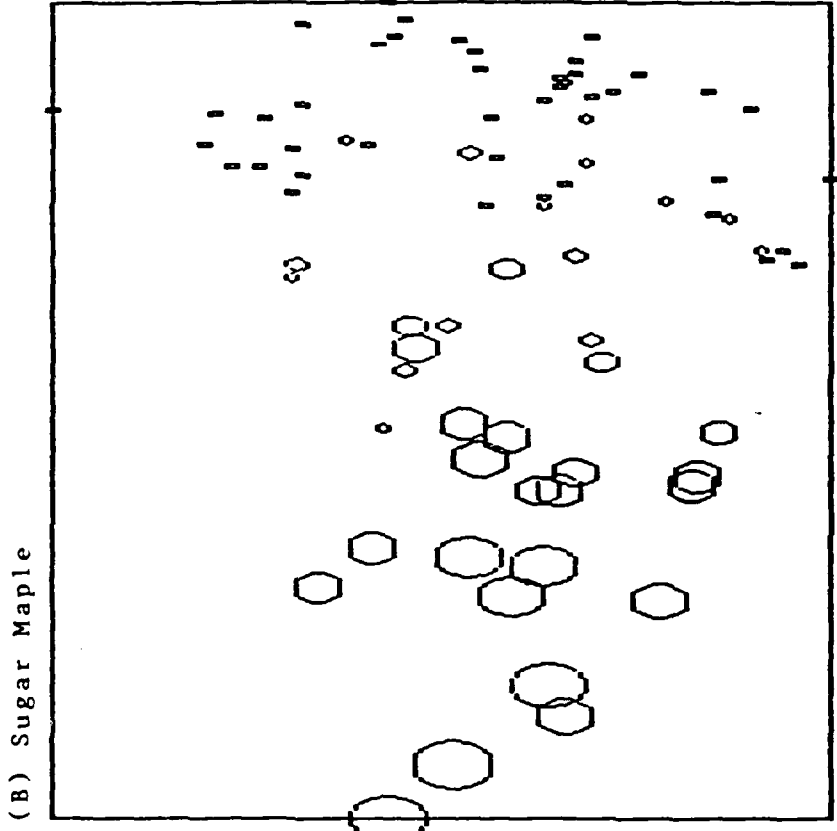
Figure 4.   Distribution of control and treatment segments along the first two BCA axes (see Figure 3) showing relative values (indicated by size of circles) for (A) balsam fir and (B) sugar maple, the two species that correlated most strongly with the first axis.

(Table 5, Fig. 3).

Logging effects

Vegetation on five segments in Wisconsin was affected by logging. Two segments were logged over at only two points (Appendix 8) whereas three segments experienced logging over at least 50% of their length. All segments affected by logging were excluded in between year comparisons of bird abundance.

Intensity of logging varied among segments, with tree density on logged parts of the segments reduced from 21 to 69% (Table 6); reductions in density were significant on two segments. Significant increases following logging were noted for five variables on one segment each (shrub density, shrub height, grass-sedge density, fallen log density, and ground cover) (Table 6). Overall height was significantly different (lower) on only one segment. Canopy cover was the only variable to show a significant difference on all segments (Table 6). The apparently large increases in canopy cover after logging may represent sampling effects, rather than real increases.

<div align="center">BIRDS</div>

SPECIES RICHNESS AND ABUNDANCE OF INDIVIDUALS

1987 results

Total number of species and individuals observed varied among seasons on control and treatment transects in both states (Figs. 5, 6; Tables 7, 8). Number of observations for all species are in Appendix 9. Abundance was highest during June and July in Michigan and in May and June in Wisconsin (Fig. 5). Part of the difference between states was due to differences in census time; Wisconsin

Table 6. Mean values of vegetation variables on three Wisconsin segments that were logged between 1986 and 1987 (see Appendix 8 for values for each point).

| | Segment | | | | | |
| | 60 (N=10) | | 77 (N=11) | | 79 (N=10) | |
Variable	86	87	86	87	86	87
grass-sedge density per m2	108.0	220.6	108.5 *	142.5	17.3	261.0
forb density per m2	71.1	141.7	47.3	113.6	70.3	102.3
shrub density per m2	29.3	21.1	105.4	75.4	70.8 *	116.2
tree density per 100 m2	12.6 *	5.8	26.3 ***	8.1	19.7	15.6
fallen log density per 100 m	32.5	63.8	88.4	84.6	36.7 *	201.9
% ground cover	6.1	12.5	8.1 **	17.3	16.5	16.5
% water cover	0.0	0.0	0.0	0.0	0.0	0.0
water depth, cm	0.0	0.0	0.0	0.0	0.0	0.0
% canopy cover	19.2 ***	38.6	7.2 ***	25.9	14.8 ***	52.3
shrub height, dm	12.6	10.6	7.4 *	9.7	8.4	8.8
tree height, m	12.6	12.5	12.1	13.9	9.5	7.4
overall height, m	16.1	16.1	18.8	20.0	13.9 *	10.1

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

Figure 5. Mean number of species recorded per 500 m segment on treatment (★) and control (■) segments in Michigan and Wisconsin in 1986 (---) and 1987 (——).

MICHIGAN
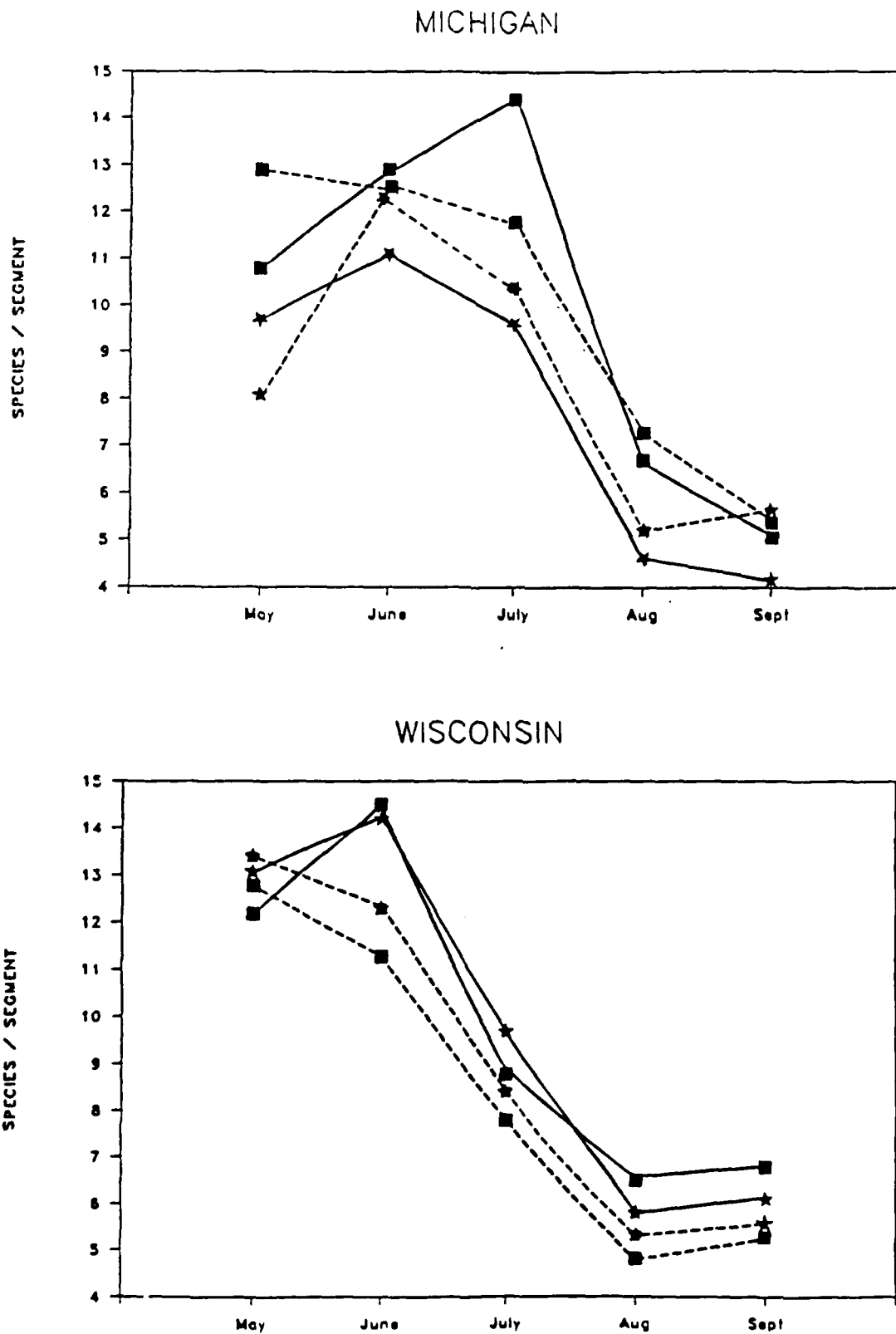
WISCONSIN

Figure 6. Mean number of individuals recorded per 500 m segment
on treatment (★) and control (■) segments in
Michigan and Wisconsin in 1986 (---) and 1987 (——).

MICHIGAN
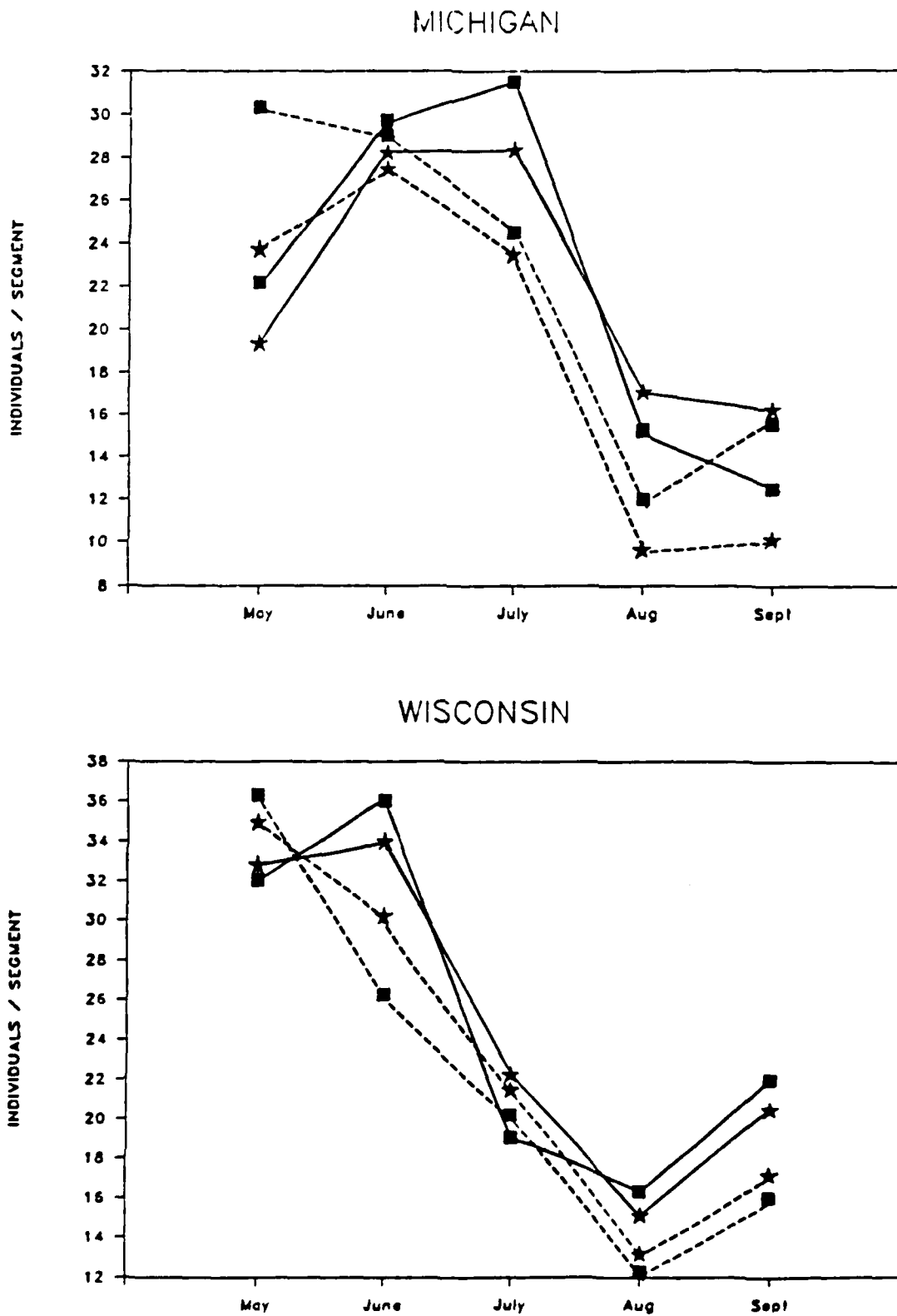
WISCONSIN

Table 7. Total numbers of individuals and species observed on treatment (T) and control (C) transects in Michigan and Wisconsin, 1985-1987. A combined species total for treatment and control segments is in parentheses.

		1985		1986		1987	
		T	C	T	C	T	C
MICHIGAN							
May:	individuals			949	1210	775	888
	species			54 (76)	69	50 (67)	62
June:	individuals	1629	1327	1098	1169	1131	1162
	species	70 (81)	72	60 (74)	68	71 (81)	73
July:	individuals			938	978	1136	1258
	species			59 (75)	63	68 (81)	73
August:	individuals			380	478	682	610
	species			53 (61)	46	59 (68)	54
Sept.:	individuals			402	627	634	501
	species			36 (55)	48	46 (55)	41
WISCONSIN							
May:	individuals			1396	1452	1305	1302
	species			67 (78)	62	72 (83)	62
June:	individuals	1548	1348	1207	1050	1358	1439
	species	76 (81)	66	66 (72)	57	69 (76)	65
July:	individuals			858	808	861	761
	species			50 (64)	54	66 (81)	63
August:	individuals			522	477	606	653
	species			40 (47)	38	51 (63)	50
Sept.:	individuals			682	644	819	880
	species			31 (48)	39	46 (56)	42

Table 8. Mean observations in a 500m segment on control (C) and treatment (T) segments, 1985-87; 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 T	1985 C	1986 T	1986 C	1987 T	1987 C	ANOVA T	ANOVA Y	ANOVA I
MICHIGAN									
May: individuals			23.7**	30.3	19.4	22.2	**	***	
species			9.7**	12.9	8.1**	10.8	***	***	
June: individuals	40.8**	33.3	27.5	29.2	28.3	29.1		***	*
species	14.2	14.0	11.1	12.5	12.5	12.9		***	
July: individuals			23.5	24.5	28.4	31.5		***	
species			9.6	10.4	11.8	14.4	**	***	
August: individuals			9.6	12.0	17.1	15.3		***	
species			4.6	5.2	7.3	6.7		***	
Sept.: individuals			10.1 *	15.7	15.9	12.5			**
species			4.0	5.6	5.4	5.1			**
WISCONSIN									
May: individuals			34.9	36.3	32.6	32.5	*		
species			13.4	12.8	13.1	12.2			
June: individuals	38.7**	33.8	30.2 *	26.3	34.0	36.0		***	*
species	15.0 *	13.0	12.3	11.3	14.3	14.4		***	
July: individuals			21.5	20.2	21.5	19.0			
species			8.4	7.8	9.7	8.8			
August: individuals			13.1	12.2	15.2	16.3		*	
species			5.3	4.8	5.8	6.5		**	
Sept.: individuals			17.1	16.0	20.5	22.0		*	
species			5.3	5.3	6.1	6.8		**	

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

sites were sampled 7 to 10 days after Michigan. Differences between treatment and control segments were not consistent across seasons in either state (Fig. 5). Mean number of individuals observed per segment did not differ between control and treatment segments in either state or any season (Table 8).

Patterns in the abundance of species generally followed those for individuals (Table 8, Fig. 6), particularly in Michigan. Species richness per segment was highly correlated with individuals per segment in Michigan (r=0.98) and Wisconsin (r=0.94). Mean number of species recorded per segment was higher on control than on treatment segments in Michigan during May (Table 8). Differences between treatment and control segments were not significant in any other season or in Wisconsin. More short-distance migrants were observed first on control (15 species) than on treatment transects (5 species) in Michigan. No other comparisons were significant in either state.

Annual differences

Considerable annual variation in number of individuals and species was noted, particularly in Michigan. Number of individuals and species recorded per segment during spring migration were lower in 1987 than in 1986 in both Michigan and Wisconsin (Figs. 5, 6; Tables 7, 8) although the difference in species richness was not significant in Wisconsin. Total number of species observed was slightly higher in 1987 in Wisconsin (Table 7). The significant treatment effect (both years, two-way ANOVA) observed for individuals in Michigan primarily reflects large differences in 1986; differences between treatment and control segments in number of individuals per segment were lower and not significant in 1987

(Table 8). Difference in mean number of species recorded per segment were significant in both 1986 and 1987 in Michigan (Table 8).

Significant annual variation in abundance and number of species also was apparent during the June breeding season in both states (Table 8; Fig. 7). Much of the variation was due to generally lower values in 1986 than in either 1985 or 1987 (Table 8), particularly in Wisconsin.

A significant interaction between treatment and year (Table 8) was observed in both states for number of individuals observed per segment during the breeding season. Birds were significantly more abundant on treatment segments in Michigan in 1985, but were more abundant (but not significantly so) on control segments in 1986 and 1987. Similarly, birds were more abundant in Wisconsin on treatment segments in 1985 and 1986, but the reverse was true in 1987 (Table 8, Fig. 7).

Abundance during the late breeding season (July) increased from 1986 to 1987 on both treatment and control segments in Michigan, but remained the same (treatment) or declined slightly (control) in Wisconsin (Table 8). Differences between years were significant only in Michigan. Species richness in July was higher in both states in 1987 than in 1986 (Table 8; Fig. 5) but the difference was not significant in Wisconsin.

Bird abundance was higher in 1987 than in 1986 on both treatment and control segments during early fall migration in Michigan and Wisconsin (Table 8; Fig. 5). Species richness per segment also was significantly higher in 1987 in both states (Table
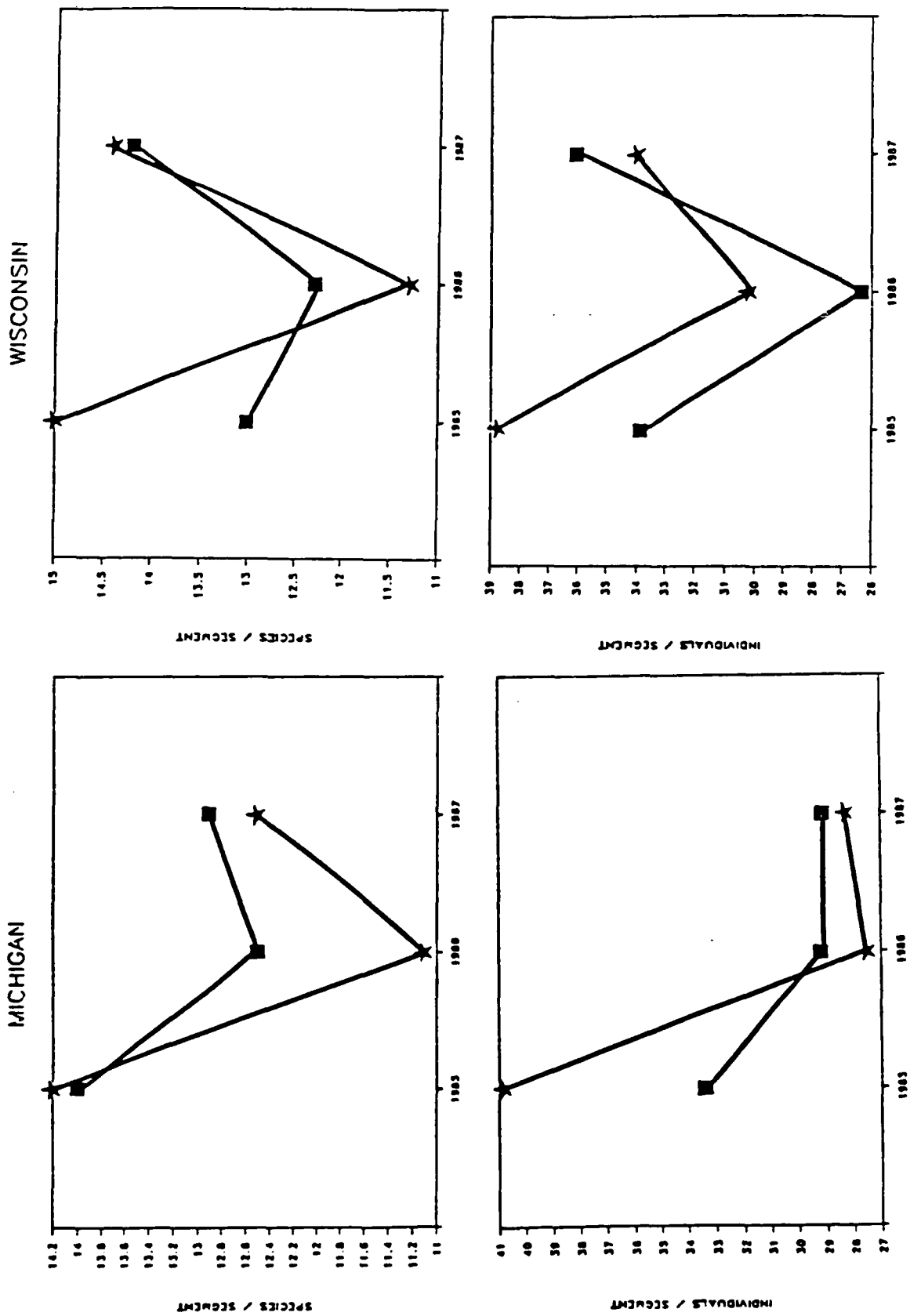
Figure 7. Mean number of species and individuals recorded per 500 m segment on treatment (★) and control (■) segments in Michigan and Wisconsin, June 1985, 1986, and 1987.

8; Fig. 5).

During late fall migration in Wisconsin, bird abundance and number of species were higher in 1987 than in 1986 on both control and treatment segments. However, in Michigan, numbers increased from 1986 to 1987 on treatment segments, but declined on control segments (Table 8), producing a significant interaction effect (Table 8).

DISTRIBUTION OF ABUNDANT SPECIES

Spring migration

The Nashville Warbler was the most abundant species on both control and treatment segments in Michigan (Appendix 9a). Six species were recorded with an average abundance of at least one bird per segment, but only two showed a significant difference between controls and treatments (Table 9). Both (Black-capped Chickadee and Black-throated Green Warbler) were more abundant on control segments.

The Ovenbird was the most abundant species in Wisconsin, followed closely by the Nashville Warbler (Appendix 9b). Two of nine abundant species showed a significant difference in abundance between treatment and control segments (Table 9); the Least Flycatcher was more abundant on control and the Blue Jay on treatment segments.

The significant year effect in number of individuals observed in Michigan (Table 8) was reflected in the abundances of several species (Table 10). Of seven species that showed a significant change in abundance between years in Michigan (Table 10), only the Golden-crowned Kinglet increased; all others declined on both treatments and controls. Only the Nashville Warbler showed a

Table 9. 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 1987.

Species	Michigan		Wisconsin	
	T	C	T	C
MAY[1]				
Least Flycatcher			0.2 *	1.1
Blue Jay			1.3 *	0.6
Black-capped Chickadee	0.4 *	1.2		
Black-throated Green Warbler	0.4 *	1.4		
JUNE[2]				
Chestnut-sided Warbler			2.3 *	1.6
Ovenbird			2.8 *	4.9
White-throated Sparrow	1.8 **	0.7		
JULY[3]				
Red-breasted Nuthatch			1.2 *	0.6
Nashville Warbler	2.6 *	1.3		
White-throated Sparrow	2.4 **	1.1		
AUGUST[4]				
White-throated Sparrow	1.4 **	0.5		
SEPTEMBER[5]				
Golden-crowned Kinglet	2.7 **	0.6		

[1] Species tested: 6 in Michigan; 9 in Wisconsin.
[2] " " 8 " " 10 " "
[3] " " 10 " " 5 " "
[4] " " 4 " " 5 " "
[5] " " 5 " " 6 " "
* P < 0.05; ** P < 0.01

Table 10. Mean number of individuals recorded on control (C) and treatment (T) segments during May, July, August, and September and significance of two-way ANOVAs. Data from logged segments are not included. Species are included if abundance per segment was at least 1.0 in at least one year, either on treatment or control segments and if a significant annual effect was found. For two-way ANOVAs, T=treatment effect and Y=year effect.

	Michigan						Wisconsin					
	1986		1987		ANOVA		1986		1987		ANOVA	
Species	T	C	T	C	T	Y	T	C	T	C	T	Y
MAY[1]												
Least Flycatcher	0.4	1.0	0.1	0.3		*	0.5	1.3	0.1	1.1	**	
Blue Jay	1.4	1.5	0.6	0.8		**						
Golden-crowned Kinglet	1.0	0.5	1.4	1.1		*						
American Robin	1.0	1.0	0.6	0.6		*						
Nashville Warbler	5.4	5.2	4.8	3.1		*	5.9	6.0	4.3	4.5		*
Northern Parula							0.2	1.1	0.5	0.9	**	
Yellow-rumped Warbler	1.6	0.9	1.6	1.1	*							
Blk-thr'td Grn. Warb.	1.6	2.4	0.4	1.4	*	***						
Black-and-white Warb.							0.9	1.9	0.9	1.4	**	
Ovenbird	1.3	2.5	0.3	0.7	***	***	4.6	6.4	4.4	6.2	**	
JULY[2]												
Least Flycatcher	0.1	0.3	1.1	0.9		**						
Red-breasted Nuthatch							0.6	0.4	1.0	0.6		*
Golden-crowned Kinglet	1.1	0.6	1.9	0.7	*							
Hermit Thrush							1.6	1.1	2.2	1.5	*	
Nashville Warbler	2.2	0.7	2.7	1.4	***	**						
White-throated Sparrow	1.9	1.3	2.0	1.1	**							
AUGUST[3]												
Black-capped Chickadee	1.2	2.1	1.8	2.8		**	1.6	2.3	1.9	2.6	*	
Red-breasted Nuthatch	0.5	0.3	0.6	1.1		**	0.6	0.5	1.3	2.1		***
Cedar Waxwing							0.0	0.0	0.9	1.4		***
Ovenbird							1.2	0.9	0.3	0.2		***
SEPTEMBER[4]												
Blue Jay							0.4	0.4	1.0	1.5		***
Red-breasted Nuthatch	0.3	0.5	1.5	1.5		***	1.4	1.4	4.1	4.8		***
Golden-crowned Kinglet	1.3	1.4	2.7	0.6	5							
Yellow-rumped Warbler							5.1	2.5	2.2	2.4		**

[1] Species tested: 12 in Michigan; 11 in Wisconsin.
[2] " " 10 " " 6 " "
[3] " " 4 " " 7 " "
[4] " " 6 " " 6 " "
[5] Significant interaction effect, P < 0.05.
* P < 0.05; ** P < 0.01; *** P < 0.001

significant year effect in Wisconsin, where it declined in abundance from 1986 to 1987 on both treatment and control segments (Table 10).

Early breeding

Study areas were dominated in June by Ovenbirds and Nashville Warblers in Michigan and by Ovenbirds, Nashville Warblers, and White-throated Sparrows in Wisconsin (Appendices 9a, 9b).

Differences between control and treatment segments were not pronounced. One of eight abundant species in Michigan (more White-throated Sparrows on treatment segments) and two of 10 in Wisconsin showed significant differences between treatment and control segments (Table 9). The Ovenbird was more abundant on control segments in Wisconsin whereas the Chestnut-sided Warbler showed the opposite pattern.

The substantial variation in total bird abundance among years (Tables 7, 8) was reflected in changes in abundance of several species (Table 11). Ten species showed significant variation in abundance among years in Michigan. Changes in abundance generally were most pronounced between 1985 and 1986; only three species showed slight increases in abundance from 1986 to 1987 (Table 11). Seven species showed a significant difference among years in Wisconsin (Table 11). Two species declined and three increased steadily from 1985 to 1987; two others declined from 1985 to 1986 and then increased (Table 11).

Treatment effects in both states were about evenly divided between species that were more abundant on control segments and those that were more abundant on treatments. Changes in abundance among years largely were consistent on treatment and control

Table 11. Mean number of individuals recorded on control (C) and treatment (T) segments during June. Data from logged segments are not included. Species are included if abundance per segment was at least 1.0 in at least one year, either on treatment or control segments, and if a significant annual effect was found. For two-way ANOVAs, T=treatment effect, Y=year effect, and I=interaction.

Species	1985		1986		1987		ANOVA		
	T	C	T	C	T	C	T	Y	I
MICHIGAN[1]									
Yellow-bellied Flycatcher	1.1	0.2	0.9	0.3	0.5	0.2	***		
Least Flycatcher	0.9	1.2	0.6	1.7	0.5	1.5	*		
Black-capped Chickadee	1.0	1.1	0.3	0.2	0.2	0.7		***	
Golden-crowned Kinglet	0.6	0.1	0.7	0.5	1.1	0.7	**	*	
Hermit Thrush	1.0	1.1	0.3	0.4	0.8	0.6		***	
Red-eyed Vireo	4.7	3.6	2.4	2.5	2.1	2.3		**	
Nashville Warbler	5.9	2.4	3.6	1.6	2.8	1.6	***	**	
Chestnut-sided Warbler	4.6	1.4	1.7	1.3	1.6	1.0	***	**	*
Black-throated Green Warbler	1.6	2.5	1.2	1.7	1.0	1.6	*	**	
Black-and-white Warbler	0.4	1.1	0.5	0.6	0.6	0.8	**		
Ovenbird	6.0	6.1	4.3	5.0	4.0	4.0		*	
Mourning Warbler	1.5	0.5	0.4	0.4	0.5	0.4		*	
Rose-breasted Grosbeak	0.8	1.3	0.9	1.4	0.7	0.6	*	*	
White-throated Sparrow	1.9	0.9	1.6	0.8	1.6	0.7	***		
WISCONSIN[2]									
Least Flycatcher	0.9	1.6	0.5	0.7	0.4	0.8	*	*	
Winter Wren	0.2	0.8	0.7	0.6	0.8	1.1	*	*	
Hermit Thrush	0.8	0.8	0.9	0.7	1.6	1.3		*	
Red-eyed Vireo	4.8	4.5	2.4	2.6	1.9	2.5		***	
Chestnut-sided Warbler	2.0	1.0	1.7	1.4	2.1	1.5	***		
Black-throated Green Warbler	2.3	3.1	1.3	1.0	1.9	1.9		***	
Ovenbird	7.1	6.1	4.5	4.9	2.8	5.0		***	
Common Yellowthroat	1.2	0.5	0.6	0.3	0.9	0.7	*		
White-throated Sparrow	1.2	0.9	2.3	1.9	2.7	3.0		***	

[1] 15 species tested.
[2] 12 " " .
* P < 0.05; ** P < 0.01; *** P < 0.001

segments. Consequently, interaction effects were not significant except for the Chestnut-sided Warbler (Table 11).

Late breeding

The Ovenbird was the most abundant species overall in Michigan and the Red-eyed Vireo in Wisconsin (Appendices 9a, 9b). Two species in Michigan (Least Flycatcher and Nashville Warbler) and one in Wisconsin (Red-breasted Nuthatch) showed significant differences in abundance between treatment and control transects (Table 9); all were more abundant on treatment segments.

Nashville Warblers and Least Flycatchers were more abundant in Michigan in 1987 than in 1986 on both treatment and control segments (Table 10). In Wisconsin, only the Red-breasted Nuthatch was significantly more abundant in 1987 on both treatment and controls (Table 10).

Early fall migration

Bird communities were dominated by Black-capped Chickadees, Golden-crowned Kinglets, and Red-breasted Nuthatches during early fall migration (Appendices 9a, 9b). Only the White-throated Sparrow showed a significant difference in abundance between control and treatment segments (higher on treatment segments), however, and only in Michigan (Table 9).

More Red-breasted Nuthatches were observed in 1987 than in 1986 in both states (Table 10), and on both treatment and control segments. Similarly, abundances of Cedar Waxwings in Wisconsin and Black-capped Chickadees in Michigan were significantly higher in 1987 than in 1986. The Ovenbird was the only species to show a significant decline from 1986 to 1987, and only in Wisconsin (Table 10).

Late fall migration

Red-breasted Nuthatches were common in Wisconsin and Black-capped Chickadees were common in both states (Appendices 9a, 9b). The Golden-crowned Kinglet was the only species that showed a significant difference in abundance between cont il and treatment segments, however, and only in Michigan (Table 9) where it was more abundant on treatment segments.

Red-breasted Nuthatches were more common in 1987 than in 1986 in both states, as were Blue Jays in Wisconsin (Table 10). The Yellow-rumped Warbler was the only species that declined in abundance from 1986 to 1987 (Table 10). Relative abundance of Golden-crowned Kinglets on treatment and control segments differed between 1986 and 1987, producing a significant interaction effect (Table 10).

DISTRIBUTION PATTERNS OF COMMON SPECIES

1987 results

Abundances of common species (as measured by prominence values) differed between treatment and control transects in 21 comparisons during 1987 in Michigan (Table 12). In all but two cases (Yellow-bellied Flycatcher and Golden-winged Warbler during June), prominence values were higher on control than on treatment segments (Table 12). This pattern differs from that shown by abundant species (Table 9), where most species were more abundant on treatment segments. Few species, however, were consistently and significantly more abundant on either treatment or control segments. Only three species showed a significant difference in more than one season; Yellow-bellied Sapsucker, Swamp Sparrow, and Red-winged Blackbird were all more abundant on controls (Table 12).

Table 12. Prominence values (see text) for species showing significant differences (G-test) between treatment (T) and control (C) segments in 1987. Prominence values are given only when differences are significant.

Species	Michigan		Wisconsin	
	T	C	T	C
MAY[1]				
Yellow-bellied Sapsucker	3.8 *	14.3		
Great Crested Flycatcher			1.3 *	7.5
Magnolia Warbler			6.6 **	0.2
Black-and-white Warbler	0.4 **	7.1		
Ovenbird	3.2 **	16.0		
Common Yellowthroat			15.7 *	6.3
Canada Warbler			1.6 *	8.4
Rose-breasted Grosbeak			13.5 *	29.6
Swamp Sparrow	2.7 *	9.4		
Red-winged Blackbird	3.2 ***	19.0		
Purple Finch	9.7 *	22.2		
JUNE[2]				
Eastern Wood-Pewee			1.1 *	7.2
Yellow-bellied Flycatcher	9.0 *	1.9		
Great Crested Flycatcher	2.1 ***	16.4		
Black-capped Chickadee	2.2 ***	16.0		
American Robin			9.7 *	23.3
Golden-winged Warbler	8.9 *	1.8		
Blackburnian Warbler	0.4 *	5.9		
Chipping Sparrow			11.5 ***	0.2
Red-winged Blackbird	1.4 **	12.3		
JULY[3]				
American Woodcock	0.2 *	4.2		
Yellow-bellied Sapsucker	2.3 ***	20.2		
Brown Creeper	4.2 *	13.0		
Winter Wren			6.3 *	16.3
Golden-crowned Kinglet			24.8 *	11.9
Veery	10.3 *	23.4		
Ovenbird			13.1 *	28.3
Common Yellowthroat	5.4 *	13.7		
Swamp Sparrow	4.1 *	12.0		
Red-winged Blackbird	1.1 **	10.0		
White-winged Crossbill			13.5 **	2.2
AUGUST[4,5]				
Yellow-bellied Sapsucker	0.2 *	5.7		
Eastern Wood-Pewee	3.8 *	12.4		
Ruby-crowned Kinglet			0.9 *	7.2
Red-eyed Vireo			4.9 *	14.8

[1] Species tested: 26 in MI; 29 in WI. [2] Species tested: 32 in MI; 25 in WI. [3] Species tested: 30 in MI; 24 in WI. [4] Species tested: 18 in MI; 13 in WI. [5] Species tested in September: 12 in MI; 14 in WI.
* P < 0.05; ** P < 0.01; *** P < 0.001

Fewer common species showed significant differences in abundance between control and treatment transects during 1987 in Wisconsin than in Michigan (Table 12). Nine of 14 comparisons involved higher prominence values on control transects (Table 12). No species, however, showed a significant difference in more than one season.

Annual variation

Annual variation in abundances of common species are examined from two perspectives. First, we compare abundances on treatment and control segments to determine if there was a switch between years (i.e., were species more abundant on treatment segments in one year but on control segments in the other). Second, we combine values from treatment and control segments to determine if there was an overall change in abundance between (or among) years.

Relative abundance on treatment and control segments did not change between years for most species (Tables 13, 14). The Common Yellowthroat was more abundant in all breeding seasons (June) on control segments in Michigan, but the extent of difference between segment types varied among years (more pronounced difference in 1986) and produced a significant year effect (Table 14). In all other cases, abundance was higher on treatment (or control) segments in one year and on control (or treatment) segments in the next. In each season and state, the number of species that showed a significant change in relative abundance on control versus treatment segments was no more than might be expected by chance alone. Of 241 comparisons, only nine (3.7%) were significant (Tables 13, 14).

A greater number of species, in both states, showed a significant change in total abundance between years (Tables 15, 16).

Table 13. Prominence values for species showing significant annual variation in in prominence values (G-test) on control (C) relative to treatment (T) segments during May, July, August, and September. A significant result reflects an interaction effect.

Species	Michigan 1986		Michigan 1987		Wisconsin 1986		Wisconsin 1987	
	T	C	T	C	T	C	T	C
MAY[1]								
Canada Warbler					3.2	0.3 *	1.7	7.8
Chipping Sparrow	4.9	18.6 ***	13.8	7.5				
JULY[2,3]								
Blue Jay					7.9	20.3 *	17.3	12.4
SEPTEMBER[4]								
American Robin					7.3	3.9 *	0.5	4.3
Ovenbird	2.0	8.9 *	7.5	2.9				

[1] Species tested: 23 in Michigan; 28 in Wisconsin.
[2] " "   " 32 " " 27 " "
[3] " "   " in August: 18 in Michigan; 13 in Wisconsin.
[4] " "   " 16 in Michigan; 16 in Wisconsin.
* $P < 0.05$; *** $P < 0.001$

Table 14. Prominence values for species showing significant annual variation (G-test) in prominence values on control (C) relative to treatment (T) segments during June.

Species	1985		1986		1987		Interaction
	T	C	T	C	T	C	
MICHIGAN[1]							
Blue Jay	13.1	21.8	15.6	5.5	21.1	23.5	*
Common Yellowthroat	6.2	8.9	1.4	13.5	6.6	10.4	*
WISCONSIN[2]							
Veery	1.2	5.8	1.2	10.3	9.0	4.7	**
Yellow-rumped Warbler	9.0	2.1	2.7	0.8	3.4	7.1	*

[1] 33 species tested.
[2] 35 "   " .
* $P < 0.05$; ** $P < 0.01$

Table 15. Species showing significant differences (G-test) in mean prominence value (control and treatment segments combined) between 1986 and 1987, during May, July, August, or September.

Species	Michigan		Wisconsin	
	1986	1987	1986	1987
MAY[1]				
Wood Thrush			6.8 **	0.4
American Robin			16.4 **	3.6
Tennessee Warbler			12.9 *	4.0
Black-and-white Warbler	14.7 **	3.4		
Rose-breasted Grosbeak	10.8 *	2.4	7.5 *	18.3
JULY[2]				
Ruffed Grouse	5.3 *	0.3		
Northern Flicker	13.7 **	3.3		
Blue Jay	7.5 **	24.9		
Brown Creeper	1.6 *	7.8		
Winter Wren	7.4 *	18.4		
Veery	3.0 **	15.8		
Cedar Waxwing			1.2 *	7.0
Mourning Warbler	1.5 *	7.9		
AUGUST[3]				
Winter Wren	0.2 *	4.0		
Hermit Thrush	1.2 *	7.3		
SEPTEMBER[4]				
Brown Creeper	3.6 *	11.7	2.6 *	12.1
Ruby-crowned Kinglet			5.2 *	0.7
Hermit Thrush	8.4 *	1.9		
Cedar Waxwing	0.1 ***	11.1		
Ovenbird			0.2 **	5.8

[1] Species tested: 23 in Michigan; 28 in Wisconsin.
[2]   "   "   32 "   "   27 "   "
[3]   "   "   18 "   "   13 "   "
[4]   "   "   16 "   "   16 "   "
* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

Table 16. Species showing significant differences in mean prominence value (control and treatment segments combined) between 1985 and 1987, during June.

Species	Michigan[1]				Wisconsin[2]			
	1985	1986	1987		1985	1986	1987	
Yellow-bell. Sapsucker					0.4	7.2	5.8	*
Great Crested Flycatcher					15.5	4.3	4.4	**
Red-breasted Nuthatch	12.7	1.4	5.4	**	9.1	0.4	7.0	**
Golden-crowned Kinglet					1.2	13.6	10.8	**
American Robin					13.7	4.9	16.1	*
Cape May Warbler					6.9	0.8	0.5	*
Blackburnian Warbler					2.9	11.8	12.4	*
Song Sparrow					3.3	8.5	14.1	*

[1] 33 species tested.
[2] 35   "   " .
* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

About twice as many species in Michigan increased from 1986 to 1987
as declined (Tables 15, 16), whereas in Wisconsin, the number that
increased or decreased was about equal. In most (but not all)
seasons, the number of significant differences was slightly more
than expected by chance alone. Overall, only 13% of comparisons
were significant.

GUILD COMPOSITION - EARLY BREEDING SEASON

Behavior of many species (e.g., habitat selection, diet) may
change markedly from one season to the next. Consequently,
distribution of individuals among guilds is analyzed for the primary
breeding period (June) only. A complete breakdown for all guilds,
by season, is in Appendix 10.

Diet

Differences between treatment and control segments were
examined for five major groups (Table 17). We combined species that
feed both on insects and fruit (e.g., foliage insects and fruit)
with those that feed almost entirely on insects (e.g., foliage
insects) because little fruit is available during the breeding
season as compared with the fall migration seasons.

There were few significant differences within a year in number
of individuals per group in treatment versus control segments (Table
17) and little consistency among years. Foliage insectivores were
significantly more abundant on treatment segments in Michigan during
1985 but this difference was not supported by data in 1986 or 1987.
Changes in relative abundance on treatment and control segments
resulted in a significant interaction between year and treatment for
foliage insectivores (Table 17). Flycatchers were more abundant on

Table 17. Mean number of individuals in five major foraging guilds recorded on control (C) and treatment (T) segments in Michigan and Wisconsin, 1985-87; means and significance of one-way ANOVAs shown are based on all segments. Two-way ANOVAs (T=treatment effect; Y=year effect; I=interaction) were calculated with logged segments excluded.

Guild	1985		1986		1987		ANOVA		
(substrate & food)	T	C	T	C	T	C	T	Y	I
MICHIGAN									
Ground invertebrates	9.1	8.7	6.3	7.0	6.3	6.2		***	
Ground invertebrates and seeds	2.8	2.2	2.3	3.0	2.6	2.5			
Foliage insects	22.9***	15.7	13.0	12.9	12.6	11.9	***	***	***
Flying insects	2.8	2.2	2.1	3.2	2.0 *	3.2			*
Bark insects	1.7	2.2	0.9	0.9	1.0	1.6	*	***	
WISCONSIN									
Ground invertebrates	9.1	7.8	6.1	6.3	5.5	7.5		**	
Ground invertebrates and seeds	2.7***	1.3	4.5 **	2.6	4.9	4.0	***	***	
Foliage insects	20.1	16.9	14.2	12.4	15.9	15.6	*	***	
Flying insects	3.0	4.8	1.7	2.0	1.9 *	2.9	**	***	
Bark insects	1.5	1.7	1.0	1.1	1.8	1.9		**	

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

control segments in 1987, in contrast to 1985 when more flycatchers were recorded on treatment segments, producing a significant interaction. No other within year comparisons were significant for Michigan. Overall abundance of three groups varied among years in Michigan, primarily due to higher numbers of individuals observed in 1985.

Marked annual variation in abundance of different foraging guilds also occurred in Wisconsin (Table 17). Significant differences primarily were due to generally lower values recorded in 1986. Differences within years were most pronounced for ground insectivores; more individuals were recorded on treatment segments in each year. Consistent patterns also were noted for foliage insectivores (more abundant on treatment segments) and flycatchers (more abundant on controls) and resulted in significant treatment effects when all years were analysed (Table 17). Flycatchers also were significantly more abundant on control segments during 1987 alone (Table 17).

Migratory strategy

Both long- and short-distance migrants were more abundant on treatment than on control segments in Michigan during 1985, but differences were not significant in later years (Table 18). In contrast, permanent residents were significantly more abundant on control segments in Michigan, but only in 1987. The inconsistent pattern among years produced significant interaction effects for permanent residents and long-distance migrants. Substantial differences in abundance among years in Michigan also were noted for permanent residents and long-distance migrants.

Short-distance migrants were more abundant in Wisconsin on

Table 18. Mean number of individuals in three migratory categories recorded on control (C) and treatment (T) segments in Michigan and Wisconsin, 1985-87; means and significance of one-way ANOVAs shown are based on all segments. Two-way ANOVAs (T=treatment effect; Y=year effect; I=interaction) were calculated with logged segments excluded.

Migratory Category	1985		1986		1987		ANOVA		
	T	C	T	C	T	C	T	Y	I
MICHIGAN									
Permanent resident	3.3	3.6	1.8	1.1	1.6 **	3.2		***	*
Short-distance migrant	7.5 *	6.3	5.8	7.5	8.0	7.0			
Long-distance migrant	29.9**	23.2	19.1	20.1	16.7	17.8		***	**
WISCONSIN									
Permanent resident	2.9	2.3	1.7	1.4	2.4	2.7		***	
Short-distance migrant	7.6***	4.3	9.2 **	5.7	10.7	9.8	***	***	
Long-distance migrant	28.0	27.1	18.4	18.7	19.3	21.6		***	

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

treatment segments in both 1985 and 1986, but no other comparisons between treatment and control segments were significant in Wisconsin (Table 18). Significant annual variation (i.e., increase or decrease) in abundance was noted for all groups but patterns of variation differed among groups (Table 18).

Nesting location

Distribution of individuals on treatment and control segments was examined for four nest site categories. Consistent differences were noted for gound nesting species in Michigan; more were recorded on treatment segments in each year (Table 19) although differences were not significant in 1986. Cavity nesters, in contrast, were more common on control segments in each year, but differences were significant only in 1987 and when all years were combined. Only subcanopy nesters showed no significant variation in overall abundance among years. Numbers were higher on control segments in 1986 but this pattern was inconsistent, resulting in a significant interaction effect.

Differences between control and treatment segments were less pronounced in Wisconsin (Table 19); only canopy nesters showed a signficant difference between control and treatment segments and only in 1985 when more were recorded on treatment segments. Cavity nesters were consistently more abundant on control segments (1985, 1986, and 1987) and a weak treatment effect was noted (two-way ANOVA); differences were not significant in any one year (Table 19).

Preferred breeding habitat

Differences between control and treatment segments in Michigan were most pronounced for birds nesting in early successional

Table 19. Mean number of individuals in four nesting categories recorded on control (C) and treatment (T) segments in Michigan and Wisconsin, 1985-87; means and significance of one-way ANOVAs shown are based on all segments. Two-way ANOVAs (T=treatment effect; Y=year effect; I=interaction) were calculated with logged segments excluded.

Nesting Category	1985		1986		1987		ANOVA		
	T	C	T	C	T	C	T	Y	I
MICHIGAN									
Ground	19.0***13.7		12.8	10.7	12.8**	9.8	***	***	
Subcanopy	7.4	6.4	4.6**	8.0	4.6	6.0			*
Canopy	11.3	9.7	7.7	8.2	7.7	9.3		**	
Cavity	3.0	3.3	1.5	1.6	1.2 **	2.6	**	***	
WISCONSIN									
Ground	16.6	15.8	14.3	12.9	15.0	16.4		*	
Subcanopy	6.7	4.4	5.3	4.6	6.8	5.5			
Canopy	13.5 *	11.1	8.4	6.6	8.6	9.6		***	
Cavity	1.9	2.5	1.3	1.7	2.0	2.5	*	*	

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

habitats, particularly in 1985 when they were much more abundant on treatment segments (Table 20). In contrast to most results for other guilds, relative abundance of birds in habitat categories remained relatively consistent between treatment and control segments among years (Table 20).

Differences in abundance also were most pronounced in Wisconsin in 1985 (Table 20), when four of six categories showed significant differences between control and treatment segments. Unlike Michigan, however, there were several changes in relative abundance on control and treatment segments among years (e.g., for mixed forest species and species preferring fields and meadows) (Table 20).

EDGE EFFECTS

Results from 1986 indicated that there was no consistent difference in total number of individuals observed on the side of treatment transects that was adjacent to the antenna versus the side away from the antenna (Hanowski et al. 1987). There also was no significant difference in distribution of individuals on treatment transects in 1987. Significantly more individuals were observed on the right than on the left side of control transects in three cases (July in Wisconsin; May and August in Michigan). No particular biological significance can be attributed to such differences at present.

Among species that showed significant differences in abundance between treatment and control segments in 1986, seven also showed a significant difference in abundance between the two sides of treatment (5 species) or control transects (2 species) (Hanowski et al. 1987). Only one of these species also showed a significant

Table 20. Mean number of individuals in six preferred breeding habitat categories recorded on control (C) and treatment (T) segments in Michigan and Wisconsin, 1985-87; means and significance of one-way ANOVAs shown are based on all segments. Two-way ANOVAs (T=treatment effect; Y=year effect; I=interaction) were calculated with logged segments excluded.

Habitat Category	1985		1986		1987		ANOVA		
	T	C	T	C	T	C	T	Y	I
MICHIGAN									
Deciduous	16.2	16.2	11.2	13.2	9.2 *	12.2	*	***	
Coniferous	2.7	1.3	1.9	1.5	2.2	2.2			
Mixed deciduous & coniferous	10.1	8.6	6.1	5.4	6.3	5.8		***	
Lowland coniferous	1.2 *	0.4	1.2	0.8	0.9	0.7			
Early successional	8.5***	3.3	4.3	3.2	4.5 *	2.8	***	*	
Fields, meadows	1.6	1.7	1.4 *	2.3	1.8	2.2			
WISCONSIN									
Deciduous	15.2	15.8	9.8	11.5	9.1 *	12.1	*	***	
Coniferous	2.8 **	1.4	2.6 **	1.2	2.4	2.2	***		
Mixed deciduous & coniferous	9.9	9.5	7.3	6.4	8.9	9.2		***	
Lowland coniferous	1.4 *	2.4	1.4	1.2	1.8	1.9			
Early successional	4.8**	3.1	5.1	3.9	6.5	5.6	**	*	
Fields, meadows	1.8***	0.7	1.4	1.0	1.6	1.8	*	*	*

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

difference in 1987; the Indigo Bunting was recorded more often (8 times) on the antenna side of treatment transects than on the opposite side (1 record).

Distribution patterns of 11 species that normally require large tracts of forest for breeding were tested for a possible edge related effect in 1987. If the antenna right-of-way influences the distribution of these species, we would expect them to be recorded more frequently on the side of treatment transects away from the antenna. Species were tested in June and July (breeding season) when habitat preferences are likely to be most pronounced. In no case was there a significant difference detected on treatment transects.

One species, the Ovenbird, was recorded more often on one side of control transects, but no edge effect can be ascribed to this difference. Also, with 88 distribution patterns tested (11 species, 2 seasons, 2 states), one significant (P<0.01) difference is not unexpected by chance alone. That is, given 100 tests, one might expect that one result would appear significant at the 0.01 level and five at the 0.05 level simply by chance.

OBSERVER VARIATION

Average number of individuals observed per segment (N=8) did not differ between observers for any single species (11 tested). The first observer recorded a greater total number of individuals per segment (47) than did the second observer (28). Much of the difference was attributable to small flocks or family groups (e.g., Winter Wren, Yellow-rumped Warbler) that were observed only by the first observer. More Ovenbirds were recorded by the first observer

(5.6/segment) than by the second (3.6/segment), repeating a pattern observed in 1986 when the order of observers was the reverse of that in 1987. In 1987, however, differences were not signficant.

DISCUSSION

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, treatment areas support more coniferous habitat, particularly lowland conifer, whereas control areas support more deciduous habitat. Differences in a variety of other habitat features also occur but the deciduous-coniferous difference was most pronounced and, as will be discussed below, likely influenced composition of related bird communities. Several differences in bird community characteristics observed between treatment and

control segments likely are related to habitat.

SPECIES DISTRIBUTION AND ABUNDANCE PATTERNS

Total individuals and species

No consistent patterns have emerged to suggest that birds are more or less abundant on treatment relative to control segments in either state. Few significant differences have been found and differences in one season or year are not always reflected in subsequent year(s) or season.

Results from Michigan are slightly more consistent than those from Wisconsin suggesting that some factor(s) other than the EM fields is (are) responsible for the observed differences. In both 1986 and 1987, species and individuals were more abundant (not significantly so in all cases) on control segments in Michigan during May, June, and July. A consistent pattern during these months (which encompass the period when birds establish territories and carry out breeding) suggests that habitat related effects may be important. Data from 1985 do not clearly support this pattern, however. Many more individuals were recorded on treatment segments during June 1985 than on controls.

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.

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 when all species are considered together. 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 these species to show similar patterns among years and seasons.

There were few cases when differences in abundance of a species between treatment and control segments remained consistent and significant among seasons and years (Tables 21, 22). Nine abundant species in Michigan and seven in Wisconsin showed a significant treatment effect (by ANOVA) in May, June, and/or July. (Few species are sufficiently abundant in August or September to meet the criterion of an abundant species.) The Nashville Warbler was more abundant on treatment segments in Michigan during two June samples (1985, 1986) and both July samples (Table 21). The White-throated Sparrow displayed similar results for June in Michigan. The Chestnut-sided Warbler was more abundant on treatment segments in June 1985 and 1987 in Wisconsin.

Many species showed significant differences in abundance among years. Such fluctuations in abundance (see Hanowski et al. 1987) may drop a species below the level of "abundant". If we combine results from abundant and common species we can further examine species distribution patterns for evidence of consistency. When

Table 21. Summary of species that were significantly more abundant on treatment (T) or control (C) segments in Michigan during 1985, 1986, or 1987. Asterisks denote "abundant" species that were tested by ANOVA. Differences for common species (no asterisks) were based on goodness-of-fit G-tests.

Species	May		June			July		August		Sept.	
	86	87	85	86	87	86	87	86	87	86	87
American Woodcock							C				
Ruffed Grouse						C					
Yellow-bellied Sapsucker	C	C					C		C		
Downy Woodpecker								C			
Eastern Wood-Pewee									C		
Yellow-bellied Flycatcher			T	T	T						
Least Flycatcher						C					
Great Crested Flycatcher					C						
Blue Jay				T						C	
Black-capped Chickadee		C*			C						
Brown Creeper							C				
Winter Wren	C		C								
Golden-crowned Kinglet			T								T*
Veery							C				
Hermit Thrush						T*					
American Robin			T								
Golden-winged Warbler					T						
Nashville Warbler			T*	T*		T*	T*				
Chestnut-sided Warbler			T*								
Yellow-rumped Warbler			T	T						C	
Black-throated Green Warbler		C*									
Blackburnian Warbler					C						
Black-and-white Warbler	C	C									
American Redstart										C	
Ovenbird	C*	C								C	
Mourning Warbler			T*								
Common Yellowthroat				C		C	C				
Rose-breasted Grosbeak	C		C*								
Chipping Sparrow	C		T								
Song Sparrow			C								
Swamp Sparrow		C					C				
White-throated Sparrow			T*		T*		T*		T*	T	
Red-winged Blackbird	C	C		C	C	C					
Brown-headed Cowbird	C			C							
Purple Finch		C									
More abundant on controls	8	8	3	3	4	3	7	1	2	4	0
More abundant on treatments	0	0	9	4	3	2	2	0	1	1	1

Table 22. Summary of species that were significantly more abundant on treatment (T) or control (C) segments in Wisconsin during 1985, 1986, or 1987. Asterisks denote "abundant" species that were tested by ANOVA. Differences for common species (no asterisks) were based on goodness-of-fit G-tests.

Species	May		June			July		August		Sept.	
	86	87	85	86	87	86	87	86	87	86	87
Ruffed Grouse			C							C	
Eastern Wood-Pewee					C						
Yellow-bellied Flycatcher			C*								
Alder Flycatcher			T								
Least Flycatcher		C*	C*								
Great Crested Flycatcher		C	C	C							
Blue Jay		T*				C					
Red-breasted Nuthatch							T*				
Winter Wren			C				C				
Ruby-crowned Kinglet									C		
Golden-crowned Kinglet				T		T					
Veery				C							
Hermit Thrush								T			
American Robin			T		C						
Red-eyed Vireo									C		
Nashville Warbler								T			
Northern Parula	C*										
Chestnut-sided Warbler			T*		T*						
Magnolia Warbler	T	T									
Cape May Warbler	T										
Yellow-rumped Warbler			T								
Black-and-white Warbler	C*										
Ovenbird					C*	C	C				
Common Yellowthroat		T									
Canada Warbler		C		C							
Rose-breasted Grosbeak	C	C		C							
Indigo Bunting				T							
Chipping Sparrow			T	T	T						
Song Sparrow	T										
Swamp Sparrow			T	T			T				
White-winged Crossbill							T				
Evening Grosbeak			T								
More abundant on controls	3	4	5	4	3	2	2	0	2	1	0
More abundant on treatments	3	3	7	4	2	1	3	2	0	0	0

examined in this way, more species showed consistent patterns in
abundance between treatment and control segments among seasons and
years (Tables 21, 22). Seventeen species in Michigan and 14 in
Wisconsin showed a significant difference between treatment and
control segments in more than one case (season or year). Of these,
only three species in Michigan (Blue Jay, Yellow-rumped Warbler, and
Chipping Sparrow) and two in Wisconsin (Blue Jay, American Robin)
were more abundant on either treatment or control segments in one
case and had the reverse true in a second case (Tables 21, 22).
Such reversals may reflect differences in the precision of habitat
selection by species among seasons. For example, the Yellow-rumped
Warbler was more abundant on treatment segments in June 1985 and
1986 in Michigan but was recorded more frequently on control
segments during fall migration (September, Table 21).

A majority of species that showed a significant difference in
abundance between treatment and control segments did so in only one
season in both states (Tables 21, 22). Thus, for those species we
are not yet able to determine if the difference seen in one season
is biologically meaningful (i.e., likely to be repeated in
subsequent seasons or years).

There were 66 significant differences in individual species
comparisons over all seasons in Michigan and 51 in Wisconsin. In
Michigan, 43 comparisons revealed higher abundances on control
segments. There was, however, considerable variation among seasons
in number of significant differences (Table 21). In contrast,
comparisons were evenly divided between those more abundant on
treatment and those more abundant on controls in Wisconsin (Table

Differences in abundance of some species between treatment and control segments likely are related to habitat, at least in some cases. White-throated Sparrows, for example, were consistently more abundant on treatment segments in Michigan. This species favors early successional habitats and often is abundant in young clear cuts. Such habitats are 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. Later analyses that examine species-habitat relationships in more detail, particularly in Wisconsin, will help resolve the influence of habitat on bird species distribution patterns. Such analyses may eventually require dividing transects on the basis of habitat rather than on length (i.e., 500 m segments).

GUILD ANALYSES

Species that belong to the same "guild" share some biological characteristics. Thus, if the ELF antenna system influences the distribution 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.

We noted some differences in distribution patterns of different groups within guilds. For the most part, however, differences were not present in each year or consistent from year to year. In Michigan, differences that occur now are most likely due to differences in habitat between treatment and control segments. This supposition is supported by the fact that distribution of

individuals among groups defined by preferred breeding habitat varied least, overall, from year to year. Significant interaction effects (two-way ANOVAs) were noted for one or two categories in all other guilds (food, nesting, and migration) but were not noted for any of the habitat groups in Michigan.

Treatment segments in Michigan support more early successional habitat than do control areas and birds breeding in such habitats showed the strongest treatment effect, being more abundant in treatment segments. Control areas, in contrast, supported more deciduous habitat and also more birds that breed in such habitat. Similarly, deciduous trees were more abundant on control areas in Wisconsin as were birds that depend on this habitat. The reverse was true for coniferous habitat.

We will be better able to assess the relative influence of habitat versus EM related effects on the distribution of guild members in Michigan after the system begins operation. Similarly, we will be able to examine guild patterns more closely in Wiscosnin after we pair segments on the basis of habitat structure. At present, without related information on resource and nesting site abundance, we cannot make any definitive statements regarding the cause of observed differences in related bird guilds. Additional years of data will more clearly define any differences that may exist between treatment and control segments.

ANNUAL VARIATION

Substantial variation occurred between years in abundance of many bird species. Abundance was highest in June 1985 and lowest in June 1986. Causes of such variation largely are unknown but likely

are related to weather (see Hanowski et al. 1987). Two, or even three years of data are too few to adequately address the causes and consequences of annual variation in bird populations. By the completion of this project, however, we will be able to analyse such variation in some detail.

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. This is not always completely possible because of problems associated with procurring lodging. 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.

OBSERVER DIFFERENCES

Observer variability in bird detection and recording of birds observed is a potential source of error in bird census work (Kavanagh and Recher 1983). Several factors may contribute to variation in the ability to detect and record birds. They include: observer's hearing acuity (Cyr 1981; Ramsey and Scott 1981), avian density (Bart and Schoultz 1984), and ability to estimate distance to singing birds (Emlen and DeJong 1981; Scott et al. 1981). We

considered potential effects that observer variation could have on results of this investigation when the study was designed (see methods). For example, observers census the same number of control and treatment segments in each census period and, although we estimate a distance to each bird observed, we do not use these values to calculate densities.

Despite these controls for observer variability in our study design, we still were interested in identifying variability between observers. Our test (an almost simultaneous census of 8 segments) was completed during the June breeding season when almost all bird observations are recorded by sound. Observer one started censusing 10 minutes before observer two (start time was offset to eliminate any affect that observers may have on each other). In 1986, observer one recorded more Ovenbirds than observer two. It was not clear what caused this difference between observers. It is unlikely that it was due to differences in hearing ability because the Ovenbird's song is loud, very distinct, and can easily be detected for > 100 m. It is more likely that the Ovenbird's singing behavior was affected by passage of the first observer. This suggestion was supported by our data from 1987. Once again the first observer recorded more Ovenbirds (not significantly) than the second observer. Because the order of observers was the reverse of that used in 1986, we feel that the differences were due to behavioral changes in Ovenbirds produced by the passage of the first observer. Similarly, the first observer recorded a greater total number of individuals than did the second in 1987. Much of this difference was attributable to the occurrence of family groups and small flocks

that were not seen by the second observer. Similarly, birds such as

the Ruffed Grouse were flushed by the first observer and not

recorded by the second.

EDGE EFFECTS

Analyses conducted on 1986 data revealed no clearly detectable

"edge" effect on the distribution of bird species (Hanowski et al.

1987). We repeated our analyses using 1987 data, examining all

species that showed a significant difference in lateral distribution

patterns in 1986. One species, the Indigo Bunting, was

significantly more abundant on the antenna side of treatment

segments in both 1986 and 1987. No other species showed a

significant difference in both years.

This year we also examined distribution patterns of birds that

typically require large expanses of forest for breeding. Such

species might be expected to be more abundant on the side of

treatment segments away from the transmission line. No differences

were detected for any species that require large forest tracts.

Thus, with the likely exception of the Indigo Bunting, a

relatively uncommon species in this region, there appears to be

little if any direct effect of the ROW and associated edge habitat

on our results.

FUTURE PLANS AND OBJECTIVES

Vegetation analyses - Wisconsin

Vegetation sampling has been completed at all Wisconsin sites.

These data will be used in several future analyses of the influence

of the ELF system on bird communities. As stated in the original

proposal, we will attempt to pair treatment and control segments on

the basis of vegetational similarity. Such pairing can be done

using structural characteristics of the vegetation (e.g., tree density), plant species composition, or some combination of both types of attributes. If a sufficient number of similar pairs can be determined, we will then be able to compare bird community attributes.

A second potential analysis will involve matching bird species with vegetation attributes. Abundance of that bird species in treatment and control segments can be compared on the basis of vegetation present in each segment. Segments with vegetation that more closely matches the preferred habitat of the species being analysed are expected to support more individuals of that species. If the antenna has exerted an influence on the distribution patterns of the species (negatively or positively) then we would expect treatment segments to support fewer (or more) individuals of that species than control segments, after taking differences in vegetation into account.

Objectives

Our major objectives for 1987 were to complete bird censuses during all seasons in both states and to complete sampling of vegetation in Wisconsin. These objectives were met fully. Our objectives for 1988 and beyond are to continue our sampling of bird communities, following our established procedures. We also will be using the vegetation data from Wisconsin in more detailed analyses of bird - habitat relationships for that state. Such analyses will continue for the entire period that birds are sampled.

LITERATURE CITED

American Ornithologists' Union. 1983. Check-list of North American
      birds. Sixth Edition. American Ornithologists' Union,
      Washington, D.C.

_____. 1985. Thirty-fifth supplement to the
      American Ornithologists' Union check-list of North American birds.
      Auk 102:680-686.

Anderson, S.H. 1979. Changes in forest bird species composition
      caused by transmission-line corridor cuts. Amer. Birds 33:3-6.

_____, K. Mann, and H.H. Shugart, Jr. 1977. The effect of
      transmission-line corridors on bird populations. Amer. Midl.
      Natur. 97:216-221.

Bart, J. and J.D. Schoultz. 1984. Reliability of singing bird
      surveys: changes in observer efficiency with avian density.
      Auk 101:307-318.

Beals, E. 1960. Forest bird communities in the Apostle Islands of
      Wisconsin. Wilson Bull. 72:156-181.

Beals, E. W. 1984. Bray-Curtis ordination: an effective strategy for
      analysis of multivariate data. Adv. Ecol. Res. 14:1-55.

Beason, R.C. and W.J. Brennan. 1986. Natural and induced
      magnetization in the Boboblink Dolichonyx oryzivorus (Aves:
      Icteridae). J. Exp. Biol. in press.

Beaulaurier, D.L., B.W. James, P.A. Jackson, J.R. Meyer and J.M. Lee.
      1982. Mitigating the incidence of bird collisions with
      transmission lines. Third Symp. on Env. Concerns in ROW
      Management, San Diego, CA.

Beaver, D.L., J.H. Asher, and R.W. Hill. 1985. Small vertebrates:
      The Michigan study site. In Tech. Rpt. EO6549-17 U.S. Naval
      Electronics Systems Command, Washington, D.C.

Bell, H.L. 1980. The effects of a powerline clearing on birds of dry
      sclerophyll forest at Black Mountain Reserve, Australian Capital
      Territory. Corella 4:8-19.

Bent, A.C. 1963. Life histories of North American wood warblers.
      Dover Publications, New York.

Bent, A.C. 1964. Life histories of North American thrushes,
      kinglets, and their allies. Dover Publications, New York.

Blake, J.G. 1982. Influence of fire and logging on nonbreeding bird
      communities of ponderosa pine forests. J. Wildl. Manage.
      46:404-415.

Blake, J.G. and J.R. Karr. 1984. Species composition of bird

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communities and the conservation benefit of large versus small forests. Biol. Conserv. 30:173-187.

Bramble, W.C., W.R. Byrnes and M.D. Schuler. 1984. The bird population of a transmission right-of-way maintained by herbicides. J. Arboriculture 10:13-20.

Brosh, R.M., J.R. Gauger, and J.E. Zapotosky. 1986. ELF communications system ecological monitoring program: electromagnetic field measurements and engineering support-1985. IIT Research Institute Tech. Rpt. E06549-24 Chicago, IL.

Burnham, K.P., D.R. Anderson, and J.L. Laake. 1981. Line transect estimation of bird population density using a fourier series. Studies in Avian Biol. No. 6: 466-482.

Chasko, G.G. and J.E. Gates. 1982. Avian suitability along a transmission-line corridor in an oak-hickory forest region. Wildl. Monogr. 82:1-41.

Cody, M.L. ed. 1985. Habitat selection in birds. Academic Press, Inc., Orlando, Florida.

Cottam, G. and J.T. Curtis. 1956. The use of distance measurements in phytosocialogical sampling. Ecology 37:451-460.

Cyr, A. 1981. Limitation and variability in hearing ability in censusing birds. Studies in Avian Biol. No. 6: 327-333.

Dawson, B.A. and J.E. Gates. 1979. Habitat-niche discrimination of passerines along a transmission-line corridor. 2nd Symp. on Env. Concerns in Rights-of-Way Management, Univ. of Mich., Ann Arbor.

Durfee, W.K., C. Polk, L.T. Smith, T.J. Keefe, and S. Muthukishan. 1976. Influence of extremely low frequency magnetic fields on growth, development, and behavior in domestic birds. Univ. of Rhode Island, Final Report, Phase II, December.

Emlen, J.T. 1971. Population densities of birds derived from transect counts. Auk 88:323-342.

_____. 1977. Estimating breeding season bird densities from transect counts. Auk 94:455-468.

Emlen, J.T. and M.J. DeJong. 1981. The application of song detection threshold distance to census operations. Studies in Avian Biol. No. 6: 346-352.

Emlen, S.T. 1975. Migration: Orientation and navigation, pp. 129-219. In D.S. Farner, J.R. King, and K.C. Parkes (eds). Avian Biol. 5., Academic Press.

Green, J.C. and G.J. Niemi. 1978. Birds of the Superior National Forest. Publ. of U.S. Dept. Agric. Forest Service. 82 pp.

Greig-Smith, P. 1983. Quantitative plant ecology, third edition. Blackwell Scientific Publ., Oxford.

Hanowski, J.M., G.J. Niemi, and J.G. Blake. 1987. ELF communications system ecological monitoring program: bird species and communities. Annual Report 1986, Subcontract No. E06549-84-011. In Compilation of 1986 Annual Reports of the Navy ELF Communications System Ecological Monitoring Program, July, 1987; Technical Report E06549-38, Contract No. N00039-84-C-0070. pp. 117.

Haradem, D.P., J.R. Gauger, and J.E. Zaptosky. 1987. ELF communications system ecological monitoring program: electromagnetic measurements and engineering support - 1986. IITRI Technical Report E06549-37 to Space and Naval Warfare Systems Command, Washington, D. C.

Hilden, O. 1965. Habitat selection in birds. Ann. Zoo. Fennici 2:53-75.

James, F.C. 1971. Ordinations of habitat relationships among breeding birds. Wilson Bull. 83:215-236.

Jarvinen, O. and R. Vaisanen. 1975. Estimating the relative densities of breeding birds by the line transect method. Oikos 26:316-322.

Kavanagh, R. and H.F. Recher. 1983. Effects of observer variability on the census of birds. Corella 7:93-100.

Kroodsma, R.L. 1982. Edge effect on breeding birds along a power-line corridor. J. Appl. Ecology 19:361-370.

Krueger, W.F., A.J. Giarola, J.W. Bradley, and S.R. Daruvalla. 1972. Influence of low level electronic and magnetic fields on the growth of young chickens. Biomed. Sci. Instrum. 9:183-186.

Lack, D. 1933. Habitat selection in birds: with special reference to the effects of afforestation on the Breckland Avifauna. J. Anim. Ecol. 2:239-262.

Lakela, O. 1965. A flora of northeastern Minnesota. 541 p. Univ. Minn. Press. Minneapolis, MN.

Larkin, R.P. and P.J. Sutherland. 1977. Migrating birds respond to project seafarer's electromagnetic field. Science 195:777-778.

Lee, J.M., Jr., T.D. Bracken, and L.E. Rogers. 1979. Electric and magnetic fields as considerations in environmental studies of transmission line, pp. 55-73. In Biological effects of extremely low frequency electromagnetic fields. Conf-78106. National Tech. Inf. Serv. Springfield, Va.

Lee, J.M., Jr. and D.B. Griffith. 1978. Transmission line audible noise and wildlife, pp. 105-168. In Effect of noise on

wildlife (J.M. Fletcher and R.G. Busnel, Eds.) New York,
Academic Press.

Martin, A.C., H.S. Zim, and A.L. Nelson. 1951. American wildlife and
plants. Dover Publ., Inc., New York.

Meyers, J.M., and E.E. Provost. 1979. Bird population responses to a
forest-grassland and shrub ecotone on a transmission line
corridor, pp. 60-1-60-13. In Proc. 2nd Symp. Enviro. Concerns
in Rights-of-Way Mgmt. Ann Arbor, Mi., Univ. Michigan.

National Academy of Science. 1977. Biological effects of electric
and magnetic fields associated with proposed project seafarer.
Report of the committee on biosphere effects of extreme low
frequency radiation. Division of Medical Sciences, National
Research Council.

Niemi, G.J. 1985. Patterns of morphological evolution in bird genera
of new world and old world peatlands. Ecology 66:1215-1288.

_____ and J.M. Hanowski. 1984. Effects of a transmission line
on bird populations in the Red Lake Peatland, northern Minnesota.
Auk 101:487-498.

_____. 1986. ELF communications system ecological monitoring
program: Bird species and communities. In Tech. Rpt.
E06549-17 U.S. Naval Electronics Systems Command, Washington,
D.C.

Ramsey, F.L. and J.M. Scott. 1981. Tests of hearing ability.
Studies in Avian Biol. No. 6: 341-345.

Richardson, W.J. 1978. Timing and amount of bird migration in
relation to weather: a review. Oikos 30:224-272.

Scott, J.M., F.L. Ramsey, and C.B. Kepler. 1981. Distance estimation
as a variable in estimating bird numbers from vocalizations.
Studies in Avian Biology No. 6: 334-340.

Snedecor, G.W. and W.G. Cochran. 1967. Statistical methods, sixth
edition. The Iowa State University Press, Ames, Iowa, USA.

Sokal, R.R. and F.J. Rohlf. 1981. Biometry. W.H. Freeman and Co.
San Francisco, CA.

Southern, W.E. 1972. Influence of disturbances in the earth's
magnetic field on Ring-billed Gull orientation. Condor
74:102-105.

_____. 1975. Orientation of gull chicks exposed to project
Sanguine's electromagnetic field. Science 189:143-145.

Stapleton, J., and E. Kiviat. 1979. Rights of bird populations and
rights of way. Amer. Birds 33:7-10.

Svensson. 1977. Land use planning and bird census work with
    particular reference to the application of the point sampling
    method. Pop. Ecol. Stud. 3(4):99-117.

Terres, J.K. 1982. The Audubon Society Encyclopedia of North
    American Birds. Alfred A. Knopf, New York.

Verner, J. 1984. The guild concept applied to management of bird
    populations. Environ. Manage. 8:1-14.

Wiens, J.A. 1969. An approach to the study of ecological
    relationships among grassland birds. Orn. Mono. No. 8, Allen
    Press, Lawrence, Kansas.

_____, and J.T. Rotenberry. 1981. Habitat associations and
    community structure of birds in shrubsteppe environments. Ecol.
    Monogr. 51:21-41.

Williams, T.C. and J.M. Williams. 1976. A radar investigation of the
    effects of extremely low frequency electromagnetic fields on free
    flying migrant birds; final report; Office of Naval Research,
    U.S. Dept. of the Navy.

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

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

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

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

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

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

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

addition, if our estimates of the mean and variances are correct, transect counts are slightly more efficient in terms of effort (Table A1).

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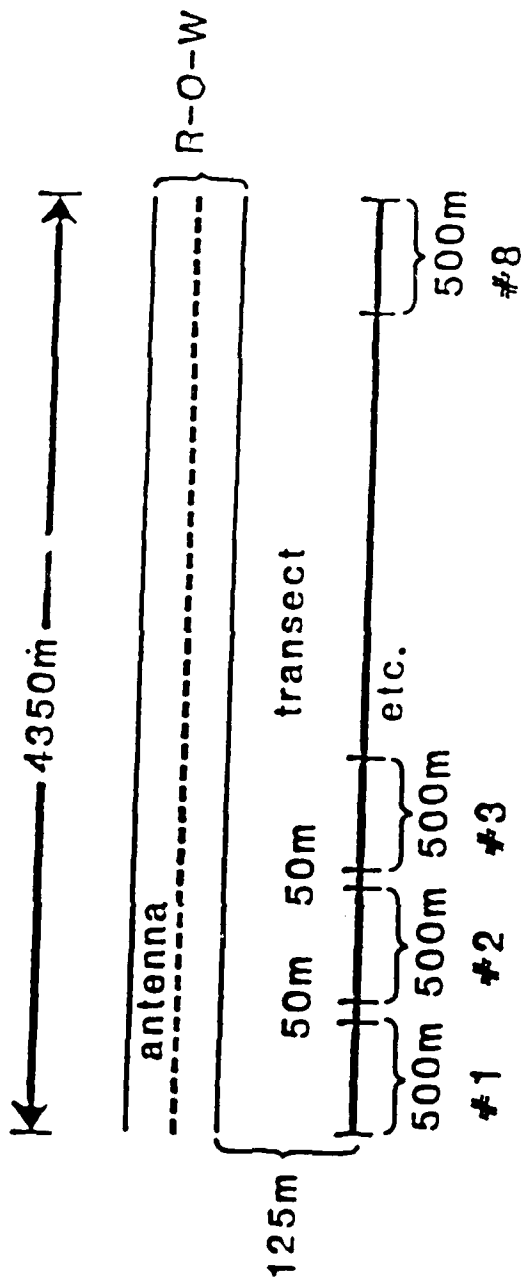
Figure Al. Schematic of a treatment transect layout. ROW = right-of-way.

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).

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). 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
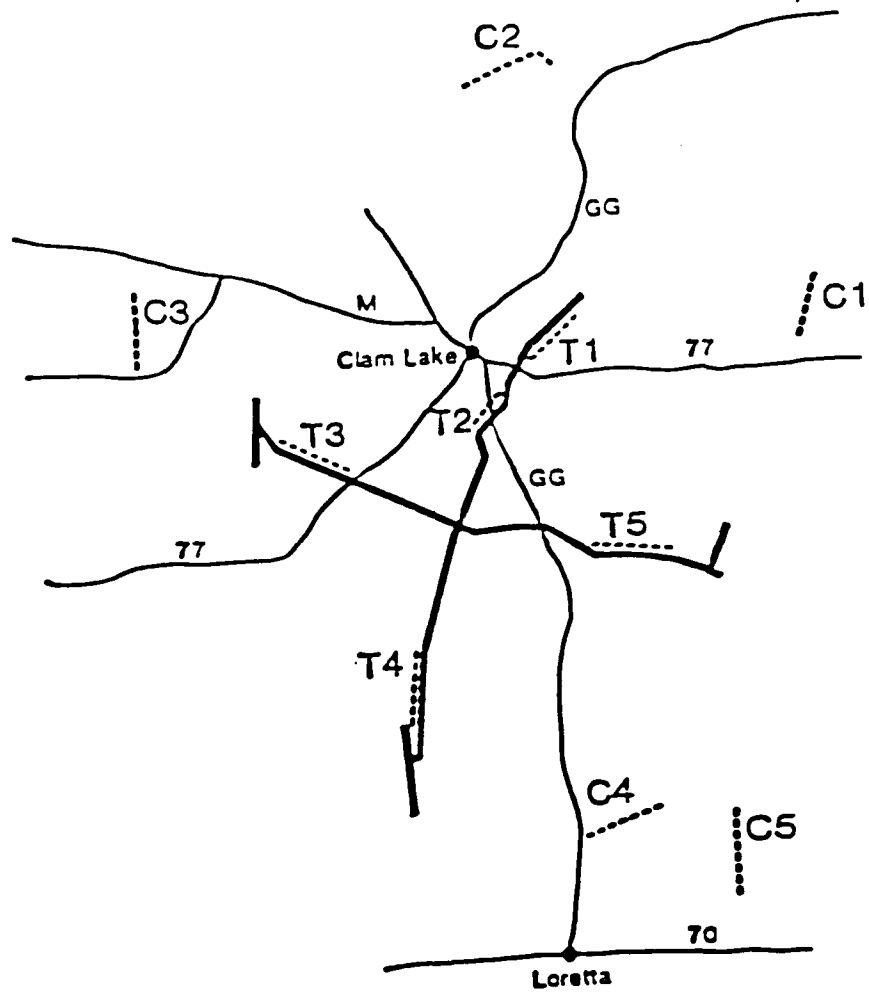
Figure A2.   Location of Wisconsin antenna and study transects.
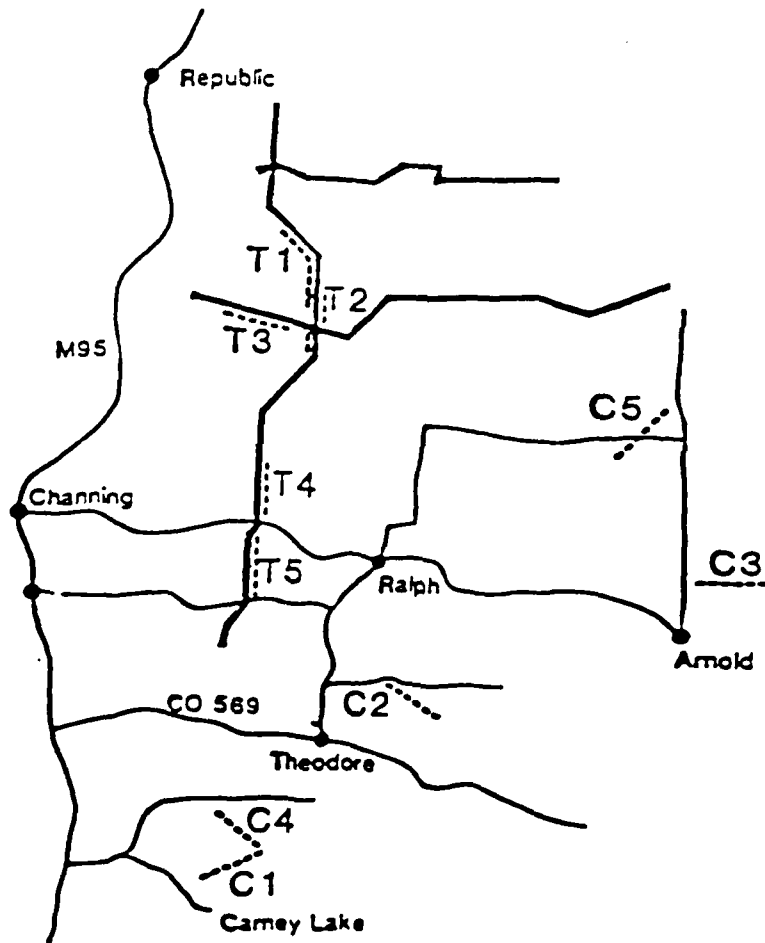
Figure A3. Location of Michigan antenna and study transects.

"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 are scheduled for logging in Michigan
effective through 1990 (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).
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

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.

Number and Name	Township	Range	Sections	Number of 500 m segments affected
MICHIGAN				
C1 Carney Lake	41N	29W	33,34,35,36	2
C2 Skunk Creek	42N	28W	14,23,24	2 (thinning)
	42N	27W	19,30	
C3 Arnold	43N	25W	31,32,33,34	1 *
C4 Lost Lake	41N	29W	21,26,27,28,35	1
C5 Bob's Creek	44N	26W	13,23,24,26	0
T1 Heart Lake	45N	28W	7,18	1
	46N	29W	1	
T2 Flat Rock Creek	44N	28W	6	3 *
	45N	28W	19,30,31	
T3 Schwartz Creek	45N	28W	31	1
	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
WISCONSIN				
C1 Spillerberg Lake	43N	3W	23,26,35	0
C2 Mineral Lake	44N	4W	15,16,17,18	0
C3 Rock Lake	42N	6W	6	1 (thinning)
	43N	6W	19,30,31	
C4 Blaisdell Lake	40N	4W	13,14,22,23	0
	40N	3W	18	
C5 Brunette River	40N	3W	16,21,28	1 (thinning)

Number and Name	Township	Range	Sections	Number of 500 m segments affected
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) * 1 (thin all) *
T4 Black Lake	41N	5W	24,25,36	0
T5 Moose River	42N	3W	31	1 (thin part) * 2 (thin all) *
	42N	4W	35,36	

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.

Eight transect segments were censused daily by each observer. Each observer walked the designated transect segment at a rate of 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 directly from field sheets. Birds flying over (i.e., above the canopy) were not included. Data were checked for accuracy by someone other than the original data entry person.

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 migra-

tion 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 3. 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 classifications 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
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
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	93
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	
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
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
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
Rusty Blackbird	3	8	9	2
Brewer's Blackbird	3,1	8	5	2

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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

5 Ledge or platform

6 Cavity - tree roots

7 Nest parasite

B. Food

1 Aquatic vertebrates, including species feeding on fish or other aquatic vertebrates

2 Predator on birds, small mammals, large insects

3 Scavenger

4 Species feeding on vegetation such as buds, pine needles, and seeds but excluding species concentrating on seeds or fruits

5 Omnivores; various small vertebrates (including eggs and young), invertebrates, plants, carrion, etc.

6 Ground invertebrates

7 Seeds (plus a smaller amount of fruit by some species)

8 Ground insects and seeds

9 Ground insects and fruit

10 Foliage insects

11 Aerial insects - taken while in continuous flight

12 Flycatchers

13 Foliage insects and fruit

14 Fruit

15 Foliage insects and seeds

16 Bark insects

17 Nectar and sap

18 Aquatic vegetation

19 Aquatic invertebrates

C. Habitat

1 Deciduous forest

2 Coniferous forest

3 Mixed deciduous - coniferous forest

4 Early successional deciduous - coniferous forest

5 Fields and meadows

6 Shrub swamp

7 Urban

8 Open wetlands (e.g., sedge fen, cattail)

9 Ponds, lakes, rivers, and streams

10 Muskeg

11 Lowland coniferous forest

D. Migration

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

    2 Short-distance migrant; generally includes breeders; individuals generally winter south of study areas but most winter north of the tropics

    3 Long-distance migrant; generally winter south of the U.S.

    4 Winter resident

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

Appendix 3.   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 in m^2 surrounding the center point
Water Cover	Estimate of percent of standing water in m^2 surrounding the center point
Water Depth	Depth at center point
Overall Height	Estimate of the average height of vegetation in 25 m^2 surrounding center point
Tree Density	Density of trees greater than 2.5 cm diameter breast height (dbh) measured by the point-centered 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 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)

Appendix 3 (continued)

Shrub Height	Height of four shrubs measured for shrub density
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 method

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)
Upland Deciduous Forest	Upland forest with > 90% mixed deciduous species
Maple Forest	Upland deciduous forest with > 90% maple species
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% 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 < 3m
Young Cut Mixed	Logged area with mixed species < 3m
Short Aspen	Logged area with aspen > 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 5. Summary statistics for habitat variables measured in Wisconsin. Control segments are 1-40; treatment segments are 41-80.

Appendix 5. Summary statistics for habitat variables measured in Wisconsin. Control segments are 1-40; treatment segments are 41-90.

segment	grass-sedges per m2		forbs per m2		shrubs per 25 m2		trees per 100 m2		fallen logs per 100 m2	
	mean	% cv	mean	% cv	mean	% cv	mean	% cv	mean	% cv
1	0.8	0.0	400.0	0.0	41.9	0.0	8.2	0.0	6.3	0.0
2	2.0	78.8	13.1	147.8	84.5	94.2	15.1	44.6	139.8	160.7
3	718.5	319.3	22.8	82.4	138.9	123.2	12.3	37.3	130.9	164.5
4	42.8	121.8	30.0	123.8	33.2	90.0	14.9	63.0	69.3	126.3
5	143.6	242.3	191.1	152.2	21.2	87.0	27.9	95.5	58.5	172.3
6	236.6	234.2	71.8	129.0	49.7	97.6	22.7	86.7	110.6	118.9
7	49.7	225.6	70.4	93.0	81.6	152.6	28.9	64.2	253.8	147.2
8	2.0	0.0	219.5	0.0	28.6	0.0	9.0	0.0	28.9	0.0
9	78.2	376.9	50.6	84.4	48.0	89.1	24.6	79.0	155.7	128.4
10	447.1	265.1	55.8	80.4	61.8	67.9	49.2	60.9	155.9	106.2
11	38.6	279.6	31.0	107.9	81.0	122.4	16.7	70.5	74.6	90.2
12	657.9	344.6	39.9	77.6	69.5	95.7	13.1	73.6	62.8	172.9
13	93.9	378.3	58.5	81.9	101.1	116.0	17.6	87.1	89.7	117.2
14	16.5	271.6	78.2	204.7	90.5	112.8	14.6	72.0	166.1	172.4
15	566.2	392.4	40.4	116.9	51.7	85.8	34.1	85.1	144.7	102.3
16	22.6	214.0	26.3	130.7	98.0	95.2	13.5	53.3	120.9	121.3
17	47.4	198.9	54.3	115.1	46.3	142.1	13.2	82.4	41.7	134.5
18	50.1	180.3	53.1	100.6	54.7	97.3	23.5	87.0	35.8	108.9
19	32.9	214.9	53.1	98.9	71.7	114.3	6.6	80.2	17.1	134.7
20	26.6	177.4	68.2	104.6	76.2	85.9	19.5	88.9	19.8	96.0
21	141.0	191.5	104.6	81.5	47.3	85.4	13.3	47.4	28.6	63.5
22	92.8	277.7	110.7	95.5	49.1	64.6	18.8	76.1	86.2	99.3
23	391.4	153.2	61.4	65.1	71.9	60.0	17.1	103.5	30.6	125.4
24	152.5	147.7	91.9	99.2	46.9	83.4	12.0	86.1	24.9	115.9
25	105.7	109.6	52.5	87.6	37.8	146.3	25.2	89.7	39.0	207.8
26	39.3	153.7	29.5	158.7	69.5	118.0	8.9	94.1	34.7	207.2
27	97.4	81.6	70.1	226.1	81.9	91.0	13.6	63.3	84.4	201.6
28	278.8	212.2	33.4	113.2	57.5	166.3	0.7	169.1	431.2	131.1
29	590.5	377.4	23.1	74.1	54.5	101.7	14.1	71.8	67.5	155.1
30	136.4	222.1	33.3	90.3	65.4	110.2	16.6	157.2	136.3	148.2
31	231.8	315.2	78.2	103.8	114.6	191.9	10.2	72.7	36.0	160.6
32	321.4	306.3	88.6	171.6	115.0	97.8	13.5	109.6	99.4	90.2
33	234.3	242.9	73.5	178.7	68.5	100.1	9.1	55.0	136.6	109.6
34	613.2	362.6	44.6	93.6	69.8	88.4	13.7	65.1	552.5	187.6
35	83.0	210.9	51.5	92.6	31.6	98.8	19.8	87.5	140.8	131.7
36	172.6	319.4	61.3	101.1	46.2	149.8	19.0	71.1	110.7	143.3
37	571.9	388.6	139.0	117.4	62.7	111.2	29.3	68.9	93.9	140.2
38	44.9	190.7	58.7	74.1	29.2	83.9	23.0	78.3	88.5	102.4
39	146.7	79.2	71.9	111.1	83.1	70.9	11.8	150.0	18.2	351.3
40	60.0	177.5	61.8	86.6	118.5	87.7	22.3	57.8	67.2	179.8

Appendix 5 (continued)

segment	ground cover		% water cover		water depth (cm)		% canopy cover	
	mean	% cv	mean	% cv	mean	% cv	mean	% cv
1	5.0	0.0	0.0	0.0	0.0	0.0	5.0	0.0
2	5.6	274.3	35.0	110.9	13.8	131.5	17.8	112.1
3	4.7	104.5	0.1	435.9	0.1	435.9	4.7	22.4
4	3.7	63.6	0.0	0.0	0.0	0.0	4.1	38.8
5	56.8	81.0	1.3	435.9	0.1	435.9	42.8	64.1
6	62.2	63.1	0.4	292.0	0.3	311.4	32.8	97.4
7	21.0	102.9	1.6	407.3	0.4	311.4	7.7	37.9
8	5.0	0.0	0.0	0.0	0.0	0.0	11.0	0.0
9	25.4	126.1	0.3	435.9	0.2	435.9	4.5	44.7
10	66.8	43.9	8.4	138.4	2.5	71.9	7.2	51.9
11	6.9	103.1	3.8	435.9	0.8	435.9	6.0	40.1
12	39.0	97.2	4.3	408.9	0.8	311.4	13.1	82.0
13	46.8	79.9	5.8	312.8	1.9	351.3	14.1	101.1
14	19.6	122.0	4.4	317.9	1.0	191.9	13.9	89.6
15	54.3	72.8	1.8	372.8	0.6	363.4	16.3	114.9
16	8.0	174.3	2.5	350.9	0.3	292.0	7.3	28.0
17	28.2	105.3	0.0	0.0	0.0	0.0	31.8	88.0
18	21.4	117.3	0.0	0.0	0.0	0.0	18.3	83.2
19	25.8	104.8	0.0	0.0	0.0	0.0	36.5	76.8
20	15.6	66.3	0.0	0.0	0.0	0.0	10.8	27.3
21	61.8	37.7	7.3	136.7	1.2	101.0	16.0	52.3
22	37.0	82.0	0.0	0.0	0.0	0.0	24.0	65.3
23	44.0	51.3	2.2	301.7	0.3	237.3	17.5	54.1
24	37.0	77.5	0.0	0.0	0.0	0.0	45.9	55.4
25	63.2	51.6	0.0	0.0	0.0	0.0	19.2	80.4
26	75.8	41.7	0.0	0.0	0.0	0.0	31.3	46.5
27	24.0	75.0	1.0	435.9	0.2	435.9	25.5	124.8
28	19.0	72.9	8.0	239.6	2.0	255.1	91.7	15.4
29	24.7	85.2	0.0	0.0	0.0	0.0	16.8	85.6
30	27.0	109.3	0.0	0.0	0.0	0.0	17.6	99.8
31	12.3	116.2	0.0	0.0	0.0	0.0	15.0	87.3
32	12.1	83.3	0.0	0.0	0.0	0.0	24.5	91.5
33	7.9	205.9	0.0	0.0	0.0	0.0	9.6	114.5
34	12.9	115.8	2.3	385.9	0.3	311.4	15.9	71.7
35	46.0	80.0	6.8	273.7	0.9	199.9	11.7	72.0
36	38.0	76.0	0.8	311.4	0.3	311.4	17.5	122.5
37	50.5	61.6	36.5	76.4	8.8	61.7	9.4	47.9
38	16.6	154.1	1.0	435.9	0.2	435.9	6.1	40.1
39	24.1	112.7	7.8	264.8	1.3	257.8	33.3	92.3
40	10.8	105.6	0.0	0.0	0.0	0.0	10.8	77.0

Appendix 5 (continued)

segment	shrubs (dm)		trees (m)		overall (m)		% deciduous trees
	mean	% cv	mean	% cv	mean	% cv	mean
1	9.5	0.0	7.2	0.0	16.0	0.0	76.3
2	6.9	56.0	13.0	40.5	17.4	26.7	76.3
3	6.1	31.6	17.0	25.6	20.3	7.1	100.0
4	7.6	49.6	14.7	19.1	18.2	9.9	93.8
5	9.9	38.0	6.8	25.9	8.5	36.3	30.0
6	9.1	41.3	8.1	48.0	11.3	54.9	48.8
7	7.6	34.2	10.0	29.8	15.1	11.9	58.7
8	8.3	0.0	10.2	0.0	16.0	0.0	56.3
9	9.8	61.3	11.1	29.6	16.0	25.4	86.3
10	9.8	50.6	8.0	25.0	11.1	18.9	71.3
11	6.9	30.9	13.8	23.6	17.5	16.7	82.5
12	9.0	55.9	11.7	32.3	13.3	33.0	50.6
13	10.9	37.0	8.5	34.7	11.6	49.8	47.5
14	10.0	43.0	10.4	32.6	12.1	37.5	56.9
15	11.0	51.8	7.6	41.3	11.4	39.1	28.8
16	7.9	41.3	16.2	22.6	17.9	14.5	87.5
17	10.1	46.6	10.1	44.6	13.9	38.2	61.2
18	10.4	57.5	10.5	36.6	17.6	25.0	70.9
19	11.3	42.2	10.0	49.5	13.9	42.2	62.5
20	9.7	47.5	12.4	19.0	18.5	14.7	93.8
21	13.2	40.1	8.9	31.5	12.6	24.3	39.5
22	14.0	40.6	7.6	30.7	13.0	22.2	42.5
23	15.6	27.6	8.3	35.8	12.8	21.6	68.1
24	17.5	34.0	5.4	47.3	8.9	47.5	56.9
25	10.1	29.1	10.6	29.7	13.6	14.5	46.8
26	12.0	42.6	9.7	49.9	11.9	50.8	72.2
27	7.9	70.1	12.6	29.0	14.9	32.7	97.5
28	7.2	88.8	5.5	48.7	3.8	41.5	100.0
29	7.5	46.1	11.0	33.8	17.8	23.7	80.3
30	9.3	55.2	10.9	45.7	13.9	34.8	65.3
31	7.3	24.5	12.4	31.4	15.5	24.5	78.8
32	12.0	44.5	9.0	44.0	12.7	47.3	75.0
33	8.9	44.8	15.0	29.3	19.7	22.8	100.0
34	8.2	38.8	15.7	24.3	16.8	18.9	98.8
35	9.2	51.3	10.0	27.2	13.4	22.0	68.8
36	8.2	42.8	10.4	31.3	12.2	35.5	38.8
37	10.4	44.6	10.6	22.7	13.6	14.4	81.3
38	9.7	54.0	11.6	27.8	17.0	17.7	93.4
39	11.8	48.9	5.2	44.5	6.3	46.7	50.0
40	8.5	46.7	8.7	33.6	12.6	41.1	80.0

Appendix 5 (continued)

segment	grass-sedges per m2		forbs per m2		shrubs per 25 m2		trees per 100 m2		fallen logs per 100 m2	
	mean	% cv	mean	% cv	mean	% cv	mean	% cv	mean	% cv
41	18.8	199.2	44.2	107.2	59.0	142.4	34.9	66.6	33.2	145.0
42	61.8	118.6	41.5	85.9	25.5	107.2	22.2	63.1	102.3	130.1
43	604.4	367.9	36.6	159.4	109.1	72.5	10.2	69.6	184.4	142.4
44	17.6	202.5	35.8	138.4	102.2	110.6	11.1	100.6	323.0	118.1
45	596.7	371.4	73.4	211.0	269.8	171.0	1.7	170.7	48.7	144.8
46	621.1	356.8	101.0	141.3	47.7	91.3	14.6	145.2	97.2	116.3
47	193.2	287.3	54.5	76.5	40.4	91.5	19.4	134.2	23.3	106.0
48	29.3	187.9	63.2	101.4	49.1	132.3	31.8	103.7	75.2	81.0
49	526.9	423.3	99.8	240.8	54.8	107.6	13.0	112.2	20.4	194.8
50	10.9	170.4	41.5	131.3	57.3	120.2	22.6	74.9	155.9	152.3
51	3.3	178.5	12.4	217.9	25.1	152.4	33.5	58.2	133.5	187.1
52	7.6	151.0	42.1	123.2	13.3	102.2	27.5	83.1	22.8	122.9
53	26.8	260.2	49.4	126.5	52.9	121.7	21.8	63.5	118.0	136.8
54	173.2	420.3	110.5	81.5	118.5	151.8	18.6	53.6	116.6	151.4
55	1027.2	298.8	113.7	99.1	40.1	80.0	18.2	59.6	127.9	207.7
56	11.9	157.0	80.6	106.4	127.0	99.5	13.6	94.5	180.0	144.4
57	731.9	311.7	123.8	87.5	95.4	251.5	25.3	64.2	13.6	76.1
58	79.2	193.1	103.9	139.9	48.0	162.1	18.7	84.0	67.1	184.0
59	652.6	338.5	134.8	112.6	17.6	98.4	9.8	71.7	76.7	339.5
60	153.3	234.1	63.9	80.3	51.0	168.2	13.8	48.4	50.5	123.5
61	791.1	281.4	33.7	80.6	95.9	90.0	13.3	126.2	53.7	283.5
62	135.2	203.3	60.9	72.7	64.4	226.7	36.1	54.7	128.9	277.5
63	56.1	130.4	80.2	79.9	68.4	110.0	26.8	60.3	51.0	166.6
64	597.0	372.0	49.6	157.3	68.4	107.0	9.8	95.1	72.7	102.7
65	71.0	195.5	69.6	100.4	28.4	120.0	17.8	79.9	26.6	125.9
66	117.9	140.3	116.2	134.4	61.8	110.0	22.8	119.5	12.1	130.2
67	333.0	176.9	80.0	65.5	69.9	104.5	8.1	116.6	28.3	286.5
68	74.9	182.0	105.1	73.7	32.4	105.3	28.0	76.0	64.9	170.3
69	273.7	228.5	88.4	73.0	45.6	93.8	21.4	52.5	20.9	88.4
70	219.0	250.5	131.0	95.3	44.3	119.7	18.5	65.1	20.5	157.9
71	1519.6	194.8	47.1	88.6	63.0	99.3	43.2	120.6	36.1	104.4
72	1284.8	236.0	63.0	92.4	18.9	143.9	17.6	68.5	68.3	166.1
73	202.2	176.9	43.5	86.7	104.7	125.1	17.9	84.8	130.0	208.4
74	60.6	138.9	46.0	114.9	66.5	77.2	22.3	87.3	57.2	189.6
75	104.3	181.0	79.8	135.1	37.3	139.7	26.1	103.9	43.3	122.6
76	34.3	121.5	92.5	81.5	92.1	117.3	30.6	100.3	86.0	106.2
77	138.8	220.0	34.9	94.8	80.1	138.0	23.0	67.6	67.2	107.3
78	130.0	276.2	44.4	78.8	83.0	189.2	27.8	148.7	54.6	225.2
79	216.4	334.0	71.1	104.1	92.9	171.3	18.2	110.6	83.6	152.3
80	560.9	396.9	35.2	110.3	133.5	174.2	24.5	129.8	85.0	196.6

Appendix 5 (continued)

segment	ground cover		% water cover		water depth (cm)		% canopy cover	
	mean	% cv	mean	% cv	mean	% cv	mean	% cv
41	16.9	159.7	0.0	0.0	0.0	0.0	18.1	137.7
42	7.8	195.9	0.0	0.0	0.0	0.0	16.4	55.6
43	2.9	65.1	0.0	0.0	0.0	0.0	28.3	96.6
44	2.8	53.7	0.0	0.0	0.0	0.0	11.1	62.6
45	29.8	90.2	35.1	86.8	7.3	72.4	65.1	61.9
46	41.0	83.4	5.0	153.9	1.6	124.6	23.0	75.0
47	38.6	113.6	3.5	253.6	1.4	271.0	22.0	78.5
48	20.6	138.7	1.0	435.9	0.3	435.9	17.0	96.1
49	11.9	103.8	0.0	0.0	0.0	0.0	19.0	78.4
50	6.1	100.6	0.0	0.0	0.0	0.0	11.9	55.5
51	4.8	122.1	0.0	0.0	0.0	0.0	6.8	32.2
52	9.3	154.5	0.0	0.0	0.0	0.0	9.5	42.0
53	8.8	97.2	0.0	0.0	0.0	0.0	6.9	24.0
54	22.7	128.4	0.0	0.0	0.0	0.0	22.3	60.7
55	10.3	120.1	0.0	0.0	0.0	0.0	20.4	66.6
56	8.3	116.7	0.0	0.0	0.0	0.0	10.8	86.7
57	65.4	68.1	0.0	0.0	0.0	0.0	50.0	59.5
58	54.3	78.2	0.0	0.0	0.0	0.0	59.5	40.6
59	57.3	75.6	0.0	0.0	0.0	0.0	79.3	31.2
60	25.1	138.8	0.0	0.0	0.0	0.0	29.0	50.9
61	30.3	108.6	2.0	380.1	0.2	311.4	27.5	95.5
62	15.3	98.4	0.0	0.0	0.0	0.0	19.3	85.5
63	10.2	137.2	0.1	435.9	0.1	435.9	19.5	63.7
64	46.5	73.2	2.4	170.0	1.6	170.2	49.8	77.7
65	46.8	83.5	1.8	213.3	0.7	186.4	21.6	66.4
66	76.4	42.1	6.0	297.0	0.4	294.2	37.9	64.0
67	53.5	66.2	0.8	435.9	0.2	435.9	39.1	68.7
68	38.8	100.8	0.0	0.0	0.0	0.0	19.0	71.4
69	30.5	116.0	0.0	0.0	0.0	0.0	16.8	108.4
70	51.0	80.2	0.0	0.0	0.0	0.0	44.9	86.6
71	40.3	83.7	0.0	0.0	0.0	0.0	44.0	71.1
72	29.0	85.0	0.0	0.0	0.0	0.0	23.8	121.0
73	67.8	41.7	1.8	372.8	0.6	297.0	26.7	71.9
74	47.0	64.8	1.5	299.1	0.9	224.6	14.2	57.6
75	35.1	91.6	2.6	200.7	0.4	160.5	13.4	69.6
76	55.2	49.7	1.7	231.4	0.7	232.6	8.9	51.8
77	8.9	95.3	3.8	435.9	0.3	435.9	8.5	62.1
78	25.1	98.7	0.0	0.0	0.0	0.0	10.9	55.8
79	22.9	120.8	0.0	0.0	0.0	0.0	25.4	86.2
80	47.0	78.9	0.0	0.0	0.0	0.0	25.8	98.1

Appendix 5 (continued)

segment	shrubs (dm)		trees (m)		overall (m)		% deciduous trees
	mean	% cv	mean	% cv	mean	% cv	mean
41	8.9	58.0	10.1	34.1	14.9	31.1	43.8
42	19.1	45.5	12.2	29.9	14.5	28.5	33.8
43	10.9	45.1	12.7	45.0	14.9	47.0	38.5
44	11.2	54.2	16.7	22.1	18.5	11.2	62.5
45	11.4	59.5	4.4	131.4	5.1	119.5	85.0
46	13.9	46.7	8.5	28.1	9.9	35.4	57.4
47	12.4	48.6	12.8	49.0	14.4	41.2	39.5
48	11.2	37.1	10.5	34.7	12.8	30.3	50.0
49	10.9	32.5	15.3	27.6	16.4	27.3	19.7
50	11.5	31.2	9.6	34.5	16.5	19.8	37.5
51	8.5	41.9	10.4	37.2	16.6	19.2	56.3
52	9.5	47.8	11.9	35.6	17.1	14.6	13.8
53	8.4	48.5	10.3	40.5	18.9	20.5	32.9
54	8.4	39.1	10.6	29.6	13.6	27.7	30.0
55	13.7	52.2	7.7	32.8	11.7	30.3	23.7
56	11.9	31.0	9.7	36.6	16.5	23.5	37.5
57	9.4	33.9	7.4	60.5	8.6	49.8	10.0
58	11.1	44.4	4.7	39.5	6.9	37.7	14.5
59	8.1	26.0	3.5	57.8	4.3	77.4	4.5
60	10.5	33.2	9.3	46.6	13.9	29.6	18.8
61	15.7	43.3	5.4	60.1	8.2	62.8	27.3
62	8.4	41.2	7.2	34.1	12.3	21.8	50.0
63	9.1	21.0	8.4	27.8	13.0	19.7	61.3
64	9.0	61.0	4.1	65.9	6.6	78.1	18.2
65	10.2	38.5	9.4	43.6	13.9	21.8	43.8
66	10.8	38.5	9.4	25.6	11.9	18.2	12.5
67	15.5	44.7	5.5	66.1	8.7	56.0	40.9
68	12.6	48.3	9.1	44.6	13.4	30.0	54.2
69	7.7	42.9	10.9	36.5	15.0	25.5	58.7
70	9.4	43.7	7.2	63.9	10.9	60.8	45.0
71	14.9	36.5	5.7	50.1	7.3	48.5	70.8
72	10.4	44.1	10.8	45.3	15.1	20.6	73.4
73	9.2	46.0	8.5	30.5	9.9	24.0	37.5
74	10.3	53.5	10.7	43.3	15.9	33.8	59.2
75	10.2	46.0	11.0	27.3	15.9	23.5	75.0
76	8.7	34.3	9.9	31.3	15.5	23.2	62.5
77	8.3	38.4	12.3	36.9	18.0	16.6	73.8
78	9.9	42.6	10.3	34.0	15.4	30.1	65.8
79	9.4	36.5	9.8	35.9	14.1	30.6	40.8
80	14.4	42.1	7.4	43.5	10.3	51.8	41.2

Appendix 6.   Tree (A), shrub (B), and forb (C) species identified on
Wisconsin study areas measured with the quantitative vegetation
method.   Nomenclature from Lakela (1965).

Appendix 6.   Tree (A), shrub (B), and forb (C) species identified
              on Wisconsin study areas measured with the quanti-
              tative vegetation method.   Nomenclature from Lakela
              (1965).

A. TREES

White Pine
  Pinus strobus

Red Pine
  P. resinosa

Jack Pine
  P. banksiana

Tamarack
  Larix laricina

Balsam Fir
  Abies balsamea

Hemlock
  Tsuga canadensis

White Spruce
  Picea glauca

Black Spruce
  P. mariana

Northern White Cedar
  Thuja occidentalis

Quaking Aspen
  Populus tremuloides

Large-toothed Aspen
  P. grandidentata

Balsam Poplar
  P. balsamifera

Butternut
  Juglans cinerea

Ironwood
  Ostrya virginiana

Paper Birch
  Betula papyrifera

Yellow Birch
  B. lutea

Red Oak
  Quercus rubra

Bur Oak
  Q. macrocarpa

Black Cherry
  Prunus serotina

Red Maple
  Acer rubrum

Sugar Maple
  Acer saccharum

Basswood
  Tilia americana

Green Ash
  Fraxinus pennsylvanica

Black Ash
  F. nigra

Elm
  Ulmus sp.

B. SHRUBS

White Pine
  Pinus strobus

Red Pine
  P. resinosa

Jack Pine
  P. banksiana

Tamarack
  Larix laricina

Balsam Fir
  Abies balsamea

Hemlock
  Tsuga canadensis

White Spruce
  Picea glauca

Black Spruce
  P. mariana

Northern White Cedar
  Thuja occidentalis

Cattail
  Typha latifolia

Willow
  Salix spp.

Quaking Aspen
  Populus tremuloides

Large-toothed Aspen
  P. granidentata

Balsam Poplar
  P. balsamifera

Sweet Gale
  Myrica gale

Butternut
  Juglans cinerea

Hazel
  Corylus spp.

Ironwood
  Ostrya virginiana

Paper Birch
  Betula papyrifera

Yellow Birch
  B. lutea

Dwarf Birch
  B. pumila

Alder
  Alnus spp.

Red Oak
  Quercus rubra

Bur Oak
  Q. macrocarpa

Gooseberry
  Ribes sp.

Thimbleberry
  Rubus parviflorus

Raspberry
  Rubus strigosus

Blackberry
  R. allegheniensis

Black Cherry
  Prunus serotina

Choke Cherry
  P. virginiana

Pincherry
  P. pensylvanica

Meadow Sweet
  Spiraea alba

Juneberry
  Amelanchier sp.

Mountain Ash
  Pyrus americana

Red Maple
  Acer rubrum

Mountain Maple
  Acer spicatum

Sugar Maple
  Acer _saccharum_

Basswood
  Tilia _americana_

Leatherwood
  Dirca _palustris_

Dogwood
  Cornus sp.

Green Ash
  Fraxinus _pennsylvanica_

Black Ash
  Fraxinus _nigra_

Bush Honeysuckle
  Diervilla _lonicera_

Fly Honeysuckle
  Lonicera _canadensis_

Arrowwood
  Viburnum sp.

Red Elderberry
  Sambucus _pubens_

Elm
  Ulmus sp.

C. FORBS

Equisetum
  Equisetum spp.

Lycopodium
  Lycopodium spp.

Grape Fern
  Botrychium virginianum

Cinnamon Fern
  O. cinnamonmea

Sensitive Fern
  Onoclea sensibilis

Shield Fern
  Dryopteris sp.

Oak Fern
  Dryopteris disjuncta

Beech Fern
  Thelypteris phegopteris

Lady Fern
  Athyrium Filix-femina

Maidenhair Fern
  Adiantum pedatum

Bracken Fern
  Pteridium aquilinum

Arrowhead
  Sagittaria latifolia

Jack-in-the-Pulpit
  Arisaema atrorubens

Wild Calla
  Calla palustris

Leek
  Allium tricoccum

Bluebead Lily
  Clintonia borealis

Trillium
  Trillium spp.

Mayflower
  Maianthemum canadense

3-Leaved False Soloman's Seal
  Smilacina trifolia

Twisted Stalk
  Streptopus sp.

Wild Iris
  Iris versicolor

Stinging Nettle
  Parietaria sp.

Ginger
  Asarum canadense

Swamp Smartweed
  Polygonum sp.

Arrowleaf Tear Thumb
  Polygonum sagittatum

Fringed Bindweed
  P. cilinode

Gold Thread
  Coptis groenlandica

Marsh Marigold
  Caltha palustris

Hepatica
  Hepatica americana

Anemone
  Anemone sp.

Blue Cohosh
  Caulophyllum thalictroides

Strawberry
  Fragaria spp.

Bloodroot
  Sanquinaria canadensis

Two-leaved Bishop's Cap
  Mitella diphylla

Potentilla
  Potentilla sp.

Rubus Spp.
  Rubus spp.

Hog-peanut
  Amphicarpa bracteata
	Blueberry
	  Vaccinium spp.

Clover
  Trifolium spp.
	Loosestrife
	  Lysimachia sp.

Wood-sorrel
  Oxalis sp.
	Star Flower
	  Trientalis borealis

Poison Ivy
  Rhus radicans
	Buckbean
	  Menyanthes trifoliata

Impatients
  Impatients sp.
	Spreading Dogbane
	  Apocynum androsaemifolium

St. John's Wort
  Hypericum sp.
	Mint
	  Lamiaceae family

Violet Spp.
  Viola spp.
	Mullein
	  Verbascum sp.

Sarsaparilla
  Araila nudicaulis
	Marsh Speedwell
	  Veronica scutellata

Cow Parsnip
  Heracleum lanatum
	Plantain
	  Plantago sp.

Sweet Cicely
  Osmorhiza claytoni
	Bedstraw
	  Galium sp.

Bunchberry
  Cornus canadensis
	Composite
	  Asteraceae family

Wintergreen
  Gaultheria procumbens
	Joe-Pye-Weed
	  Eupatorium maculatum

Indian pipe
  Monatropa uniflora
	Goldenrod
	  Solidago sp.

Labrador Tea
  Ledum groenlandicum
	Aster
	  Aster sp.

Bog Laurel
  Kalmia polifolia
	Large-Leaved Aster
	  Aster macrophyllus

Bog Rosemary
  Andromeda glaucophylla
	Pearly Everlasting
	  Anaphalis margaritacea

Leatherleaf
  Chamaedaphne calyculata
	Coltsfoot
	  Petasites palmatus

Bear Berry
  Arctostaphylos uva-ursi
	Dandelion
	  Taraxacum officinale

Hawkweed
  Hieracium sp.

Appendix 7. Importance values of tree species on Wisconsin segments. Control segments are 1-40; treatments are 41-80. Importance values are the sum of relative density, relative dominance, and relative frequency.

Appendix 7. Importance values of tree species on Wisconsin segments. Control segments
are 1-40; treatments are 41-80. Importance values are the sum of relative
density, relative domininance, and relative frequency.

segment	1	2	4	5	6	7	8	9	10	11	12&13	16	17	18	19	39	40	41	42	45
1	0	0	89	8	0	0	9	30	36	50	95	0	63	0	63	14	6	0	0	20
2	0	0	52	8	0	7	35	128	0	7	0	39	46	7	65	20	0	0	0	0
3	0	0	0	0	0	0	0	224	8	47	0	30	16	6	0	13	17	0	0	40
4	0	0	40	0	0	0	0	166	50	6	7	22	95	13	7	27	0	0	0	11
5	0	0	63	172	0	0	0	0	35	0	27	0	37	0	0	22	0	20	0	0
6	6	0	44	76	6	32	35	39	9	23	31	0	76	0	27	0	0	0	0	0
7	0	0	132	0	0	22	27	29	23	14	91	0	85	0	30	0	0	6	0	0
8	0	0	105	0	0	19	71	0	15	12	0	0	15	0	148	0	0	0	0	0
9	0	0	63	0	0	0	15	122	17	101	0	0	53	0	64	0	0	0	0	0
10	0	0	65	6	0	9	76	0	0	38	0	0	24	0	177	0	0	0	0	0
11	0	0	69	0	6	0	0	130	0	25	60	7	113	6	9	0	0	0	9	0
12	0	0	156	0	0	0	17	38	0	36	17	0	113	0	19	0	0	0	12	0
13	0	0	145	0	0	18	21	33	0	92	0	0	38	7	41	0	0	0	0	0
14	0	23	156	0	0	0	6	0	0	30	49	0	130	10	0	0	0	11	0	0
15	0	0	132	57	29	74	8	7	0	20	0	0	54	9	27	0	0	0	9	0
16	0	0	52	0	0	0	0	161	0	6	26	20	73	7	46	0	0	0	0	0
17	58	0	61	16	12	0	0	47	24	0	48	30	38	38	0	28	0	0	0	0
18	28	0	85	10	8	0	0	111	23	16	36	27	23	14	9	71	8	0	0	15
19	100	0	49	0	0	0	0	37	107	7	0	0	46	0	0	0	0	0	0	16
20	21	8	6	0	0	0	0	110	39	38	50	26	59	26	0	38	6	0	0	58
21	0	0	142	15	21	6	87	0	23	13	0	0	0	48	83	0	0	0	0	0
22	0	0	134	0	0	0	98	0	14	0	62	0	11	33	54	0	0	0	0	0
23	0	0	103	13	11	0	17	0	0	0	0	0	0	31	197	0	0	0	0	0
24	0	55	91	19	0	0	0	36	18	0	84	0	0	21	48	0	0	0	0	0
25	0	0	0	102	0	0	0	0	8	0	64	0	86	6	9	0	0	0	0	0
26	7	0	0	43	7	21	44	69	41	53	6	12	62	0	36	9	0	0	0	0
27	0	0	6	0	0	0	6	170	40	11	47	0	57	41	52	13	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	70	0	154	0	0	0	16	0	0	0
29	0	0	55	0	0	29	0	103	6	51	22	0	81	35	27	33	0	0	6	0
30	8	0	85	0	0	9	34	111	0	44	0	0	58	7	37	21	0	7	0	0
31	19	0	21	0	0	32	0	175	8	7	0	0	14	39	35	34	17	0	32	0
32	109	0	24	0	0	19	8	41	24	6	54	0	114	17	0	14	0	0	0	0
33	0	0	0	0	0	0	0	234	0	0	0	52	6	6	0	46	60	0	0	0
34	0	0	6	0	0	0	0	139	0	13	0	8	43	15	81	14	93	0	0	0
35	0	0	102	0	0	10	32	7	15	22	0	0	201	0	0	0	0	0	0	0
36	0	0	197	28	7	15	8	0	0	14	16	0	103	6	14	8	0	0	0	0
37	0	0	70	10	0	11	16	0	0	96	0	0	14	0	200	0	0	0	0	0
38	10	0	11	0	0	0	0	31	0	56	123	0	137	15	13	0	0	7	15	0
39	0	0	28	54	0	0	0	0	0	0	174	0	8	0	0	0	0	9	72	0
40	0	23	45	21	0	0	0	45	0	68	140	0	67	0	0	7	0	0	13	0

1 White Pine
2 Red Pine
4 Balsam Fir
5 Black Spruce
6 Tamarack
7 Hemlock
8 Cedar
9 Sugar Maple
10 Paper Birch
11 Yellow Birch
12 Quaking Aspen
13 Large-toothed Aspen
16 Basswood
17 Red Maple
18 Unknown Snag
19 Black Ash
39 Ironwood
40 Green Ash
41 Black Cherry
42 White Spruce
45 Red Oak

Appendix 7 (continued)

segment	Tree species																				
	1	2	4	5	6	7	8	9	10	11	12	13	16	17	18	19	39	40	41	42	45
41	0	47	128	13	0	0	0	0	120	0	72	0	0	0	0	0	26	0	0	45	0
42	11	203	70	24	0	0	0	8	6	0	104	0	0	7	0	0	6	0	0	0	0
43	0	192	0	13	0	0	0	32	0	9	27	7	28	0	0	9	0	0	0	0	9
44	0	151	0	0	0	0	0	124	0	0	62	13	25	0	0	23	20	0	0	0	0
45	0	19	12	0	0	0	0	0	0	0	186	0	10	0	12	0	0	0	21	0	0
46	0	0	40	67	17	0	0	0	17	0	49	0	6	0	118	0	0	0	0	6	0
47	0	0	100	22	76	0	0	0	61	0	126	0	0	14	0	0	0	0	0	0	0
48	0	0	143	16	9	0	9	0	7	13	151	0	6	7	0	0	0	0	6	0	0
49	6	242	61	0	0	0	0	0	6	0	45	0	13	0	0	0	0	0	0	6	6
50	0	112	126	0	0	0	0	24	38	21	35	0	36	6	0	0	0	0	0	0	37
51	48	0	43	8	0	9	0	91	51	15	0	0	54	7	0	31	0	0	0	95	8
52	7	150	107	21	0	0	0	11	16	0	7	0	8	27	0	0	0	0	0	91	9
53	20	7	192	0	0	0	0	15	30	6	51	0	55	21	0	0	0	0	0	6	0
54	8	33	132	29	0	7	19	0	24	7	27	0	7	70	9	0	0	0	0	66	0
55	60	0	207	0	0	0	0	0	25	0	52	0	18	0	0	0	0	0	0	0	0
56	60	0	166	0	0	0	0	7	52	0	50	0	37	23	0	14	0	0	0	0	0
57	0	124	28	117	72	0	0	0	0	0	6	0	26	19	0	0	0	0	0	8	0
58	0	0	124	94	58	0	0	0	16	0	43	0	0	6	0	0	0	0	0	33	0
59	0	0	22	158	91	0	0	0	0	0	17	0	0	11	0	0	0	0	0	0	0
60	0	124	129	21	0	0	24	0	0	0	61	0	0	21	0	0	0	0	0	6	0
61	0	0	129	35	37	0	0	0	20	0	66	0	8	8	0	0	0	0	11	0	0
62	0	0	93	47	0	0	0	0	28	0	150	0	21	0	0	0	0	0	0	52	0
63	118	13	65	39	0	0	0	0	6	0	161	0	20	6	0	0	0	0	0	13	0
64	0	0	122	11	13	0	111	0	0	0	35	0	0	8	0	0	0	0	0	0	0
65	8	0	104	22	52	0	27	53	20	6	0	0	41	66	0	29	0	0	0	0	0
66	0	0	31	106	153	0	33	0	0	0	7	0	0	60	0	0	0	0	0	0	0
67	0	0	28	160	0	0	0	0	0	0	92	0	7	40	0	0	0	0	0	0	0
68	0	0	83	46	36	0	0	28	41	0	98	0	21	26	0	17	0	0	0	0	0
69	0	0	75	44	24	0	0	91	10	0	39	10	56	23	0	84	0	0	0	0	0
70	0	0	38	58	66	0	10	36	43	0	0	31	38	24	18	58	6	0	0	0	0
71	0	0	0	28	133	0	0	0	0	0	145	0	0	14	0	0	0	0	0	0	0
72	0	0	36	27	0	0	28	109	11	7	22	0	96	21	0	15	0	0	0	0	0
73	0	0	174	7	0	0	28	0	0	25	0	0	33	15	100	0	0	0	0	6	0
74	0	0	80	0	0	10	73	22	16	78	0	0	26	26	77	0	0	0	7	26	0
75	0	0	29	9	0	42	45	59	0	23	0	0	15	18	120	0	0	0	7	13	0
76	0	0	77	0	0	18	93	0	0	55	0	0	22	14	143	0	0	0	0	9	0
77	50	0	64	0	0	6	0	44	32	72	13	0	44	25	27	44	0	0	0	32	0
78	68	0	63	0	0	0	10	0	0	6	43	0	115	27	36	0	0	0	0	65	0
79	49	0	137	53	7	0	6	0	22	0	62	0	70	45	0	6	0	0	0	0	0
80	17	0	112	47	25	0	23	6	54	0	60	0	35	14	0	0	0	0	0	14	0

1	White Pine
2	Red Pine
4	Balsam Fir
5	Black Spruce
6	Tamarack
7	Hemlock
8	Cedar
9	Sugar Maple
10	Paper Birch
11	Yellow Birch
12	Quaking Aspen
13	Large-toothed Aspen
16	Basswood
17	Red Maple
18	Unknown Snag
19	Black Ash
39	Ironwood
40	Green Ash
41	Black Cherry
42	White Spruce
45	Red Oak

Appendix 8. Values of vegetation variables for points on five Wisconsin segments that were logged between 1986 and 1987.

Appendix 8. Values of vegetation variables for points on five Wisconsin segments that were logged between 1986 and 1987.

seg	ydis	grass-sedges per m2		forbs per m2		shrubs per 25 m2		trees per 100 m2		fallen logs per 100 m2	
		86	87	86	87	86	87	86	87	86	87
8	50	1.3	400.0	493.8	166.5	1.3	21.2	8.5	2.5	7.7	105.2
8	75	0.2	2.6	35.6	330.6	10.1	90.7	11.1	4.4	674.7	400.0
60	75	190.2	41.6	86.5	51.0	4.2	3.9	12.3	10.5	14.7	38.7
60	100	17.7	400.0	25.6	100.0	13.3	8.2	11.9	3.8	44.6	156.3
60	125	59.2	9.0	39.1	138.4	6.0	12.5	10.5	4.2	27.1	37.0
60	150	166.5	5.0	110.8	156.3	226.1	8.0	17.5	6.1	53.1	12.9
60	175	7.5	277.8	57.0	39.1	5.1	12.0	35.4	7.4	10.8	76.6
60	200	7.9	12.5	79.0	277.8	7.1	11.0	8.8	6.1	6.3	6.2
60	225	493.8	1111.1	11.5	5.0	6.2	10.0	4.6	8.3	11.6	25.4
60	250	20.7	236.7	44.4	110.8	2.0	15.7	8.3	7.8	127.0	70.3
60	275	5.4	30.0	52.9	443.2	5.5	14.6	6.9	4.0	21.5	28.1
60	300	110.8	82.6	204.1	95.2	17.7	115.6	9.9	0.0	8.0	186.4
77	175	43.0	105.2	36.7	100.0	102.0	75.6	5.8	3.2	16.2	11.4
77	200	1.5	3.8	3.0	22.7	36.7	132.1	28.2	5.3	148.7	71.8
77	225	2.5	5.3	17.7	90.7	44.4	162.3	12.8	4.9	167.6	119.4
77	250	816.3	1111.1	110.8	23.2	21.2	133.6	34.1	4.4	94.7	70.9
77	275	2.9	5.1	105.2	47.6	7.1	38.1	26.9	14.4	33.5	199.8
77	300	1.9	11.1	14.5	86.5	38.1	19.9	7.4	6.6	67.7	42.9
77	325	302.5	219.5	52.9	90.7	244.1	44.7	6.5	7.9	62.0	46.9
77	350	0.9	0.8	46.0	219.5	23.0	40.3	41.8	6.8	30.9	107.9
77	375	0.5	0.8	27.7	82.6	158.2	47.2	35.5	0.0	123.5	104.1
77	400	2.1	47.6	23.2	86.5	12.5	100.0	62.5	8.6	208.5	144.3
77	425	19.3	57.0	82.6	400.0	472.6	35.9	27.8	27.5	18.9	11.7
79	300	1.2	1.2	21.1	166.5	25.6	34.8	75.0	78.0	50.3	208.5
79	325	1.8	2500.0	28.4	69.4	207.0	236.7	6.6	3.2	51.9	97.5
79	350	28.4	34.6	177.8	130.6	19.6	43.0	8.3	6.5	62.5	69.7
79	375	11.1	18.1	79.0	138.4	277.8	229.6	52.5	46.3	72.7	139.2
79	400	47.6	21.1	46.0	100.0	31.2	108.5	7.1	5.6	11.6	144.3
79	425	15.7	14.0	130.6	177.8	14.1	141.7	22.6	4.5	3.1	76.9
79	450	37.9	7.6	100.0	82.6	16.0	18.5	9.0	9.4	27.8	1189.1
79	475	5.9	6.6	100.0	27.0	24.4	233.1	10.6	3.0	7.8	12.5
79	500	23.2	6.7	19.8	130.6	92.5	115.6	5.7	0.0	79.4	80.8
79	525	9.0	66.6	13.2	6.9	7.0	69.4	79.7	0.0	13.6	242.2
80	25	0.9	0.7	7.9	12.3	840.2	207.0	7.3	0.0	42.9	377.0
80	50	23.2	82.6	39.1	123.5	135.2	127.7	8.6	11.1	16.9	16.0

Apendix 8 (continued)

seg	ydis	% ground cover		% water cover		water depth (cm)		% canopy cover	
		86	87	86	87	86	87	86	87
8	50	2.0	30.0	0.0	0.0	0.0	0.0	7.0	68.0
8	75	15.0	40.0	0.0	0.0	0.0	0.0	21.0	54.0
60	75	5.0	15.0	0.0	0.0	0.0	0.0	10.0	26.0
60	100	4.0	5.0	0.0	0.0	0.0	0.0	22.0	46.0
60	125	5.0	5.0	0.0	0.0	0.0	0.0	13.0	39.0
60	150	8.0	5.0	0.0	0.0	0.0	0.0	19.0	45.0
60	175	5.0	5.0	0.0	0.0	0.0	0.0	12.0	37.0
60	200	5.0	5.0	0.0	0.0	0.0	0.0	19.0	40.0
60	225	2.0	25.0	0.0	0.0	0.0	0.0	23.0	26.0
60	250	2.0	45.0	0.0	0.0	0.0	0.0	21.0	24.0
60	275	20.0	5.0	0.0	0.0	0.0	0.0	23.0	45.0
60	300	5.0	10.0	0.0	0.0	0.0	0.0	30.0	58.0
77	175	5.0	20.0	0.0	0.0	0.0	0.0	11.0	31.0
77	200	8.0	10.0	0.0	0.0	0.0	0.0	4.0	35.0
77	225	2.0	5.0	0.0	0.0	0.0	0.0	8.0	29.0
77	250	12.0	15.0	0.0	0.0	0.0	0.0	7.0	29.0
77	275	6.0	5.0	0.0	0.0	0.0	0.0	4.0	32.0
77	300	2.0	20.0	0.0	0.0	0.0	0.0	12.0	23.0
77	325	2.0	30.0	0.0	0.0	0.0	0.0	6.0	16.0
77	350	20.0	40.0	0.0	0.0	0.0	0.0	11.0	35.0
77	375	5.0	5.0	0.0	0.0	0.0	0.0	3.0	18.0
77	400	2.0	10.0	0.0	0.0	0.0	0.0	8.0	21.0
77	425	25.0	30.0	0.0	0.0	0.0	0.0	5.0	17.0
79	300	25.0	10.0	0.0	0.0	0.0	0.0	11.0	20.0
79	325	12.0	50.0	0.0	0.0	0.0	0.0	45.0	64.0
79	350	20.0	20.0	0.0	0.0	0.0	0.0	9.0	64.0
79	375	25.0	20.0	0.0	0.0	0.0	0.0	22.0	33.0
79	400	20.0	30.0	0.0	0.0	0.0	0.0	4.0	65.0
79	425	15.0	10.0	0.0	0.0	0.0	0.0	14.0	55.0
79	450	10.0	10.0	0.0	0.0	0.0	0.0	17.0	53.0
79	475	8.0	5.0	0.0	0.0	0.0	0.0	10.0	82.0
79	500	30.0	10.0	0.0	0.0	0.0	0.0	16.0	87.0
79	525	8.0	10.0	0.0	0.0	0.0	0.0	6.0	73.0
80	25	25.0	25.0	0.0	0.0	0.0	0.0	14.0	48.0
80	50	15.0	40.0	0.0	0.0	0.0	0.0	26.0	20.0

Appendix 8 (continued)

seg	ydis	shrubs (dm)		trees (m)		overall (m)	
		86	87	86	87	86	87
8	50	9.3	6.3	11.1	11.1	16.0	16.0
8	75	7.0	5.0	12.3	9.1	16.0	13.0
60	75	13.8	16.0	9.3	7.3	14.0	14.0
60	100	6.8	13.0	10.3	14.9	20.0	16.0
60	125	9.5	7.5	13.1	14.9	15.0	17.0
60	150	8.0	14.8	17.5	16.9	20.0	17.0
60	175	13.5	9.5	9.0	15.5	16.0	19.0
60	200	16.3	12.3	18.4	15.4	17.0	18.0
60	225	17.5	7.8	12.9	12.8	18.0	16.0
60	250	15.5	11.5	12.0	9.2	14.0	15.0
60	275	11.8	7.3	11.3	8.3	17.0	14.0
60	300	13.0	6.5	11.7	9.8	10.0	15.0
77	175	7.0	5.8	16.0	15.1	16.0	16.0
77	200	5.8	10.5	4.9	22.8	20.0	25.0
77	225	8.0	12.0	12.9	15.2	24.0	23.0
77	250	7.3	10.0	12.3	17.3	17.0	22.0
77	275	5.3	6.0	17.2	12.3	22.0	23.0
77	300	7.8	8.0	17.3	13.9	20.0	22.0
77	325	6.3	10.5	21.1	14.9	22.0	22.0
77	350	8.0	7.3	10.3	11.0	19.0	18.0
77	375	11.0	17.8	8.3	11.1	16.0	17.0
77	400	9.5	7.8	4.7	10.7	16.0	15.0
77	425	5.8	10.8	8.6	8.6	15.0	17.0
79	300	6.0	6.3	12.1	13.9	15.0	16.0
79	325	13.3	9.5	9.8	7.7	12.0	12.0
79	350	8.3	7.5	10.7	6.4	16.0	11.0
79	375	5.0	8.3	7.5	7.9	9.0	12.0
79	400	17.5	10.5	8.2	10.2	16.0	11.0
79	425	5.8	9.5	13.2	13.5	19.0	10.0
79	450	10.5	14.3	5.3	3.3	13.0	12.0
79	475	10.3	11.3	13.3	8.5	18.0	11.0
79	500	7.8	10.8	14.4	3.0	21.0	6.0
79	525	16.0	5.8	15.2	4.4	19.0	11.0
80	25	22.0	9.5	9.0	7.3	16.0	12.0
80	50	12.0	18.0	5.5	4.9	5.0	10.0

Appendix 9a. 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 9a. 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).

	May		June		July		August		September	
	T	C	T	C	T	C	T	C	T	C
American Bittern *Botaurus lentiginosus*	1	1								
Great Blue Heron *Ardea herodias*			0	1						
Mallard *Anas platyrhynchos*			11	0						
Blue-winged Teal *Anas discors*	0	4								
Northern Harrier *Circus cyaneus*					0	1				
Sharp-shinned Hawk *Accipiter striatus*							0	1		
Cooper's Hawk *Accipiter cooperii*							1	0		
Broad-winged Hawk *Buteo platypterus*	2	3	2	1	1	1	2	1	0	1
Red-tailed Hawk *Buteo jamaicensis*									1	0
American Kestrel *Falco sparverius*							2	0		
Ruffed Grouse *Bonasa umbellus*	12	4	5	4	3	1	15	6	3	5
Killdeer *Charadrius vociferus*	0	2	1	0						
Common Snipe *Gallinago gallinago*	0	1	1	0						
American Woodcock *Scolopax minor*	0	1	5	1	1	12	3	4	7	1
Black-billed Cuckoo *Coccyzus erythropthalmus*					1	1	0	1		
Yellow-billed Cuckoo *Coccyzus americanus*			1	1						
Barred Owl *Strix varia*	1	0	0	1	0	2				
Common Nighthawk *Chordeiles minor*					0	2	1	0		
Chimney Swift *Chaetura pelagica*					0	1				
Ruby-throated Hummingbird *Archilochus colubris*			2	0	1	2				

	May		June		July		August		September	
	T	C	T	C	T	C	T	C	T	C
Belted Kingfisher Ceryle alcyon	0	1					2	0	0	2
Yellow-bellied Sapsucker Sphyrapicus varius	12	25	10	11	6	32	1	12	3	8
Downy Woodpecker Picoides pubescens	1	7	1	2	9	16	7	13	7	8
Hairy Woodpecker Picoides villosus	2	2	1	8	0	3	0	2	6	8
Black-backed Woodpecker Picoides arcticus							1	1	0	1
Northern Flicker Colaptes auratus	15	18	9	5	6	10	12	17	12	12
Pileated Woodpecker Dryocopus pileatus	1	1	2	0	1	1	0	3	2	0
Olive-sided Flycatcher Contopus borealis			3	6	1	0				
Eastern Wood-Pewee Contopus virens			14	12	4	11	9	21	1	5
Yellow-bellied Flycatcher Empidonax flaviventris			18	7	7	5	6	2		
Alder Flycatcher Empidonax alnorum			14	10	6	3	2	1		
Least Flycatcher Empidonax minimus	4	13	22	58	41	41	1	1		
Eastern Phoebe Sayornis phoebe	1	1	0	1	2	0	0	1	1	0
Great Crested Flycatcher Myiarchus crinitus	1	3	6	26	10	17	3	3		
Eastern Kingbird Tyrannus tyrannus	0	1	1	7	2	5	3	2		
Tree Swallow Tachycineta bicolor	0	9	4	2	4	6				
Gray Jay Perisoreus canadensis			4	5	4	1	5	0	7	3
Blue Jay Cyanocitta cristata	27	30	30	40	35	37	27	20	51	41
American Crow Corvus brachyrhynchos			8	1	4	4	6	2	3	0
Common Raven Corvus corax	0	3	6	8	4	6	3	7	1	2
Black-capped Chickadee Parus atricapillus	15	48	7	27	58	103	74	117	95	110

	May		June		July		August		September	
	T	C	T	C	T	C	T	C	T	C
Boreal Chickadee *Parus hudsonicus*	2	0			1	0	1	1	3	0
Red-breasted Nuthatch *Sitta canadensis*	8	11	9	13	9	16	26	41	53	58
White-breasted Nuthatch *Sitta carolinensis*	3	2	0	2	9	6	2	5	1	8
Brown Creeper *Certhia americana*	1	8	3	5	10	22	11	15	24	28
House Wren *Troglodytes aedon*					0	2				
Winter Wren *Troglodytes troglodytes*	23	27	24	27	28	34	15	7	6	3
Sedge Wren *Cistothorus platensis*			2	1	0	1	0	1		
Golden-crowned Kinglet *Regulus satrapa*	58	44	45	27	71	27	83	51	108	22
Ruby-crowned Kinglet *Regulus calendula*	7	7			2	2	6	1	3	0
Eastern Bluebird *Sialia sialis*			1	2	6	1	3	0		
Veery *Catharus fuscescens*			20	17	23	34	2	2		
Gray-cheeked Thrush *Catharus minimus*									3	0
Swainson's Thrush *Catharus ustulatus*									7	0
Hermit thrush *Catharus guttatus*	18	25	28	22	65	63	19	9	6	6
Wood Thrush *Hylocichla mustelina*	0	1	2	4	1	3			0	3
American Robin *Turdus migratorius*	24	26	34	33	33	22	20	14	12	15
Gray Catbird *Dumetella carolinensis*	0	1			1	5	1	0	1	0
Brown Thrasher *Toxostoma rufum*	3	0	2	1	4	0	2	0	1	0
Cedar Waxwing *Bombycilla cedrorum*			0	12	13	4	24	22	23	22
European Starling *Sturnus vulgaris*	1	7	0	2	0	4				
Solitary Vireo *Vireo solitarius*	8	6	4	1	1	1	0	3		

	May		June		July		August		September	
	T	C	T	C	T	C	T	C	T	C
Yellow-throated Vireo *Vireo flavifrons*					0	2				
Red-eyed Vireo *Vireo olivaceus*	1	6	78	90	84	93	21	21	6	5
Golden-winged Warbler *Vermivora chrysoptera*	4	1	17	5					2	0
Tennessee Warbler *Vermivora peregrina*			2	4	1	1	2	0		
Nashville Warbler *Vermivora ruficapilla*	179	123	108	64	103	53	10	4	5	4
Northern Parula *Parula americana*	0	11	7	14	6	7	1	0	1	3
Yellow Warbler *Dendroica petechia*			1	3						
Chestnut-sided Warbler *Dendroica pensylvanica*	2	3	62	40	43	23	1	2	2	2
Cape May Warbler *Dendroica tigrina*			4	3	0	2				
Black-throated Blue Warbler *Dendroica caerulescens*			0	1					0	1
Yellow-rumped Warbler *Dendroica coronata*	59	45	17	9	9	9	0	4	7	12
Black-throated Green Warbler *Dendroica virens*	18	57	40	65	37	64	4	8	2	7
Blackburnian Warbler *Dendroica fusca*	1	0	2	14	1	5			0	2
Pine Warbler *Dendroica pinus*	4	2	2	3						
Palm Warbler *Dendroica palmarum*	2	2	1	0	1	0			0	1
Bay-breasted Warbler *Dendroica castanea*	0	1							1	2
Blackpoll Warbler *Dendroica striata*			1	0						
Black-and-white Warbler *Mniotilta varia*	2	13	25	33	9	12	4	0	3	5
American Redstart *Setophaga ruticilla*			0	1	1	0	0	1	0	2
Ovenbird *Seiurus aurocapillus*	9	28	149	158	91	141	5	9	15	7
Northern Waterthrush *Seiurus noveboracensis*	0	4	0	3						

Appendix 9a (continued)

	May		June		July		August		September	
	T	C	T	C	T	C	T	C	T	C
Connecticut Warbler *Opororornis agilis*			4	0	4	0				
Mourning Warbler *Opororornis philadelphia*			23	18	17	18	2	1		
Common Yellowthroat *Geothylpis trichas*			18	22	13	25	5	9	5	1
Canada Warbler *Wilsonia canadensis*			4	2	0	1	1	1		
Scarlet Tanager *Piranga olivacea*			6	5	5	8				
Rose-breasted Grosbeak *Pheucticus ludovicianus*	5	9	25	23	8	10	4	2	5	2
Indigo Bunting *Passerina cyanea*			6	10	6	7	3	4		
Rufous-sided Towhee *Pipilo erythrophthalmus*	6	2	7	1	3	2	3	2	2	1
Chipping Sparrow *Spizella passerina*	30	20	10	12	12	10	5	1		
Vesper Sparrow *Pooecetes gramineus*	0	3			0	2				
Song Sparrow *Melospiza melodia*	13	11	8	15	17	23	11	4	2	0
Swamp Sparrow *Melospza georgianna*	10	21	2	10	15	24	4	5		
White-throated Sparrow *Zonotrichia albicollis*	111	48	71	27	95	43	56	19	48	12
Dark-eyed Junco *Junco hyemalis*	6	6			0	3			0	1
Red-winged blackbird *Agelaius phoeniceus*	10	38	5	26	4	19	1	0		
Rusty Blackbird *Euphagus carolinus*	0	2								
Common Grackle *Quiscalus quiscula*	0	9	5	6	2	17	1	0		
Brown-headed Cowbird *Molothrus ater*	3	10	2	7	2	3				
Northern Oriole *Icterus galbula*	2	1	0	5						
Purple Finch *Carpodacus purpureus*	17	30			2	5			8	0
White-winged Crossbill *Loxia leucoptera*							4	1	4	0

	May		June		July		August		September	
	T	C	T	C	T	C	T	C	T	C
Pine Siskin _Carduelis_ _pinus_	1	0					2	0		
American Goldfinch _Carduelis_ _tristis_	1	1	1	3	9	4	8	8		
Evening Grosbeak _Coccothraustes_ _vespertinus_	0	2	2	2	2	0				
Unidentified passerine	21	22	48	32	41	39	116	86	61	54
Unidentified woodpecker	7	14	6	12	5	12	7	8	4	5
Unidentified non-passerine					0	1				
Total individuals	775	888	1131	1162	1136	1258	682	610	634	501
Total species	50	62	71	73	68	73	59	54	46	41

Appendix 9b. Total number of individuals and species observed on control (C) and treatment (T) transects in Wisconsin during five census periods in 1987. English and scientific names follow AOU (1983, 1985).

Appendix 9b. Total number of individuals and species observed on control(C) and treatment(T) transects in Wisconsin during five census periods in 1987. English and scientific names follow AOU(1983,1985).

	May		June		July		August		September	
	T	C	T	C	T	C	T	C	T	C
Common Loon *Gavia immer*					3	0				
Pied-billed Grebe *Podilymbus podiceps*					0	1			0	2
Great Blue Heron *Ardea herodias*	0	1	1	1	1	1				
Wood Duck *Aix sponsa*	2	3	0	1	0	1	0	2	0	10
Sharp-shinned Hawk *Accipiter striatus*							1	1		
Cooper's Hawk *Accipiter cooperii*							1	0		
Broad-winged Hawk *Buteo platypterus*			1	3	2	0	1	3	0	2
Red-tailed Hawk *Buteo jamaicensis*					1	0	1	0		
Spruce Grouse *Dendragapus canadensis*									1	0
Ruffed Grouse *Bonasa umbellus*	8	14	0	8	3	2	12	20	8	16
Common Snipe *Gallinago gallinago*	1	0							1	0
American Woodcock *Scolopax minor*	1	2	0	2	0	2	2	4	2	2
Mourning Dove *Zenaida macroura*									1	0
Barred Owl *Strix varia*	0	1							0	2
Chimney Swift *Chaetura pelagica*	0	4	5	5						
Ruby-throated Hummingbird *Archilochus colubris*			1	0	0	1	0	1		
Belted Kingfisher *Ceryle alcyon*	0	1			0	2	0	1	0	1
Yellow-bellied Sapsucker *Sphyrapicus varius*	8	3	16	10	2	2	1	4	6	13
Downy Woodpecker *Picoides pubescens*	2	2	1	2	5	10	5	3	7	7
Hairy Woodpecker *Picoides villosus*	2	1	4	2	1	1	10	4	8	8

	May		June		July		August		September	
	T	C	T	C	T	C	T	C	T	C
Black-backed Woodpecker *Picoides arcticus*					1	0	1	0		
Northern Flicker *Colaptes auratus*	10	13	4	4	8	10	8	5	7	7
Pileated Woodpecker *Dryocopus pileatus*			1	1	1	4	1	3		
Olive-sided Flycatcher *Contopus borealis*	1	1	2	2	2	1			0	1
Eastern Wood-Pewee *Contopus virens*	0	4	4	16	2	7	2	4		
Yellow-bellied Flycatcher *Empidonax flaviventris*	9	9	33	44	7	9	0	4		
Alder Flycatcher *Empidonax alnorum*	5	0	12	6	7	0				
Least Flycatcher *Empidonax minimus*	9	43	19	31	3	13				
Eastern Phoebe *Sayornis phoebe*							1	0		
Great Crested Flycatcher *Myiarchus crinitus*	4	15	5	14	1	5				
Eastern Kingbird *Tyrannus tyrannus*					0	2				
Tree Swallow *Tachycineta bicolor*	4	2	0	2						
Gray Jay *Perisoreus canadensis*	1	0	5	4	9	5	4	1	12	4
Blue Jay *Cyanocitta cristata*	50	26	46	33	31	24	36	45	40	59
American Crow *Corvus brachyrhynchos*			0	1	10	0	0	2	3	0
Common Raven *Corvus corax*	1	0	0	1			0	3	1	0
Black-capped Chickadee *Parus atricapillus*	19	10	17	25	59	64	81	109	118	156
Boreal Chickadee *Parus hudsonicus*	1	0	2	0	6	3	5	1	2	2
Red-breasted Nuthatch *Sitta canadensis*	8	10	13	19	47	22	58	84	158	188
White-breasted Nuthatch *Sitta carolinensis*	0	1	2	4	4	7	0	1	1	7
Brown Creeper *Certhia americana*	2	1	12	11	4	11	7	16	18	23

	May		June		July		August		September	
	T	C	T	C	T	C	T	C	T	C
Winter Wren *Troglodytes troglodytes*	24	22	32	42	14	25	8	2	9	12
Sedge Wren *Cistothorus platensis*	5	0	4	0	1	0				
Marsh Wren *Cistothorus palustris*					2	0				
Golden-crowned Kinglet *Regulus satrapa*	23	20	21	23	38	25	89	43	46	32
Ruby-crowned Kinglet *Regulus calendula*	4	0			0	4	6	16	3	3
Eastern Bluebird *Sialia sialis*			2	0	2	0	2	0		
Veery *Catharus fuscescens*	0	1	20	12	3	2	0	1		
Gray-cheeked Thrush *Catharus minimus*	1	0							3	0
Swainson's Thrush *Catharus ustulatus*	1	0			0	1	1	0	0	1
Hermit thrush *Catharus guttatus*	25	20	60	49	86	60	15	7	15	11
Wood Thrush *Hylocichla mustelina*	0	3								
American Robin *Turdus migratorius*	6	12	17	33	14	8	8	6	3	13
Gray Catbird *Dumetella carolinensis*	2	0	3	0			0	3		
Brown Thrasher *Toxostoma rufum*	0	1								
Cedar Waxwing *Bombycilla cedrorum*			3	8	13	24	35	54	3	5
Solitary Vireo *Vireo solitarius*	2	1	4	5	3	2	1	1	0	1
Yellow-throated Vireo *Vireo flavifrons*			2	1	1	0				
Philadelphia Vireo *Vireo philadelphicus*	1	0			0	1				
Red-eyed Vireo *Vireo olivaceus*	51	75	75	98	79	98	11	25	5	5
Golden-winged Warbler *Vermivora chrysoptera*	13	12	6	2						
Tennessee Warbler *Vermivora peregrina*	8	13	1	2					1	0

	May		June		July		August		September	
	T	C	T	C	T	C	T	C	T	C
Nashville Warbler *Vermivora ruficapilla*	172	183	128	114	8	10	8	7	0	1
Northern Parula *Parula americana*	21	34	18	23	0	3				
Yellow Warbler *Dendroica petechia*	3	2	6	4	0	1				
Chestnut-sided Warbler *Dendroica pensylvanica*	77	58	93	63	14	5	5	2	1	0
Magnolia Warbler *Dendroica magnolia*	14	1	4	1	0	1	2	0	2	3
Cape May Warbler *Dendroica tigrina*	8	0	2	2	2	0				
Black-throated Blue Warbler *Dendroica caerulescens*	2	0								
Yellow-rumped Warbler *Dendroica coronata*	16	11	9	16	8	1	17	0	80	93
Black-throated Green Warbler *Dendroica virens*	67	69	71	77	30	35	9	0	1	7
Blackburnian Warbler *Dendroica fusca*	19	27	25	24	3	1	1	0		
Pine Warbler *Dendroica pinus*	3	0	2	0	2	1				
Palm Warbler *Dendroica palmarum*	13	0	5	1	1	2			1	5
Bay-breasted Warbler *Dendroica castanea*	3	4					2	2	1	2
Blackpoll Warbler *Dendroica striata*	0	1								
Black-and-white Warbler *Mniotilta varia*	39	55	39	36	2	1	2	2		
American Redstart *Setophaga ruticilla*	1	0	0	4	2	1	1	0	2	3
Ovenbird *Seiurus aurocapillus*	176	241	114	196	24	39	13	9	18	14
Northern Waterthrush *Seiurus noveboracensis*	2	2	1	3						
Connecticut Warbler *Oporornis agilis*	4	0	4	2	1	1				
Mourning Warbler *Oporornis philadelphia*	11	2	29	22	7	1	0	2		
Common Yellowthroat *Geothylpis trichas*	30	15	38	27	29	28	4	9	6	2

	May		June		July		August		September	
	T	C	T	C	T	C	T	C	T	C
Canada Warbler *Wilsonia canadensis*	5	16	8	16	1	1	1	2		
Scarlet Tanager *Piranga olivacea*	8	8	9	11	1	0				
Rose-breasted Grosbeak *Pheucticus ludovicianus*	22	39	22	23	3	1	1	4	1	2
Indigo Bunting *Passerina cyanea*	1	1	9	0	2	0				
Rufous-sided Towhee *Pipilo erythrophthalmus*					0	1	0	1		
Chipping Sparrow *Spizella passerina*	9	1	22	1	3	6				
Lark Sparrow *Chondestes grammacus*					2	0				
Fox Sparrow *Passerella iliaca*									1	0
Song Sparrow *Melospiza melodia*	16	17	26	25	14	10	9	1	0	4
Lincoln's Sparrow *Melospiza lincolnii*	5	2	4	0	2	0				
Swamp Sparrow *Melospza georgianna*	12	0	10	1	5	3	2	0	2	0
White-throated Sparrow *Zonotrichia albicollis*	143	102	119	121	63	58	20	11	112	66
Dark-eyed Junco *Junco hyemalis*	2	0	4	0	0	2	1	1	10	16
Red-winged blackbird *Agelaius phoeniceus*	7	7	10	9	1	0				
Common Grackle *Quiscalus quiscula*	1	7	3	0					2	0
Brown-headed Cowbird *Molothrus ater*	1	8	1	4						
Northern Oriole *Icterus galbula*	1	1								
Purple Finch *Carpodacus purpureus*	17	8	5	7	1	0	0	1		
White-winged Crossbill *Loxia leucoptera*					27	7	1	3	1	0
Pine Siskin *Carduelis pinus*	0	1			0	3	1	0	10	4
American Goldfinch *Carduelis tristis*	6	0	1	2	14	2	1	1	1	0

Appendix 9b (continued)

	May		June		July		August		September	
	T	C	T	C	T	C	T	C	T	C
Evening Grosbeak Coccothraustes vespertinus	17	0	3	0	4	0	6	6	9	0
Unidentified passerine	33	29	49	60	102	63	84	97	74	62
Unidentified woodpecker	4	3	9	17	6	8	1	13	2	3
Unidentified non-passerine					1	0				
Total individuals	1305	1302	1359	1439	861	761	606	653	819	880
Total species	72	62	69	65	66	63	51	50	46	42

Appendix 10a. Mean number (per segment) of individual birds in
nesting categories for Michigan and Wisconsin.

Appendix 10a. Mean number (per segment) of individual birds in nesting categories for Michigan.

Nesting Types	June 85 T	C
Ground	19.0	13.7
Canopy	11.3	9.7
Subcanopy	7.4	6.4
Cavity, hole	3.0	3.3
Ledge	0.0	0.0
Nest parasite	0.0	0.1

Nesting Types	May 86 T	C	June 86 T	C	July 86 T	C	Aug 86 T	C	Sep 86 T	C
Ground	10.9	12.3	12.8	10.7	9.8	7.9	1.5	1.9	2.2	3.0
Canopy	8.1	9.2	7.7	8.2	7.0	7.8	3.4	3.3	2.9	5.0
Subcanopy	1.6	4.3	4.6	8.0	2.6	3.7	0.4	0.6	0.3	0.7
Cavity, hole	2.4	3.4	1.5	1.6	2.9	3.8	2.6	4.0	3.1	5.3
Ledge	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Nest parasite	0.2	0.5	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0

Nesting Types	May 87 T	C	June 87 T	C	July 87 T	C	Aug 87 T	C	Sep 87 T	C
Ground	9.3	7.2	13.0	9.8	11.3	10.6	3.6	1.6	2.4	1.1
Canopy	6.5	7.4	7.9	9.3	8.3	8.1	5.7	4.5	6.2	3.6
Subcanopy	1.2	2.8	4.7	6.0	4.4	5.4	1.1	1.0	0.5	0.2
Cavity, hole	1.6	3.5	1.3	2.6	3.1	6.0	3.5	5.8	5.2	6.1
Ledge	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Nest parasite	0.1	0.3	0.1	0.2	0.1	0.1	0.0	0.0	0.0	0.0

Appendix 10a (continued). Mean number (per segment) of individual birds in nesting categories for Wisconsin.

Nesting Types	June 85 T	C
Ground	16.6	15.8
Canopy	13.5	11.1
Subcanopy	6.7	4.4
Cavity, hole	1.9	2.5
Ledge	0.0	0.0
Nest parasite	0.1	0.0

Nesting Types	May 86 T	C	June 86 T	C	July 86 T	C	Aug 86 T	C	Sep 86 T	C
Ground	17.2	19.3	14.3	12.4	5.8	7.1	3.1	2.6	2.5	3.0
Canopy	9.2	9.3	8.4	6.6	6.8	6.5	4.0	3.5	7.5	4.7
Subcanopy	6.3	5.3	5.3	4.8	3.1	1.5	1.1	0.5	0.6	0.2
Cavity, hole	1.2	1.3	1.3	1.7	3.3	3.3	3.0	4.0	5.9	6.0
Ledge	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nest parasite	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Nesting Types	May 87 T	C	June 87 T	C	July 87 T	C	Aug 87 T	C	Sep 87 T	C
Ground	16.4	17.0	15.0	16.4	5.6	5.4	2.0	1.8	4.5	3.6
Canopy	8.4	7.5	8.6	9.6	7.2	6.6	5.9	5.4	5.6	6.0
Subcanopy	5.3	5.4	6.8	5.5	2.4	1.6	0.6	0.6	0.4	0.2
Cavity, hole	1.6	1.6	2.0	2.5	3.5	3.5	4.4	5.8	8.1	10.6
Ledge	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nest parasite	0.0	0.2	0.0	0.1	0.0	0.3	0.0	0.0	0.0	0.0

Appendix 10b. Mean number (per segment) of individual birds in habitat types for Michigan and Wisconsin.

Appendix 10b. Mean number (per segment) of individual birds in habitat types for Michigan.

Habitat Types	June 85 T	C
Deciduous	16.2	16.2
Coniferous	2.7	1.3
Mixed forest	10.1	8.6
Early succ.	8.5	3.3
Fields, meadow	1.6	1.7
Shrub swamp	0.6	1.1
Urban	0.0	0.0
Open wetland	0.1	0.5
Ponds, lakes	0.0	0.2
Muskeg	0.0	0.0
Low. conifers	1.2	0.4

Habitat Types	May 86 T	C	June 86 T	C	July 86 T	C	Aug 86 T	C	Sep 86 T	C
Deciduous	5.1	8.5	11.2	13.2	7.4	10.6	3.1	4.7	3.4	6.5
Coniferous	3.4	2.8	1.9	1.5	2.2	1.7	1.7	1.6	2.5	3.1
Mixed forest	9.1	10.7	6.1	5.4	5.7	4.5	0.9	1.1	0.7	1.8
Early succ.	2.7	2.3	4.3	3.2	2.9	2.0	1.0	1.1	1.0	0.9
Fields,meadow	2.0	3.2	1.4	2.3	2.6	2.4	1.0	0.9	0.6	0.6
Shrub swamp	0.6	0.3	0.5	1.2	0.8	1.4	0.1	0.0	0.2	0.5
Urban	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Open wetlands	0.0	1.2	0.2	1.0	0.2	0.2	0.1	0.0	0.0	0.0
Ponds,lakes	0.1	0.2	0.0	0.1	0.0	0.1	0.1	0.3	0.0	0.1
Muskeg	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Low. conifers	0.3	0.4	1.2	0.8	0.5	0.3	0.2	0.1	0.2	0.5

Habitat Types	May 87 T	C	June 87 T	C	July 87 T	C	Aug 87 T	C	Sep 87 T	C
Deciduous	2.4	4.7	9.2	12.2	9.9	14.4	4.4	5.8	5.5	5.9
Coniferous	4.2	3.3	2.4	2.2	2.7	1.9	3.3	2.7	4.4	2.5
Mixed forest	6.7	7.2	6.3	5.8	6.3	6.2	1.7	1.4	0.8	0.8
Early succ.	3.2	1.4	4.6	2.8	4.5	2.4	2.2	1.2	2.1	1.0
Fields,meadow	1.4	2.1	2.0	2.2	2.2	2.6	1.7	1.3	0.8	0.7
Shrub swamp	0.3	0.6	1.0	1.2	0.9	1.6	0.4	0.5	0.3	0.1
Urban	0.0	0.2	0.0	0.1	0.0	0.2	0.0	0.0	0.0	0.0
Open wetlands	0.3	1.0	0.2	0.7	0.1	0.5	0.0	0.0	0.0	0.0
Ponds,lakes	0.0	0.3	0.3	0.1	0.1	0.0	0.1	0.0	0.0	0.1
Muskeg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Low. conifers	0.3	0.5	0.9	0.7	0.6	0.4	0.3	0.1	0.5	0.2

Appendix 10b (continued). Mean number (per segment) of individual birds in habitat types for Wisconsin.

Habitat Types	June 85 T	C
Deciduous	15.2	15.8
Coniferous	2.8	1.4
Mixed forest	9.9	9.5
Early succ.	4.8	3.1
Fields, meadow	1.8	0.7
Shrub swamp	2.3	0.8
Urban	0.1	0.0
Open wetland	0.5	0.0
Ponds, lakes	0.1	0.2
Muskeg	0.2	0.0
Low. conifers	1.4	2.4

Habitat Types	May 86 T	C	June 86 T	C	July 86 T	C	Aug 86 T	C	Sep 86 T	C
Deciduous	10.3	12.9	9.8	11.5	6.3	7.8	4.8	5.9	4.7	5.4
Coniferous	2.7	1.8	2.6	1.2	2.4	1.1	2.7	2.0	7.8	5.1
Mixed forest	11.3	12.7	7.3	6.4	3.7	3.5	1.4	0.9	0.5	0.6
Early succ.	5.0	4.1	5.1	3.9	2.4	3.1	0.8	1.2	1.2	1.8
Fields,meadow	1.8	1.3	1.4	1.0	1.1	1	0.7	0.3	0.8	0.5
Shrub swamp	1.5	0.7	1.3	0.5	1.8	0.7	0.4	0.3	0.4	0.0
Urban	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Open wetlands	0.5	0.2	0.3	0.0	0.2	0.1	0.1	0.0	0.1	0.0
Ponds,lakes	0.1	0.1	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.2
Muskeg	0.1	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Low. conifers	0.7	1.6	1.4	1.2	1.0	0.7	0.3	0.2	1.1	0.3

Habitat Types	May 87 T	C	June 87 T	C	July 87 T	C	Aug 87 T	C	Sep 87 T	C
Deciduous	9.1	12.1	9.1	12.1	5.6	7.1	4.5	6.1	5.8	7.8
Coniferous	2.4	1.9	2.4	2.2	3.3	1.8	4.4	3.8	7.5	8.1
Mixed forest	9.4	9.8	8.9	9.2	3.8	3.5	1.3	0.9	0.9	0.9
Early succ.	6.6	4.4	6.5	5.6	2.5	2.3	1.6	1.8	3.1	2.0
Fields,meadow	1.1	1.5	1.6	1.8	1.6	0.8	0.7	0.4	0.4	0.6
Shrub swamp	1.3	0.5	1.7	1.0	1.0	0.9	0.2	0.3	0.3	0.1
Urban	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Open wetlands	0.3	0.2	0.4	0.2	0.1	0.0	0.0	0.0	0.0	0.0
Ponds,lakes	0.1	0.2	0.1	0.1	0.1	0.1	0.0	0.1	0.0	0.3
Muskeg	0.1	0.1	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Low. conifers	1.3	1.1	1.8	1.9	0.6	0.7	0.3	0.2	0.6	0.7

Appendix 10c. Mean number (per segment) of individual birds in foraging guilds for Michigan and Wisconsin (see Appendix 2).

Appendix 10c. Mean number (per segment) of individual birds in foraging guilds for Michigan (see Appendix 2).

Food Types	June 85 T	C
Aquatic vert.	0.0	0.0
Predator	0.1	0.1
Scavenger	0.0	0.0
Veg.-no sd,fr	0.2	0.1
Omnivores	0.7	1.0
Ground invert	6.5	6.4
Seeds	0.2	0.2
Ground ins,sd	2.8	2.2
Ground ins,fr	2.6	2.3
Foliage ins.	21.4	14.2
Aerial ins.	0.0	0.0
Flycatchers	2.8	2.2
Foliage ins,fr	1.5	1.5
Fruit	0.2	0.3
Foliage ins,sd	0.1	0.2
Bark insects	1.7	2.2
Nectar,sap	0.2	0.4
Aquatic veg.	0.0	0.0
Aquatic invert	0.0	0.0

Food Types	May 86 T	C	June 86 T	C	July 86 T	C	Aug 86 T	C	Sep 86 T	C
Aquatic vert.	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Predator	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.1	0.0	0.0
Scavenger	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Veg.-no sd,fr	0.3	0.2	0.2	0.0	0.1	0.7	0.1	0.2	0.3	0.5
Omnivores	1.4	1.7	0.8	0.7	0.7	0.6	0.8	0.5	0.6	1.3
Ground invert	1.6	2.7	4.5	5.1	2.7	2.9	0.3	0.3	0.3	0.7
Seeds	0.4	0.6	0.2	0.2	0.1	0.1	0.2	0.2	0.1	0.1
Ground ins,sd	3.3	4.2	2.3	3.0	3.2	3.0	0.7	0.8	1.1	0.5
Ground ins,fr	2.2	2.6	1.8	2.0	3.5	2.7	0.6	0.6	1.1	1.1
Foliage ins.	10.4	11.6	11.7	11.3	9.3	9.4	3.2	4.1	3.5	6.2
Aerial ins.	0.0	0.3	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Flycatchers	0.6	1.3	2.1	3.2	1.1	1.4	0.6	0.5	0.0	0.6
Foliage ins,fr	1.6	1.9	1.3	1.6	0.4	0.5	0.1	0.2	0.4	1.0
Fruit	0.0	0.0	0.2	0.3	0.1	0.0	0.2	0.4	0.0	0.1
Foliage ins,sd	0.1	0.2	0.3	0.2	0.4	0.4	0.0	0.0	0.0	0.0
Bark insects	1.2	1.8	0.9	0.9	0.5	1.1	0.9	1.4	0.8	1.6
Nectar,sap	0.3	0.5	0.4	0.3	0.2	0.3	0.3	0.4	0.3	0.4
Aquatic veg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0
Aquatic invert	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0

Food Types	May 87 T	C	June 87 T	C	July 87 T	C	Aug 87 T	C	Sep 87 T	C
Aquatic vert.	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1
Predator	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.0	0.0
Scavenger	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Veg.-no sd,fr	0.3	0.1	0.1	0.1	0.1	0.0	0.4	0.2	0.1	0.1
Omnivores	0.7	1.1	1.3	1.5	1.2	1.6	1.1	0.7	1.6	1.2
Ground invert	0.3	0.9	3.9	4.1	2.3	3.8	0.2	0.3	0.6	0.2
Seeds	0.5	0.8	0.0	0.1	0.3	0.2	0.3	0.2	0.3	0.0
Ground ins,sd	4.7	4.0	2.6	2.5	3.7	3.2	2.0	0.8	1.3	0.4
Ground ins,fr	1.5	1.9	2.4	2.1	3.3	3.4	1.4	1.1	1.0	0.9
Foliage ins.	8.1	8.4	11.6	10.9	11.9	11.8	5.7	5.7	6.0	4.1
Aerial ins.	0.0	0.2	0.1	0.1	0.1	0.2	0.0	0.0	0.0	0.0
Flycatchers	0.2	0.5	2.0	3.2	1.9	2.1	0.6	0.8	0.1	0.2
Foliage ins,fr	1.7	1.4	1.1	0.9	0.5	0.6	0.1	0.2	0.3	0.4
Fruit	0.0	0.0	0.0	0.3	0.3	0.1	0.6	0.6	0.6	0.6
Foliage ins,sd	0.0	0.1	0.2	0.3	0.2	0.2	0.1	0.1	0.0	0.0
Bark insects	0.5	1.1	1.0	1.6	1.2	1.9	1.3	2.0	2.4	2.9
Nectar,sap	0.3	0.6	0.3	0.3	0.2	0.9	0.0	0.3	0.1	0.2
Aquatic veg.	0.0	0.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Aquatic invert	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Appendix 10c (continued). Mean number (per segment) of individual birds in foraging guilds for Wisconsin (see Appendix 2).

Food Types	June 85 T	C
Aquatic vert.	0.1	0.0
Predator	0.0	0.0
Scavenger	0.0	0.0
Veg.-no sd,fr	0.1	0.3
Omnivores	1.1	0.7
Ground invert	7.1	6.1
Seeds	0.4	0.2
Ground ins,sd	2.7	1.3
Ground ins,fr	2.0	1.7
Foliage ins.	19.2	16.4
Aerial ins.	0.0	0.0
Flycatchers	3.0	4.8
Foliage ins,fr	0.9	0.5
Fruit	0.2	0.0
Foliage ins,sd	0.5	0.0
Bark insects	1.5	1.7
Nectar, sap	0.0	0.1
Aquatic veg.	0.0	0.1
Aquatic invert	0.1	0.0

Food Types	May 86 T	C	June 86 T	C	July 86 T	C	Aug 86 T	C	Sep 86 T	C
Aquatic vert.	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.1
Predator	0.1	0.0	0.1	0.1	0.0	0	0.1	0.0	0.0	0.1
Scavenger	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Veg.-no sd,fr	0.4	0.4	0.1	0.1	0.2	0.4	0.2	0.2	0.2	0.5
Omnivores	1.4	1.3	0.8	0.8	0.5	1.0	1.0	0.8	0.8	0.5
Ground invert	5.1	6.4	4.5	4.8	0.4	0.9	1.3	0.9	0.7	0.2
Seeds	0.3	0.2	0.2	0.1	0.2	0.2	0.3	0.0	0.0	0.2
Ground ins,sd	3.9	2.8	4.5	2.6	3.2	3.5	0.9	1.2	1.6	2.0
Ground ins,fr	2.0	1.9	1.6	1.5	2.1	1.7	0.6	0.3	1.0	0.6
Foliage ins.	17.3	17.0	13.7	11.7	9.4	8.1	4.9	4.7	5.2	4.8
Aerial ins.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Flycatchers	0.8	1.6	1.7	2.0	1.2	1.1	0.1	0.2	0.0	0.0
Foliage ins,fr	0.9	1.2	0.5	0.7	0.4	0.2	0.7	0.6	4.9	2.5
Fruit	0.0	0.0	0.1	0.0	0.2	0.1	0.0	0.0	0.0	0.0
Foliage ins,sd	0.2	0.2	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bark insects	1.3	2.2	1.1	1.1	1.1	0.8	1.1	1.4	2.1	2.2
Nectar,sap	0.3	0.2	0.3	0.4	0.3	0.2	0.1	0.2	0.2	0.3
Aquatic veg.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Aquatic invert	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Food Types	May 87 T	C	June 87 T	C	July 87 T	C	Aug 87 T	C	Sep 87 T	C
Aquatic vert.	0.0	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.1
Predator	0.0	0.0	0.0	0.1	0.1	0.0	0.1	0.1	0.0	0.1
Scavenger	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Veg.-no sd,fr	0.2	0.4	0.0	0.2	0.1	0.1	0.3	0.5	0.2	0.4
Omnivores	1.3	0.8	1.4	1.0	1.3	0.7	1.0	1.3	1.5	1.6
Ground invert	4.8	6.1	3.0	5.1	0.6	1.1	0.4	0.3	0.5	0.5
Seeds	0.6	0.2	0.2	0.2	1.1	0.2	0.1	0.1	0.1	0.0
Ground ins,sd	4.9	3.4	4.9	4.0	2.2	2.0	0.8	0.4	3.1	2.2
Ground ins,fr	1.1	1.3	2.5	2.5	2.8	2.0	0.8	0.5	0.7	0.8
Foliage ins.	15.0	14.3	15.0	14.6	7.5	7.8	5.8	5.5	4.9	5.7
Aerial ins.	0.1	0.2	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Flycatchers	0.7	1.8	1.9	2.9	0.6	1.0	0.1	0.2	0.1	0.1
Foliage ins,fr	1.0	1.3	0.9	1.0	0.3	0.1	0.5	0.2	2.0	2.4
Fruit	0.0	0.0	0.1	0.2	0.3	0.6	0.9	1.4	0.1	0.1
Foliage ins,sd	0.5	0.1	0.3	0.0	0.2	0.1	0.2	0.2	0.5	0.1
Bark insects	1.3	1.8	1.8	1.9	1.6	1.4	2.1	2.8	4.8	5.9
Nectar,sap	0.2	0.1	0.4	0.3	0.1	0.1	0.0	0.1	0.2	0.3
Aquatic veg.	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.3
Aquatic invert	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Appendix 10d.   Mean number (per segment) of individual birds in
migration categories for Michigan and Wisconsin.

Appendix 10d. Mean number (per segment) of individual birds in migration categories for Michigan.

Migration Types	June 85 T	C
Permanent	3.3	3.6
Short distance	7.5	6.3
Long distance	29.9	23.2

Migration Types	May 86 T	C	June 86 T	C	July 86 T	C	Aug 86 T	C	Sep 86 T	C
Permanent	3.0	3.3	1.8	1.1	2.4	3.5	3.0	4.2	3.3	6.0
Short distance	9.8	11.4	5.8	7.5	9.4	8.4	3.0	3.4	4.6	5.4
Long distance	10.4	15.0	19.1	20.1	10.6	11.3	2.0	2.3	0.6	2.6

Migration Types	May 87 T	C	June 87 T	C	July 87 T	C	Aug 87 T	C	Sep 87 T	C
Permanent	1.9	2.9	1.7	3.2	3.7	5.0	4.7	6.0	6.3	6.7
Short distance	10.9	11.1	8.4	7.0	10.5	10.8	7.0	4.7	6.5	3.1
Long distance	6.0	7.2	16.8	17.8	12.9	14.4	2.2	2.3	1.3	1.3

Appendix 10d. Mean number (per segment) of individual birds in migration categories for Wisconsin.

Migration Types	June 85 T	C
Permanent	2.9	2.3
Short distance	7.6	4.3
Long distance	28.0	27.1

Migration Types	May 86 T	C	June 86 T	C	July 86 T	C	Aug 86 T	C	Sep 86 T	C
Permanent	2.5	2.5	1.7	1.4	3.3	4.0	3.6	4.1	6.2	6.3
Short distance	9.6	7.0	9.2	5.7	9.1	7.7	4.7	4.0	10.1	7.3
Long distance	21.9	26.0	18.4	18.7	6.7	6.7	2.8	2.4	0.2	0.3

Migration Types	May 87 T	C	June 87 T	C	July 87 T	C	Aug 87 T	C	Sep 87 T	C
Permanent	2.7	1.6	2.4	2.7	4.6	4.2	6.4	8.4	9.4	11.4
Short distance	9.9	7.0	10.7	9.8	8.2	6.7	5.1	3.4	8.2	7.9
Long distance	19.0	23.1	19.3	21.6	5.3	6.1	1.5	1.7	0.9	1.1