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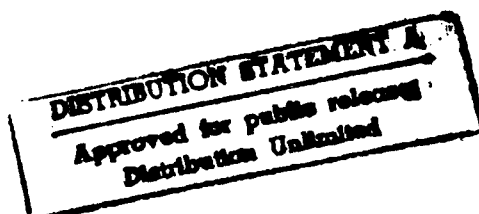
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**Compilation of 1991 Annual Reports
of the Navy ELF Communications System
Ecological Monitoring Program**

Volume 2 of 3 Volumes:
Tabs C-F

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Technical Report D06200-2
Contract No. N00039-88-C-0065
August 1992

Prepared for:

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

Submitted by:

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FOREWORD

During 1991, the Navy continued to conduct long-term studies monitoring for possible effects to biota from operation of their ELF Communications System. The Space and Naval Warfare Systems Command (SPAWAR) funded these studies through a contract to IIT Research Institute (IITRI). IITRI provided engineering support and overall program management of monitoring studies performed by university subcontractors.

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

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**ELF COMMUNICATIONS SYSTEM
ECOLOGICAL MONITORING PROGRAM**

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- I. Listing of Technical Reports.

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a. Subcontractors name and address:



Rudolph Neal Band

Department of Zoology

Michigan State University

East Lansing, MI 48824

b. Subcontract number: EO6595-88-C-003

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Program, Task 5.2, Soil Amoeba.

d. Reporting year: 1/1/91-12/31/91

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a. Subcontractors name and address:

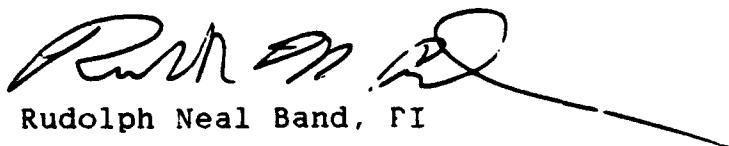
Rudolph Neal Band
Department of Zoology
Michigan State University
East Lansing, MI 48824

b. Subcontract number: EO6595-88-C-003

c. Title: ELF Communications System Ecological Monitoring
Program, Task 5.2, Soil Amoeba

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Rudolph Neal Band, PI

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Richard L. Howe, Assistant Director
Contract and Grant Administration

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4. Abstract:

Four of the years prior to 1991 were drought years (i.e. 1986 to 1989) while 1990 was moderately dry. The as yet incomplete NOAA weather data for 1991 also indicates that this was a dry year. For the fifth growing season again growth was suppressed although not as marked as in the 1986 to 1989 drought. This is in contrast with the 1984 and 1985 growing seasons, in which abundant rainfall took place and the population increases in soil amoebae during the growing season was far greater, or the 1990 season which was intermediate in growth response.

During the 1991 growing season the ELF antenna was operational. This provides 2 years of intermittent ELF exposure (i.e. 1989 and 1990) for the biological systems to react to the radiation, one year of very limited exposure, greater exposure in 1990 and operational exposure during the 1991 growing season.

The antenna, ground and control sites used in previous years were continued. The sites have been characterized by IITRI personnel so that all sites have a similar 60 cycle electromagnetic background while the control site is devoid of ELF radiation from the antenna.

I have been monitoring various physical and chemical properties of the sites as well as their biological characteristics.

At all sites, population size fluctuations were observed, as was the case in previous years. Of course the fluctuations were not as dramatic for the drought seasons, as they were in 1984 and 1985. Growth rates of amoebae in soil submerged cultures, developed over previous seasons, were performed in 1990. Isozyme analyses of amoebae grown in submerged cultures failed to reveal effects of ELF radiation at the gene level.

5. Summary:

Plot selection and characterization: soil chemistry was performed on all sites in 1990, as was done in previous years. As in past years, differences in soil chemistry were noted between sites although these were within the same order of magnitude.

Species and strain characterization: In 1986, 1987 and 1988, Acanthamoeba polyphaga was used to test for strain heterogeneity within and between the sites. Isoenzyme analysis was used to detect strain differences; since this is a measure of genetic diversity, it is sensitive to environmental stress. No differences were found between sites. Budget constraints forced the elimination of this aspect of the study for the 1989 and 1990 years. This was done again in the 1991 season. As noted below, isozyme analyses were used to detect

possible changes in amoebae grown in the presence of the electric currents generated by the ELF antenna.

Population size: the fluctuation in population of amoebae during the growing season was determined as in past years. No differences were noted in total population size between study sites for a given horizon and sampling date. As in past years differences were noted in the number of dormant cysts between sites. Again for 1991, a dry year, population sizes did not reach those observed in normal rainfall years (e.g. 1984, 1985), nor did they approach those seen in 1990. They were similar to those seen in 1986 through 1989.

Growth and feeding activity: to test growth rate of amoebae, soil submersible culture vessels were designed. The antenna was operational in the 1991 growing season, it was used for sufficient time to do growth and isozyme experiments. No differences in growth rate or isoenzyme heterogeneity was observed between sites.

Ambient monitoring: soil temperature and moisture were monitored continuously during the field season, as was done in previous years. The moisture content of soil during the growing seasons of 1986 through 1989, and to a lesser extent in 1990 was lower than normal rainfall years. Data for 1991 is incomplete, but August was a very dry month. This and total annual precipitation correlated to small populations of amoebae in the soil during these years. Soil temperature over the growing season was the same between study sites. Temperature changes from Spring to Fall for 1990 ranged from less than 10 to 17° C over the growing season.

6. Progress report:

- a. OBJECTIVES: The project objective is to determine possible effects of ELF radiation on amoebae in soil. The sites chosen for this study are adjacent to the Michigan ELF transmitter facility and include control, antenna and ground wire study sites.

The 1991 field season is the first in which the ELF antenna was operational. A proposal has been submitted to add two more growing seasons to the study (i.e. 1992 & 1993) to provide three seasons with a fully functional antenna.

- b. WORK PLAN ELEMENTS:

#0. Plot selection and characterization.

Synopsis: Statistical analysis of soil chemistry shows some variability between sites, as was the case for data since 1986. This may be due to the prolonged drought that has continued from 1986. Prior to the drought (e.g. 1985) differences were not observed between sites. Likewise this could be due to differences in the variability of data between years.

#1. Species and strain characterization.

Synopsis: using morphological and physiological markers, identify species and strains of soil amoebae from the study areas so that possible changes in the population due to ELF can be detected. The allozyme methods, developed for genetic analyses was used

here and to monitor a clonal isolate of A. polyphaga in Work Plan #3, below.

#2. Population size and activity.

Synopsis: determine population size of amoebae in soil and the ratio of vegetative to dormant amoebae over the growing season. This is a productivity measure which could be affected by ELF radiation. It could also be a reflection of changes in the microbial food organisms due to ELF radiation. Direct ELF effects on amoeba growth vs. indirect effects on food organisms can be distinguished in two ways: growth of amoebae in culture vessels exposed to ELF radiation (see #3 below) and isozyme analyses. Direct counts of bacteria in soil were not attempted, although new methods to determine bacterial biomass have been published and these will be used in the 1992 season.

Specifics: an established soil dilution counting procedure is used (Singh, 1946 as modified by Darbyshire et al., 1974). In order to count vegetative amoebae and cysts, samples are first divided in half, one-half is used to count total cysts and vegetative amoebae while the other half is treated to kill amoebae so that only cysts are counted. Differential counts are used to calculate by subtraction the total vegetative amoeba count. In the 1983 season I found that 8 random samples, subdivided into organic and mineral horizons (i.e. 8 samples per horizon), provided statistically significant data;

I will repeat this from the 1983 report: ten samples were counted from each horizon at the three sites on two dates; the results indicated a coefficient of variation that was less than 10% of the mean for a given horizon and date. From a 90% power curve, significant differences could be detected at 1.4 X std. dev. for a sample size of 10 and 1.5 to 1.6 X std. dev. for a sample size of 8. Thus sample sizes of 8 and 10 were almost equally powerful so that 8 random samples were taken from each horizon at the three sample sites on a sampling date.

One-way analysis of variance was used to detect differences in total amoeba and cyst count between control, antenna and ground sites for each horizon in 1989. I was advised by Professor John Gill at MSU, a statistician who works with biological problems, that log transformed data should be used for statistical analyses. Since the microbial population doubles over time, log transformed data more closely reflects biological events. Table 4B gives the error (i.e. among) degrees of freedom as 21. Direct counts of amoebae in soil as is done with freshwater organisms (e.g. Wright & Coffin, 1984) is not possible. Microbes adhere to soil and sonication of a soil slurry to release them might make quantitative recovery of some organisms by subsequent density flotation possible, but amoebae would be destroyed.

Bacterial biomass will be estimated in the 1992 season by the method of Tsai & Olsen (1991). Earlier methods to make this estimate were too labor intensive to fit within budgetary limits.

#3. Growth and feeding activity.

Synopsis: determine the in situ growth and feeding activity of amoebae in soil submersible culture vessels. This will provide data on growth rate, feeding activity and mean generation time (i.e. the cell cycle between nuclear mitoses).

(i.e. the cell cycle between nuclear mitoses).

Rationale: the approach utilizes a known amoeba species previously isolated from the study site, Acanthamoeba polyphaga and characterized as part of the isoenzyme study. Direct counts of amoebae are made with a microscope to determine increase in number of organisms and nuclei over time. A log transform of these data provides a straight line plot which can be quantified by regression analysis. Statistically significant differences between slopes can be detected with confidence limits of the line, a version of the t-test. This approach will be used to determine growth rate and thus mean generation time. Mean generation time is comparable to the cell cycle measurement of time between mitoses of Physarum. Isozyme analyses are done before and after serial growth in the culture vessels subjected to ELF-induced electromagnetic effects, to detect possible genetic changes in the exposed amoebae. We had previously developed this technique (e.g. Jacobson & Band, 1987) for screening clonal isolates of A. polyphaga from soil to look for genetic effects, using Nei's (Nei, 1972) statistical methods for comparing data between sites.

Culture chambers, containing electrodes to use in conjunction with ELF induced soil currents, were designed with the help of IITRI personnel. To measure growth rate of amoebae directly in soil would be ideal, but the techniques to do this are inefficient, labor intensive and not as accurate as direct counts of amoebae (i.e. soil dilution counts similar to those used to measure the number of amoebae present in soil). Further, uncontrolled interactions with other soil organisms could affect

amoeba growth. Soil water is a saline suitable for amoeba growth, but it does not exist as a continuous aqueous phase in soil. Therefore soil exhibits a higher electrical resistance than would be the case for soil water alone over a comparable distance, which is also the case for culture vessels, in which the saline is a continuous phase between the electrodes. Therefore two different culture vessel configurations are used, one to mimic the voltage induced in soil by the ELF radiation (with a greater current, since the resistance in saline is less than a comparable distance in soil) and the other to mimic soil current (with a smaller voltage than observed in soil). In previous seasons, it was established that chambers buried at research sites yielded growth rates that were not statistically different. Since 1985, IITRI personnel have cooperated in the design and construction of electrical components used in the soil growth experiments. The recent design includes continuous recording of soil voltages throughout the season as well as providing the electrical connections to the soil submersible culture vessels.

#4. Ambient monitoring.

Synopsis: soil temperature and moisture are monitored. Both measures are useful for general trends but fail to correlate to changes in amoeba populations. The multi-year drought (i.e. 1986 to 1989 and possibly 1990) had a dramatic effect on soil amoeba population size although this was better reflected in annual precipitation patterns than in soil moisture. Soil temperature

changes little over a growing season.

#5. Data analysis.

Synopsis: statistical analyses mentioned earlier are summarized here. For amoeba counts in soil, by soil dilution procedures, a one-way analysis of variance with 8 replicates per cell was adequate. One-way analysis of variance was used for soil counts (Table 4B) and soil moisture (Table 5) because it is not possible to compare accurately soil horizons or sampling dates. Soil horizons differ markedly in their densities. Bulk density of the organic and mineral horizons were presented in the 1983 annual report; the ratio of mineral to organic soil was 2.9. When this ratio is used to compare soil counts of the organic and mineral horizons some data fits this ratio but in most cases only a tendency can be observed. Thus soil counts corrected for bulk density differences between organic and mineral horizons will tend to be closer in count so that the bulk density data does indicate that mineral horizon population sizes are not too different from population sizes in the overlying organic horizon. Moisture and counts differ between sampling dates. Growth measurements in culture chambers were analyzed with regression lines, comparing slopes with Bonferoni t-tests. Other statistical comparisons (e.g. soil chemistry, soil pH, etc.) are done by analysis of variance. For isoenzyme determinations, comparisons between isolates are done by the method of Nei (1972).

SCHEDULE OF WORK ELEMENTS (Nov. 1 to Oct. 31 each year)

MONTH												
Element	1	2	3	4	5	6	7	8	9	10	11	12
0						X	X	X				
* 1												
2						X	X	X	X	X	X	
3	X	X	X	X	X	X	X	X	X	X	X	
4						X	X	X	X	X	X	
5	X	X	X	X	X							
Reports	X	X	X	X	X	X	X	X	X	X	X	X

* Omitted in the 1989 season.

c. EXPERIMENTAL

Methods and results will be presented in reference to the Work Plan, given above.

#0. Plot selection and characterization. Site selection is now complete.

Table 1 shows the chemical properties of the organic and mineral horizons for the control, antenna and ground wire sites, with replicates. As in past seasons, differences exist between sites (Table 2). This might be attributable to the drought which has extended over four years, 1986 to 1989, and again in 1991, although all sites were subjected to the same drought. The chemical content of soil in 1991 was similar to 1990. Exceptions can be seen in low NO_3 content from the mineral horizon in contrast to past years. Again the Ca content of the organic horizon was greater than in 1990 but similar to the 1989 season. As noted in the 1985 report, in view of the wide fluctuation in population size of amoebae seen throughout a given growing season, it would be of interest to see if this is reflected in soil ammonium levels. In consultation with Dr. J. Tiedje of the Department of Crop and Soil Sciences, it was determined that the rapid passage of ammonia through the ecosystem would make this impractical. Thus soil ammonium has not been determined. Table 2 demonstrates some significant differences between sites and sampling dates although values shown in Table 1 are consistent between horizons. Table 3 demonstrates the slightly acidic nature of the soil in a northern hardwood forest, with some differences between sites and horizons. Both horizons were

comparable to determinations made in past years.

#1. Species and strain characterization. Species of soil amoebae present at the study sites were isolated from soil enrichment plates. So far no species differences have been noted between sites; species composition was the same as in previous years. Species included Acanthamoeba castellanii, A. polyphaga, A. astronyxis (small strain), Hartmannella sp., Rosculus sp., Naegleria gruberi, Vahlkampfia sp., and Mayorella sp. The isoenzyme analysis of genetic heterogeneity of A. polyphaga, done in 1985, 1986 and 1987, was done again in 1991. Further analysis of this data is needed so that it will be presented in next year's annual report. Since this was a drought year (see Fig. 7 for summary), the environmental stress should be reflected in genetic heterogeneity seen in 1985 through 1987 (Hoffman & Parsons, 1991).

#2. Population size and activity. As stated in previous annual reports, the number of replicate soil samples required to statistically compare soil amoeba populations between study sites was 8. From 1983 to 1985 soil amoeba populations increased from the start of the growing season to a peak in excess of a million amoebae/gram soil in August and then dropped sharply in September to a few thousand/gram soil. Vegetative amoebae formed a significant component of each monthly sample, including the smaller September and October populations. No differences were noted for a given soil horizon between the antenna, ground and control sites. The drought, beginning in 1986, has had a pronounced effect on population size, the ratio of vegetative to dormant cysts and some site differences in 1987 (the June and

July counts. The results from the 1990 season show population sizes characteristic of a dry year but better than the prior 4 years. In 1991 the population size data resembled the 1986 to 1989 dry seasons. Table 4 gives total counts of vegetative amoebae and cysts while Table 4A gives counts of cysts alone, thus the mathematical difference gives the number of vegetative amoebae present in a sample. Figure 1 interprets Tables 4 and 4A in showing total counts and the calculated percent vegetative amoebae by horizon and site at various sampling dates as opposed to Table 2 showing data for 1985, an actively growing year. Figure 3 summarizes maximum average yields for all sites by year and month to illustrate the general trend in maximum population changes. Figure 4 replots this data as the average maximum yields per year to illustrate the annual trends that correlate to rainfall data. Table 4B demonstrates no significant differences between sites for a given horizon and sampling date. As in past years cyst counts exhibited differences between sites which reflect the susceptibility of vegetative and cyst states to local conditions (e.g. moisture, food) (Table 4A & 4B). The ANOVA for June cyst counts (Organic horizon) reflects considerable variability within the data (Table 4B).

I have summarized the NOAA Climatological Data publications for monthly deviations from normal rainfall for 1985 to date (Fig. 6 & 7) to illustrate the drought years. Soil moisture measurements indicate slightly drier soils during this period (Fig. 5), which may account for the effects of the drought on growth, although nutrient input from surface litter may be a more important component of limiting amoeba growth and would correlate

with the rainfall pattern. Note that both monthly rainfall (Fig 6) and soil moisture (Table 5) indicate that August was a dry month. Although in past years August frequently coincided with maximum population sizes, this was not the case in 1991 (e.g. Fig. 1 vs. Fig. 2).

Soil suction is an important moisture variable for soil (e.g. Darbyshire, 1975). For example, clay has finer pores than sand so that at the same water content, the larger pores in sand would be filled with water and capable of supporting growth of large microorganisms, if the water content was sufficient to do this. At the same water content, the finer pores in clay would be too small to contain larger microorganisms. Again, gross moisture content of sand and clay would differ with the same sized pores filled with water. This can be seen in the data (e.g. Table 5), modified by drainage considerations, recent rain history and soil heterogeneity -- i.e. sand has a lower moisture content. Since the capillarity of soil can be measured allowing a calculation of pore sizes filled with water at a given moisture content, it is theoretically possible to specify the water content required in a given soil to support growth of a microorganism of a given size. This was done by Darbyshire (1975) for a large ciliate. In the 1983 annual report I measured water binding in study site soils (i.e. soil suction) to ascertain the range of moisture needed to support growth of soil amoebae. Soil moisture measurements during the growing season were less than the calculated figures; further, the fluctuation in population size over the growing season did not correlate to moisture content (Fig. 1 for all years). Either the soil suction

methods I used were inaccurate or the amoebae were growing on wet surfaces as well as water-filled soil pores. In Figs. 7 and 8, the annual total rainfall correlates with the average maximum total amoeba population per year (Fig. 4); this gives a good correlation between population size and annual rainfall.

#3. Growth and feeding activity. Growth experiments in soil submersible culture vessels were done over prolonged intervals in the 1989 field season. Past years have demonstrated that the technique is suitable, although prolonged incubation did reveal that corrosion between the electrode and the soldered wire attached to it was still a significant problem. The metal ions from corrosion leached into the saline, dramatically altering conductivity. This was eventually solved with better polyurethane sealants and in 1990 IITRI personnel improved the seal further with an autoclavable silicone sealant. In 1990 and 1991 we took glutaraldehyde-fixed samples back to the lab for counting. Amoebae were counted during active growth, which was a good deal cooler than the temperatures normally used for laboratory isolates (e.g. 23 to 30° C). Cultures were left in the soil after growth reached its maximum for another 2 weeks and then subcultured. In some cases the cultures became contaminated with a small flagellate; then subcultures were made from flagellate-free cultures. At the end of the season, isoenzyme analyses were done on these amoebae. No change in isoenzyme pattern was observed between the original clone culture and subcultures grown in soil incubated at the sites (Fig. 6). Note that we used a different clonal isolate for the growth studies in 1991 than in 1990 so that isoenzyme patterns differ between

years. Growth rate data analysis is presented in Table 6 and indicated no difference between sites. In the 1990 and 1991 experiments I to used an excess of bacterial food to support both maximum amoeba growth rate and maximum yield. Thus vegetative amoebae persisted longer in the soil submersible culture vessels than they would with limiting numbers of bacteria. Analyses were done during exponential growth to simplify statistical comparisons and to avoid growth limits caused by a decrease in the bacterial food supply.

#4. Ambient monitoring. Table 5 (and Fig. 5) gives the mean % (w/w) moisture for individual measurements, taken when the soil was sampled. During the growing season (i.e. June, July and August) the soil was drier than in 1984 and 1985, roughly comparable to the drought years.

Soil temperature recordings for the season (Fig.8) were comparable to previous field seasons.

7. Peer reviewers and publications:

I plan to use the following individuals as peer reviewers:

- a. Prof. Thomas J. Byers
Department of Molecular Genetics
Ohio State University
- b. Prof. Frederick L. Schuster
Department of Biology
Brooklyn College

Publications (1991):

1. Hu, Wang-Nan, Band, R.N., Kopachik, W.J. 1991. Virulence-related protein synthesis in Naegleria fowleri. Infect. & Immun. 59, 4278-4282.
2. _____. 1992. Cloning and characterization of transcripts showing virulence-related gene expression in Naegleria fowleri. Infect & Immun. In Press.
3. _____. 1992. A simple, rapid method to create a cDNA library. Biotechniques In Press.
4. Presented at the 1991 meeting of the American Soc. for Cell Biology (J. Cell Biol. 115, abstracts 514 & 515):
 - a. The proteosome, a new organelle found in Naegleria.
 - b. An amoeba gene induced by mammalian cells in infectious Naegleria fowleri.
6. In preparation: Seasonal fluctuations and drought effects on soil amoeba population size and genetic heterogeneity.

8. LITERATURE CITED

Darbyshire, J.F., Wheatley, R.E., Graves, M.P. & Inkson, R.H.E. 1974. A rapid micromethod for estimating bacterial and protozoan populations in soil. *Rev. Ecol. Sol* 11, 465-475.

Hoffman, A.A. & Parsons, P.A. 1991. *Evolutionary Genetics and Environmental Stress*. Oxford Univ. Press.

Jacobson, L. & Band, R.N. 1987. Genetic heterogeneity in a natural population of Acanthamoeba polyphaga from soil, an isoenzyme analysis. *J. Protozool.* 34, 83-86.

Nei, M. 1972. Genetic distance between populations. *Am. Nat.* 106, 283-292.

Singh, B.N. 1946. A method of estimating the numbers of soil protozoa, especially amoebae, based on their differential feeding on bacteria. *Ann. Appl. Biol.* 33, 112-119.

Tsai, Y-L & Olson, B.H. 1991. Rapid method for direct extraction of DNA from soil and sediments. *Appl. & Env. Micro.* 57, 1070-1074.

TABLE 1. SOIL CHEMISTRY:*

ELEM.	DATE***	SITE/HORIZON**					
		CO	AO	GO	CM	AM	GM
P	1	43,43	35,34	27,30	70,73	17,18	18,22
	2	38,36	34,31	30,28	62,64	18,18	20,27
K	1	148,172	152,156	164,208	38,38	34,34	42,42
	2	152,136	216,248	156,188	42,47	42,34	42,42
Ca	1	3073,3073	3158,3158	3032,4400	618,728	840,840	728,728
	2	2990,2653	3663,3663	3537,3663	728,728	880,800	1240,1080
Mg	1	187,233	229,275	252,371	76,63	89,122	127,76
	2	172,204	267,396	236,301	70,54	104,88	88,104
NO ₃	1	4.2,4.5	4.7,5.2	4.3,4.45	.55,.65	.9,.8	.65,.65
	2	2.1,2.2	3,2.7	2.9,2.4	.4,.55	.55,.6	.55,.55
%Org N	1	11.4,8.4	8.2,8.1	7.6,9	1.5,1.5	2.2,2	1.6,1.7
	2	7.4,8.7	9.2,9.6	7.5,8.6	1.6,1.6	2,2	2.1,1.9

*Performed by Michigan State University Soil Testing Laboratory,
data expressed as ppm except for %Org. N.

**SITE: C, control; A, antenna, G, ground.
HORIZON: O, organic, M, mineral.

***Data was obtained June 6 and August 5, 1991,
each of which were taken from 20 random samples.

TABLE 2. SOIL CHEMISTRY 2X ANOVA, between sites and dates.

ELEMENT		ORGANIC			MINERAL	
		D.F.	M.S.	F	M.S.	F
P	Site	2	127.8	56.7**	3024.3	459**
	Date	1	18.8	8.3	6.8	1.03
	Interact.	2	10.8	4.8	39	5.92
	Error	6	2.3		6.6	
K	Site	2	1737.3	4.3	42.8	5.76*
	Date	1	768	1.9	36.8	4.98
	Interact.	2	2884	7.2*	10.8	1.45
	Error	6	402.6		7.4	
Ca	Site	2	520681	3.12	59712	16.2**
	Date	1	6302	.0378	79056	21.5**
	Interact.	2	162715	.976	3625	15.1**
	Error	6	3458233		225529	
Mg	Site	2	11257.8	.02	1545	.44
	Date	1	70.1	3.35	168.8	4.01
	Interact.	2	4291.6	1.28	4	.01
	Error	6	3356.9		385.6	
NO ₃	Site	2	.426	7*	.032	8.38*
	Date	1	12.2	201**	.083	22.2**
	Interact.	2	.056	.92	.009	2.4
	Error	6	.061		.004	
%Org. N	Site	2	.69	.59	.251	33.4**
	Date	1	.24	.21	.041	5.4
	Interact.	2	2.4	2.1	.051	6.8
	Error	6	1.2		.008	

* = 5% significance level

** = 1% significance level

TABLE 3. SOIL pH:

DATE	SITE	HORIZON	MEAN $\pm$ S.D. (n = 10)
4 JUN	Control	Organic	6.57 $\pm$ 0.1567
		Mineral	6.65 $\pm$ 0.2799
	Antenna	Organic	6.82 $\pm$ 0.23
		Mineral	6.99 $\pm$ 0.3035
	Ground	Organic	6.74 $\pm$ 0.3978
		Mineral	6.72 $\pm$ 0.1476
6 AUG	Control	Organic	6.43 $\pm$ 0.283
		Mineral	6.31 $\pm$ 0.4358
	Antenna	Organic	6.59 $\pm$ 0.4332
		Mineral	6.63 $\pm$ 0.3889
	Ground	Organic	6.53 $\pm$ 0.2263
		Mineral	6.45 $\pm$ 0.4503

TWO WAY ANOVA, Site, Horizon:

DATE		DF	MS	F
4JUN	Site	2	0.442	6.1722*
	Horizon	1	0.0882	1.2363
	Interaction	2	0.0452	0.6333
	Error	54	0.0713	
6AUG	Site	2	0.288	2.0026
	Horizon	1	0.0427	0.2967
	Interaction	2	0.0347	0.2411
	Error	54	0.1438	

* = 5% significance level

TABLE 4. Total counts from 8 samples per horizon/site:

SITE	HORIZON	DATE	MEAN #/g soil $\pm$ S.D.* (log#)	MEAN**	C.V.***
Control	Organic	6/10	3.7945 $\pm$ 0.3199	7,738	8.4
		7/15	3.8307 $\pm$ 0.2229	7,437	5.8
		8/12	3.8047 $\pm$ 0.2753	7,673	7.2
		9/24	4.8927 $\pm$ 0.2072	86,201	4.2
		10/20	4.1747 $\pm$ 0.2154	16,575	9.7
	Mineral	6/10	2.9686 $\pm$ 0.1101	958	3.7
		7/15	3.0634 $\pm$ 0.2195	1,303	7.2
		8/12	3.0943 $\pm$ 0.1842	1,344	6
		9/24	4.1524 $\pm$ 0.2265	15,862	5.5
		10/20	3.4738 $\pm$ 0.2247	3,330	6.5
Antenna	Organic	6/10	3.8747 $\pm$ 0.4425	10,436	11.4
		7/15	4.2185 $\pm$ 0.3056	20,055	7.2
		8/12	3.8350 $\pm$ 0.1938	7,552	5.1
		9/24	4.7986 $\pm$ 0.2477	72,341	5.2
		10/20	4.0353 $\pm$ 0.3947	15,067	9.7
	Mineral	6/10	2.9008 $\pm$ 0.1112	820	3.8
		7/15	2.8840 $\pm$ 0.1555	810	5.4
		8/12	3.0934 $\pm$ 0.2194	1,394	7.1
		9/24	4.0654 $\pm$ 0.2422	13,396	6
		10/20	3.2778 $\pm$ 0.1673	2,028	5.1
Ground	Organic	6/10	3.6119 $\pm$ 0.4282	6,687	11.9
		7/15	4.0755 $\pm$ 0.3542	16,985	8.7
		8/12	3.7108 $\pm$ 0.2193	5,784	5.9
		9/24	4.6986 $\pm$ 0.2409	56,946	5.1
		10/20	4.2019 $\pm$ 0.2686	18,682	6.4
	Mineral	6/10	2.8689 $\pm$ 0.2553	881	8.9
		7/15	3.0067 $\pm$ 0.1950	1,116	6.5
		8/12	2.9787 $\pm$ 0.1962	1,052	6.6
		9/24	3.9547 $\pm$ 0.1202	9,348	3
		10/20	3.2605 $\pm$ 0.2526	2,166	7.7

* Mean expressed as $\log_{10}$ number, used to calculate analysis of variance (Table 4B).

** Mean calculated from arithmetic data which will differ from converting the mean of log data to an arithmetic figure. The log of the arithmetic mean will not be the same as the mean of the log transformed data.

*** Coefficient of Variability, %.

TABLE 4A. Cyst counts from 8 samples per horizon/site:

SITE	HORIZON	DATE	MEAN #/g soil $\pm$ S.D.* (log#)	MEAN**	C.V.***
Control	Organic	6/10	3.8144 $\pm$ 0.3694	8,633	9.7
		7/15	3.6851 $\pm$ 0.2767	5,707	7.5
		8/12	3.6919 $\pm$ 0.3267	6,260	8.8
		9/24	4.5114 $\pm$ 0.3441	43,867	7.6
		10/20	4.2275 $\pm$ 0.4152	24,631	9.8
	Mineral	6/10	2.8505 $\pm$ 0.0544	714	1.9
		7/15	2.8181 $\pm$ 0.1530	703	5.4
		8/12	3.0374 $\pm$ 0.1797	1,182	5.9
		9/24	3.8124 $\pm$ 0.3700	9,387	9.7
		10/20	3.4550 $\pm$ 0.3020	3,517	8.7
Antenna	Organic	6/10	3.9679 $\pm$ 0.4629	14,264	11.7
		7/15	3.8121 $\pm$ 0.2707	7,364	7.1
		8/12	4.1762 $\pm$ 0.3041	18,197	7.3
		9/24	4.6781 $\pm$ 0.3346	62,500	7.2
		10/20	3.8797 $\pm$ 0.3962	11,091	10.2
	Mineral	6/10	2.9998 $\pm$ 0.1440	1,049	4.8
		7/15	2.8558 $\pm$ 0.1853	786	6.5
		8/12	3.1458 $\pm$ 0.1296	1,449	4.1
		9/24	4.3704 $\pm$ 0.4780	36,859	10.9
		10/20	3.2638 $\pm$ 0.1715	1,980	5.3
Ground	Organic	6/10	3.8762 $\pm$ 0.4161	12,294	10.7
		7/15	4.1659 $\pm$ 0.3195	17,674	7.7
		8/12	3.8472 $\pm$ 0.2370	7,917	6.2
		9/24	4.7363 $\pm$ 0.2844	63,764	6
		10/20	3.7601 $\pm$ 0.3186	7,162	8.5
	Mineral	6/10	2.9044 $\pm$ 0.1201	830	4.1
		7/15	3.1858 $\pm$ 0.2481	1,772	7.8
		8/12	3.0873 $\pm$ 0.1676	1,300	5.4
		9/24	3.7331 $\pm$ 0.2390	6,094	6.4
		10/20	3.6988 $\pm$ 0.3971	6,845	10.7

* Mean expressed as $\log_{10}$ number, used to calculate analysis of variance (Table 4B).

** Mean calculated from arithmetic data which will differ from converting the mean of log data to an arithmetic figure. The log of the arithmetic mean will not be the same as the mean of the log transformed data.

*** Coefficient of Variability.

TABLE 4B. One-way analysis of variance by date and horizon. Data log transformed (see Table 4 & 4A).

HORIZON	DATE	GROUPS	DF	TOTAL COUNT		F	POWER
				MS			
ORGANIC	6/10	among	2	0.1451		0.9041 NS	0.19
		within	21	0.1605			
	7/15	among	2	0.3077		3.4372 NS	0.59
		within	21	0.0895			
	8/12	among	2	0.0335		0.6232 NS	0.14
		within	21	0.0538			
	9/24	among	2	0.0754		1.3927 NS	0.27
		within	21	0.0541			
	10/20	among	2	0.0639		0.6987 NS	0.16
		within	21	0.0914			
MINERAL	6/10	among	2	0.0208		0.6945 NS	0.15
		within	21	0.0299			
	7/15	among	2	0.0673		1.8284 NS	0.34
		within	21	0.0368			
	8/12	among	2	0.0353		0.8797 NS	0.21
		within	21	0.0402			
	9/24	among	2	0.0785		1.8929 NS	0.36
		within	21	0.0415			
	10/20	among	2	0.1123		2.3675 NS	0.43
		within	21	0.0474			
				CYST COUNT			
				MS			
ORGANIC	6/10	among	2	0.0477		0.2732 NS	0.07
		within	21	0.1746			
	7/15	among	2	0.4963		5.9105 **	(0.83)
		within	21	0.0840			
	8/12	among	2	0.4891		5.7465 **	(0.82)
		within	21	0.0851			
	9/24	among	2	0.1089		1.0499 NS	0.21
		within	21	0.1038			
	10/20	among	2	0.4717		3.2847 NS	0.57
		within	21	0.1436			
MINERAL	6/10	among	2	0.0457		3.5976 *	(0.61)
		within	21	0.0042			
	7/15	among	2	0.3274		8.2320 **	(0.94)
		within	21	0.0256			
	8/12	among	2	0.0236		0.9165 NS	0.19
		within	21	0.0257			
	9/24	among	2	0.9652		6.8536 **	(0.88)
		within	21	0.1408			
	10/20	among	2	0.3802		4.0985 *	(0.35)
		within	21	0.0928			

* = 5% significance level

** = 1% significance level

TABLE 5. SOIL MOISTURE (% W/W)¹

HORIZON DATE	CONTROL SITE		ANTENNA SITE		GROUND SITE	
	ORG	MIN	ORG	MIN	ORG	MIN
JUN 10	31.4 $\pm$ 5.1	17.0 $\pm$ 2.4	31.2 $\pm$ 4.9	13.9 $\pm$ 2.5	27.6 $\pm$ 7.8	14.0 $\pm$ 3.1
JUL 15	26.5 $\pm$ 3.6	15.2 $\pm$ 2.1	32.6 $\pm$ 9.4	14.3 $\pm$ 4	29.4 $\pm$ 7.7	15.3 $\pm$ 2.2
AUG 12	23.5 $\pm$ 6.3	13 $\pm$ 1.6	21.4 $\pm$ 5.9	8 $\pm$ 1.7	20.2 $\pm$ 5.8	9.7 $\pm$ 3.4
SEP 24	41.3 $\pm$ 9.5	14.4 $\pm$ 2.4	45 $\pm$ 8.3	15 $\pm$ 2.8	31.8 $\pm$ 5.3	17.4 $\pm$ 2.5
OCT 20	40 $\pm$ 5.7	14.6 $\pm$ 2.5	40.3 $\pm$ 6.2	12 $\pm$ 1.4	37.2 $\pm$ 5.7	15.2 $\pm$ 2.4

ONE WAY ANOVA (between sites)

Date	ORGANIC		MINERAL	
	D.F.	M.S.	D.F.	M.S.
JUN10 Between	2	36.3	2	25.7
Within	21	37.1	21	7.26
F =		0.97		3.54*
JUL15 Between	2	76	2	2.3
Within	21	53.7	21	8.3
F =		1.42		0.28
AUG12 Between	2	21.4	2	51.1
Within	21	36	21	5.66
F =		0.59		9.01**
SEP24 Between	2	371.8	2	20.3
Within	21	62.1	21	6.7
F =		5.99*		3.01
OCT20 Between	2	22.7	2	23
Within	21	35.3	21	4.51
F =		0.64		5.09*

1 = mean $\pm$ S.D. (n=8)

* = 5% significance level

** = 1% significance level

TABLE 6. Regression calculations for growth of Acanthamoeba polyphaga in soil submersible culture vessels, data log transformed.

Details of electric currents in vessels given in Table 7.

Date	Experiment*	Slope**	Std Error***
6/24 to 6/28/91	E-Field, control	0.01607	0.00062
	" , antenna	0.01542	0.00129
	" , ground	0.01558	0.00277
	Current, control	0.01321	0.00215
	" , antenna	0.01843	0.00086
	" , ground	0.01491	0.00228
7/29 to 8/2/91	E-Field, control	0.01868	0.00141
	" , antenna	0.01569	0.0004
	" , ground	0.02035	0.00264
	Current, control	0.02069	0.00032
	" , antenna	0.01444	0.00561
	" , ground	0.01868	0.00285
8/19 to 8/23/91	E-Field, control	0.01063	0.00031
	" , antenna	0.01118	0.00061
	" , ground	0.01036	0.00031
	Current, control	0.01074	0.00335
	" , antenna	0.01001	0.00115
	" , ground	0.01074	0.00022

* Three replicate experiments were done both E-field and Current density experiments at each site. Duplicate counts were done on each culture.

** Mean generation times were: 16 to 28 hr.

*** For the slope of the curve; Bonferoni T-tests of slopes:

		E. Field	Current Density
6/24/91	Control vs. Antenna	0.45415	2.25426
	Control vs. Ground	0.17362	0.54247
	Antenna vs. Ground	0.05236	1.44452
7/29/	Control vs. Antenna	2.0401	1.11228
	Control vs. Ground	0.67343	0.70086
	Antenna vs. Ground	2.241	1.19839
8/19/91	Control vs. Antenna	0.80379	0.20611
	Control vs. Ground	0.61587	0.00001
	Antenna vs. Ground	1.19839	0.62348

14 d.f. for error; no significant differences were noted.

TABLE 7a. Culture cell current densities and E-field voltages measured during growth experiments (Table 6) for June 26, 1991.

Electrodes ¹	Voc (mv)	Vcl (mv) ⁴	Vr (mv)	Ecl (mv/m) ²	Jcl (ma/m ²) ³
Control, CD:					
1	2.37	*	2.32	*	0.006
2	2.24	*	2.29	*	0.006
3	2.76	*	2.71	*	0.008
Control, EF:					
1	3.69	0.32	*	2.83	*
2	2.87	0.32	*	2.83	*
3	3.68	0.32	*	2.83	*
Antenna, CD:					
1	54	*	36	*	0.09
2	46	*	46	*	0.12
3	53	*	53	*	0.14
Antenna, EF:					
1	64	6.3	*	53.8	*
2	89	6.2	*	54.9	*
3	62	6.2	*	54.9	*
Ground, CD:					
1	22	*	21	*	0.05
2	22	*	21	*	0.05
3	24	*	22	*	0.06
Ground, EF:					
1	27	3.4	*	28.8	*
2	24	2.8	*	24.8	*
3	16	3.7	*	32.7	*

¹CD = current density cultures; EF = E-field cultures.

²E-field: $Ecl (mv/m) = Vcl / 0.113$ (length between electrodes).

³Current density: $Jcl (mA/m^2) = Vr / R * xs. \text{ area of } cl (m^2)$, where $R (ohms) = 2.5 * 10^4$ for J; 100 for E. Area of cl varied depending on submerged electrode area; for this experiment it was $1.57 * 10^{-4} m^2$.

⁴Vcl for EF adjusted to this value, calculated: $E (1m) * 0.113$ (length between electrodes).

*Value too low for meter to accurately record.

TABLE 7b. Culture cell current densities and E-field voltages measured during growth experiments (Table 6) for July 29, 1991.

Electrodes ¹	Voc (mv)	Vcl (mv) ⁴	Vr (mv)	Ecl (mv/m) ²	Jcl (ma/m ²) ³
Control, CD:					
1	1	*	1	*	0.003
2	0.9	*	0.9	*	0.002
3	1.1	*	1	*	0.003
Control, EF:					
1	1.4	0.14	*	1.24	*
2	1.2	0.14	*	1.24	*
3	1.4	0.14	*	1.24	*
Antenna, CD:					
1	51	*	50	*	0.13
2	43	*	43	*	0.11
3	55	*	55	*	0.14
Antenna, EF:					
1	61	6.1	*	54	*
2	92	6.3	*	56	*
3	62	6.3	*	56	*
Ground, CD:					
1	22	*	21	*	0.05
2	22	*	22	*	0.06
3	22	*	22	*	0.06
Ground, EF:					
1	23	3.1	*	27	*
2	26	2.9	*	26	*
3	17	2.6	*	23	*

¹CD = current density cultures; EF = E-field cultures.

²E-field: Ecl (mv/m) = Vcl / 0.113 (length between electrodes).

³Current density: Jcl (ma/m²) = Vr / R * xs. area of cl (m²), where R (ohms) = 2.5 * 10⁴ for J; 100 for E. Area of cl varied depending on submerged electrode area; for this experiment it was 1.57 * 10⁻⁴ m².

⁴Vcl for EF adjusted to this value, calculated: E (1m) * 0.113 (length between electrodes).

*Value too low for meter to accurately record.

TABLE 7c. Culture cell current densities and E-field voltages measured during growth experiments (Table 6) for August 21, 1991.

Electrodes ¹	Voc (mv)	Vcl (mv) ⁴	Vr (mv)	Ecl (mv/m) ²	Jcl (ma/m ²) ³
Control, CD:					
1	1.3	*	1.2	*	0.003
2	1.1	*	1.2	*	0.003
3	1.3	*	1.3	*	0.003
Control, EF:					
1	2	0.16	*	1.42	*
2	1.5	0.16	*	1.42	*
3	1.9	0.16	*	1.42	*
Antenna, CD:					
1	52	*	51	*	0.13
2	45	*	45	*	0.11
3	53	*	54	*	0.14
Antenna, EF:					
1	64	6.5	*	58	*
2	91	6.1	*	54	*
3	60	6.4	*	57	*
Ground, CD:					
1	22	*	21	*	0.05
2	24	*	23	*	0.06
3	24	*	23	*	0.06
Ground, EF:					
1	26	3.3	*	29	*
2	29	3.6	*	32	*
3	17	3.4	*	30	*

¹CD = current density cultures; EF = E-field cultures.

²E-field: Ecl (mv/m) = Vcl / 0.113 (length between electrodes).

³Current density: Jcl (mA/m²) = Vr / R * xs. area of cl (m²), where R (ohms) = 2.5 * 10⁴ for J; 100 for E. Area of cl varied depending on submerged electrode area; for this experiment it was 1.57 * 10⁻⁴ m².

⁴Vcl for EF adjusted to this value, calculated: E (1m) * 0.113 (length between electrodes).

*Value too low for meter to accurately record.

Figure 1. Summary of soil counts for 1991.

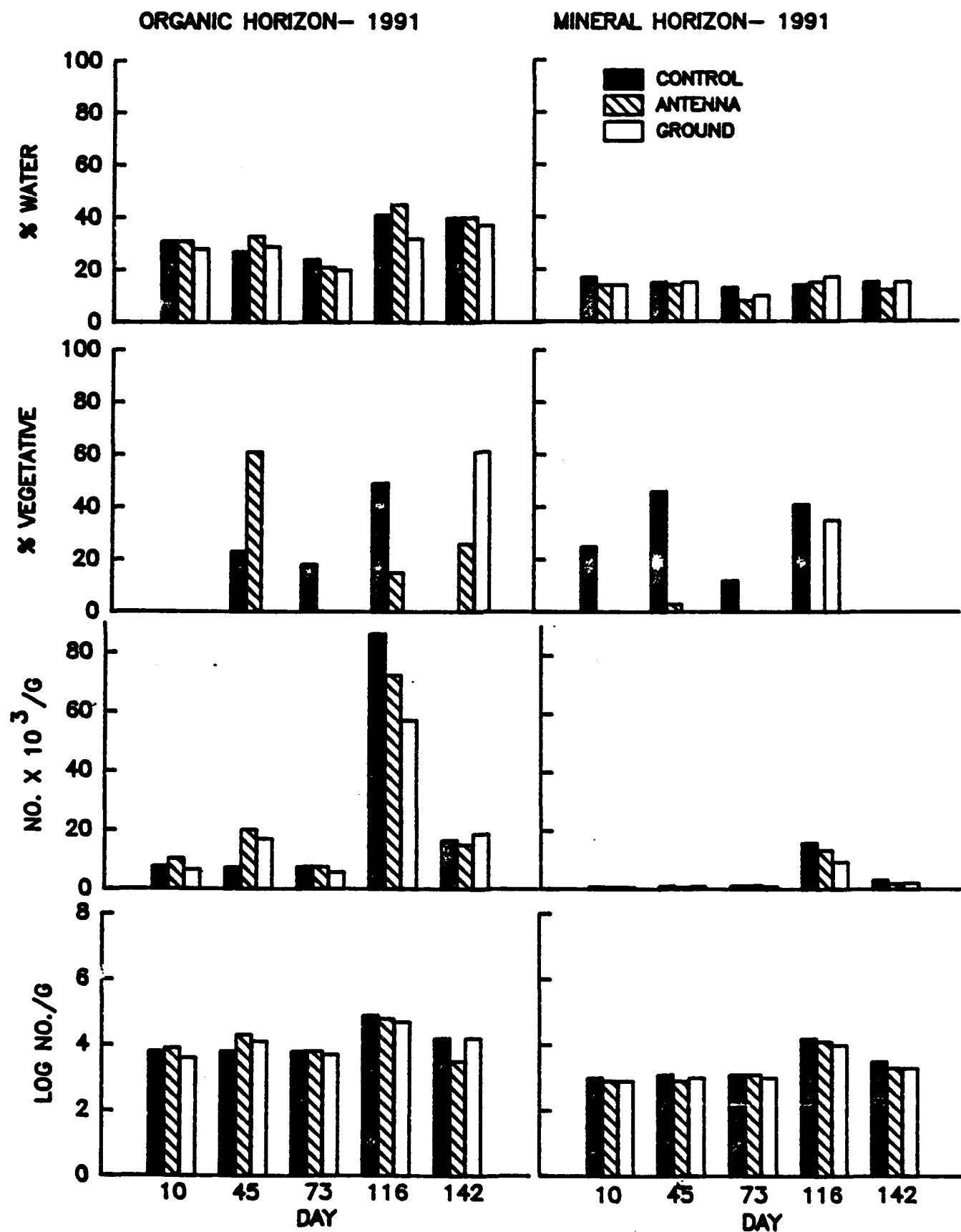


Figure 2. Summary of soil counts for 1984.

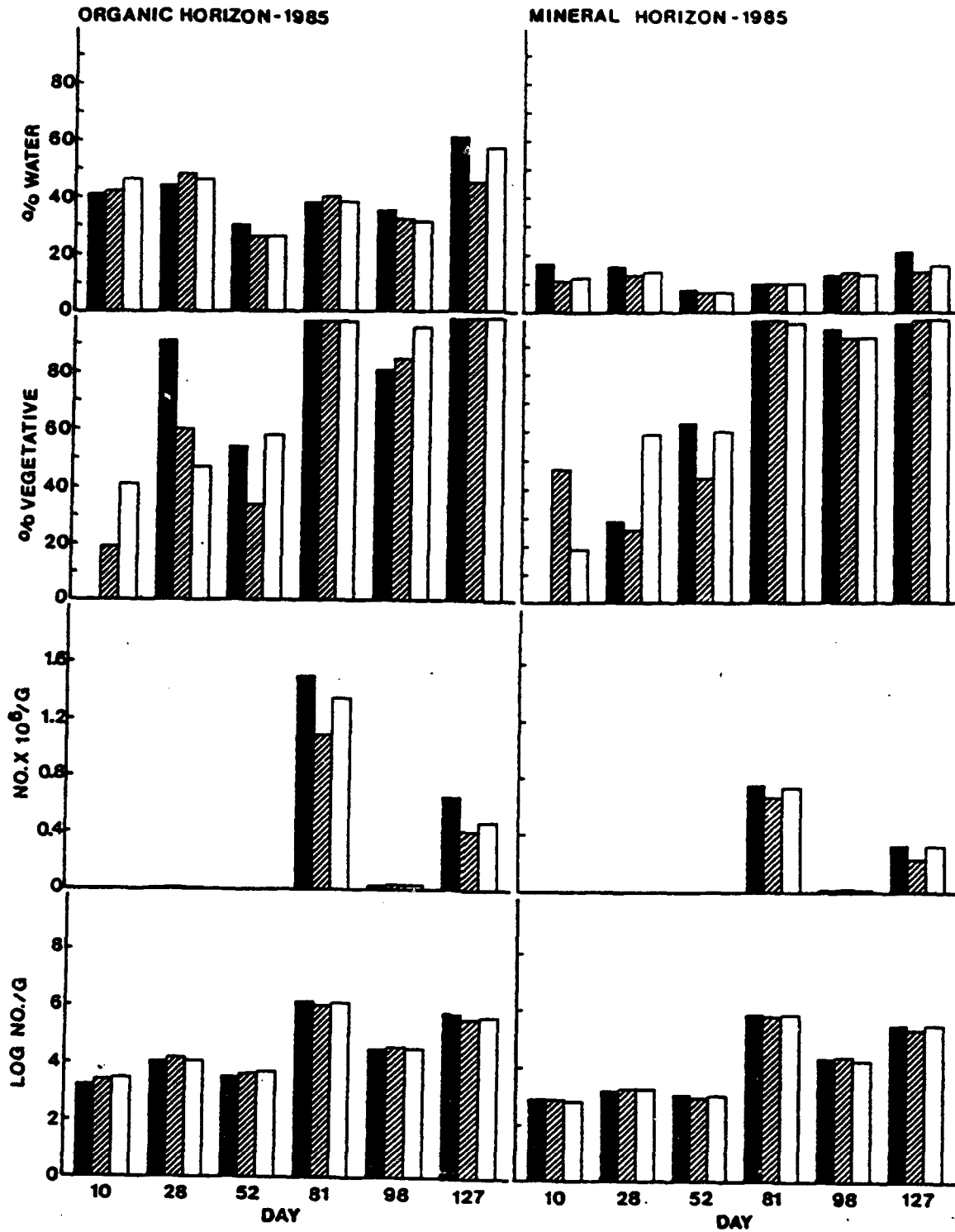


Figure 3. Average yields by month and year for all sites.

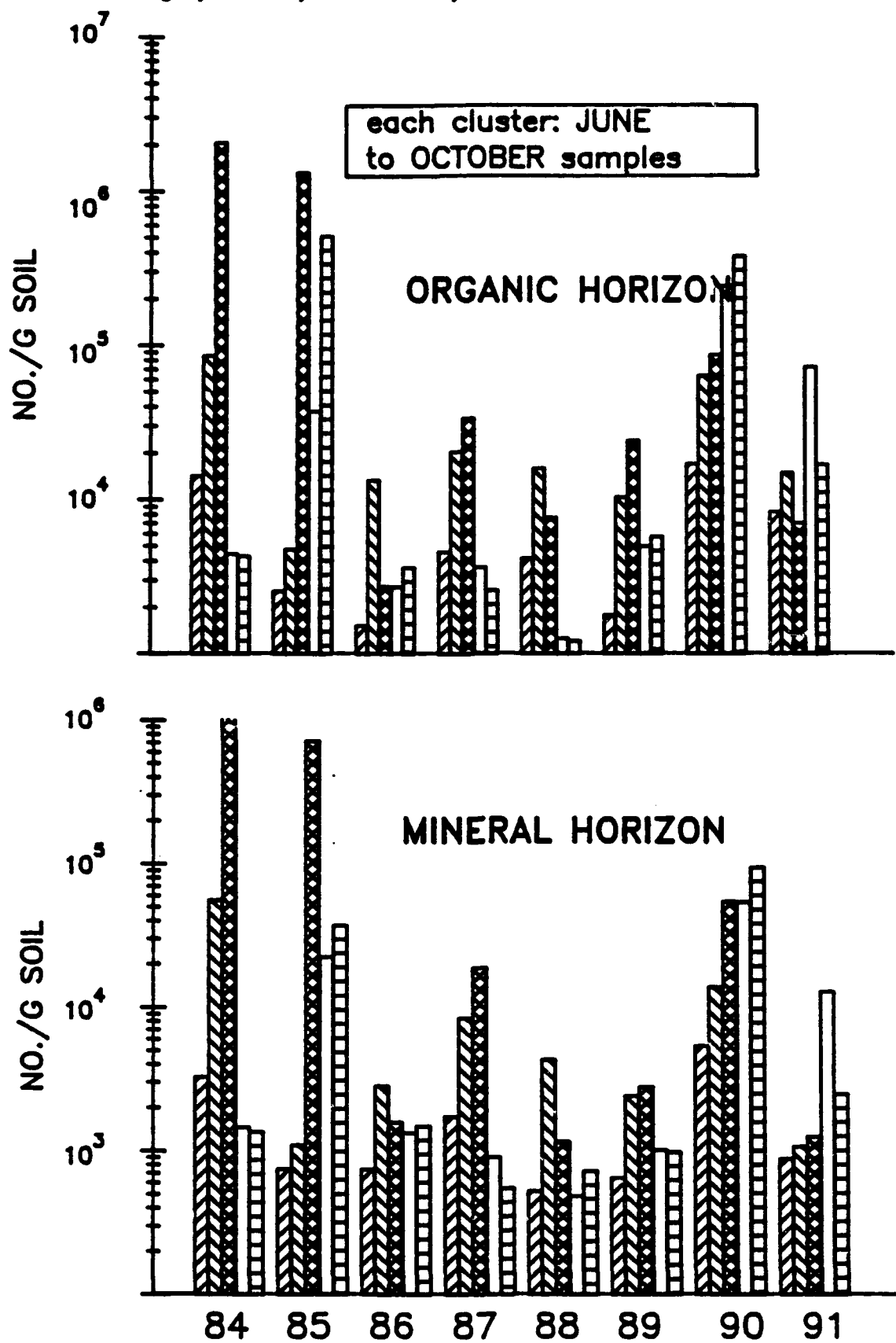


Figure 4. Average maximum total amoebae per year.

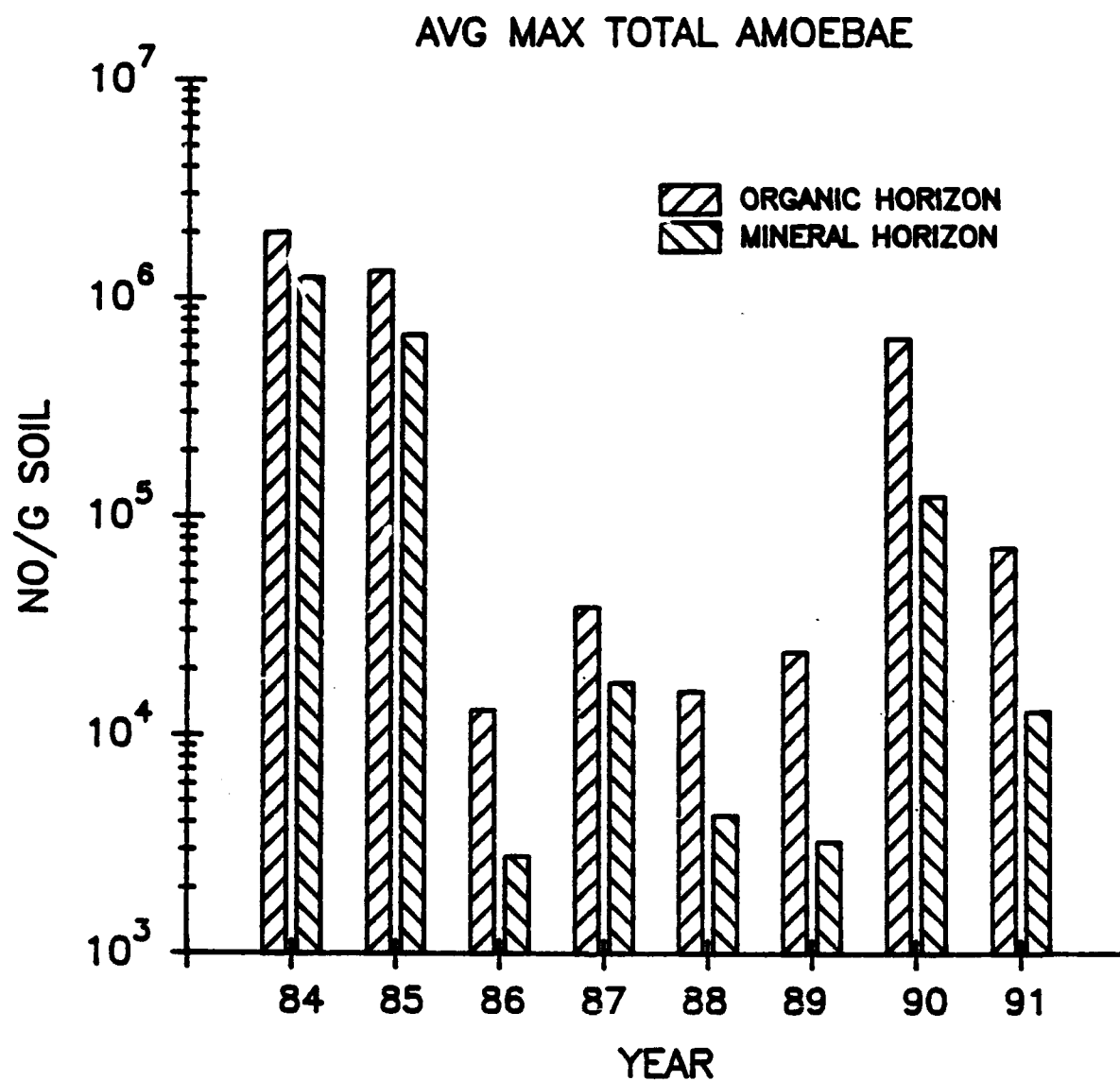


Figure 5. Moisture content of soil samples taken for counting amoebae.

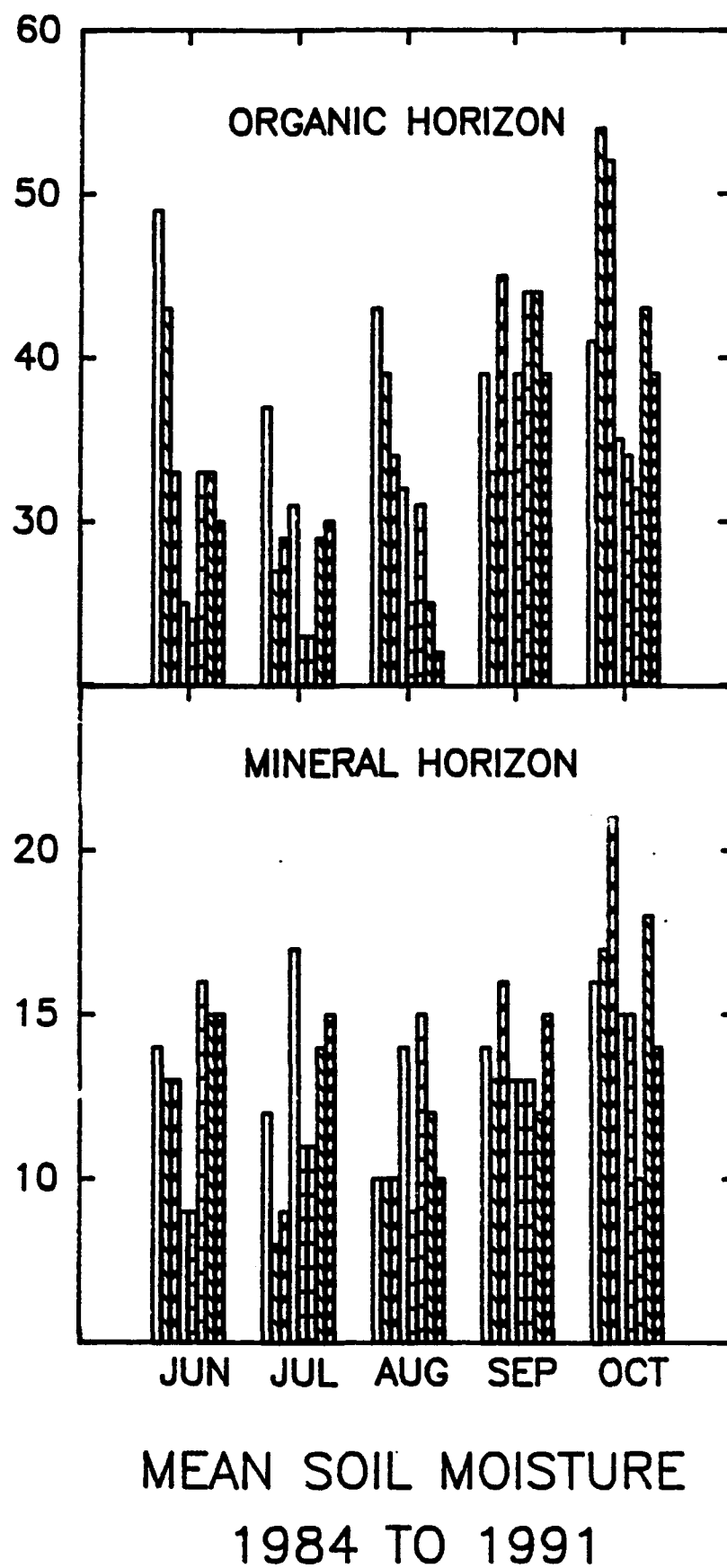


Figure 6. Annual rainfall departure from normal for all years.

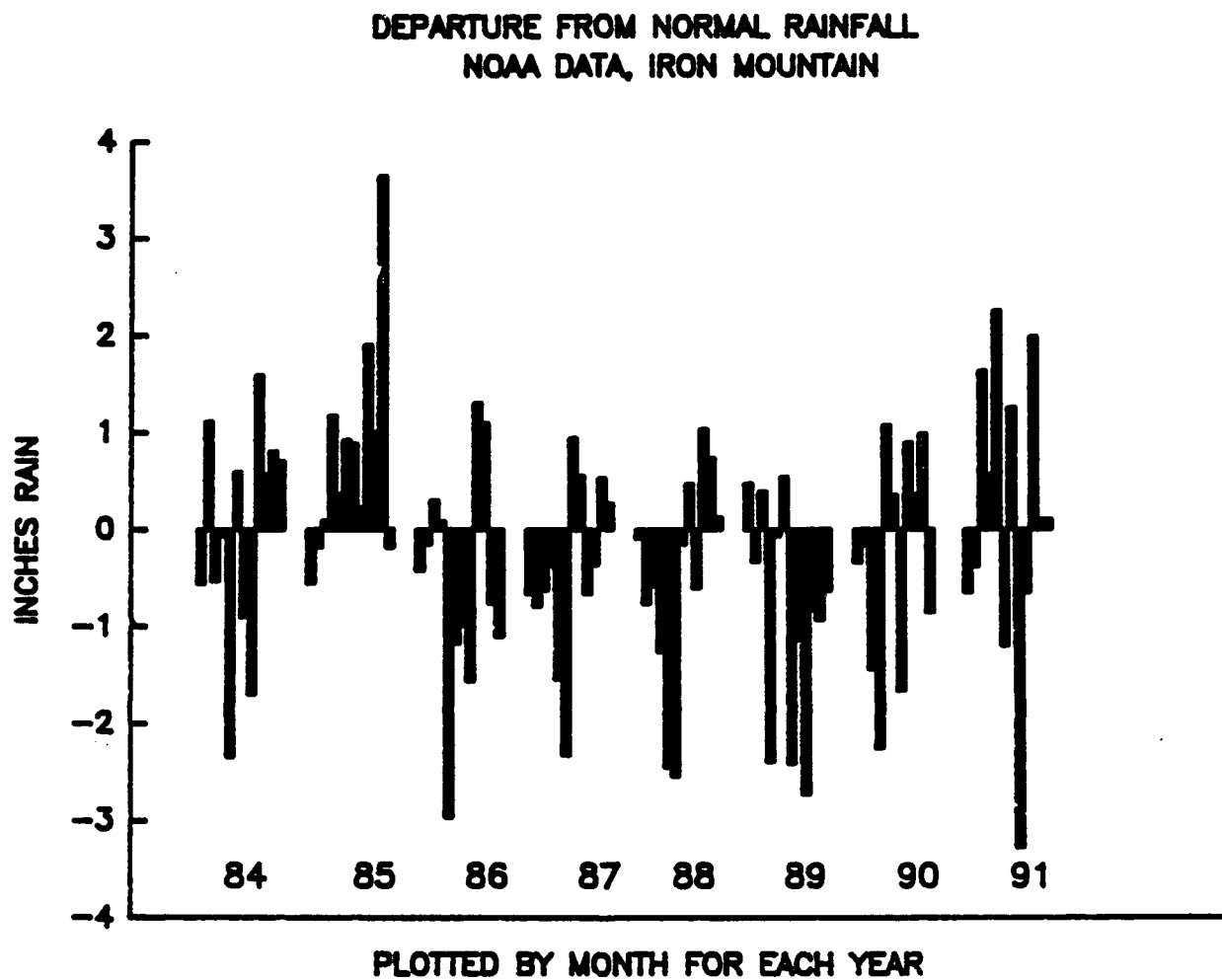
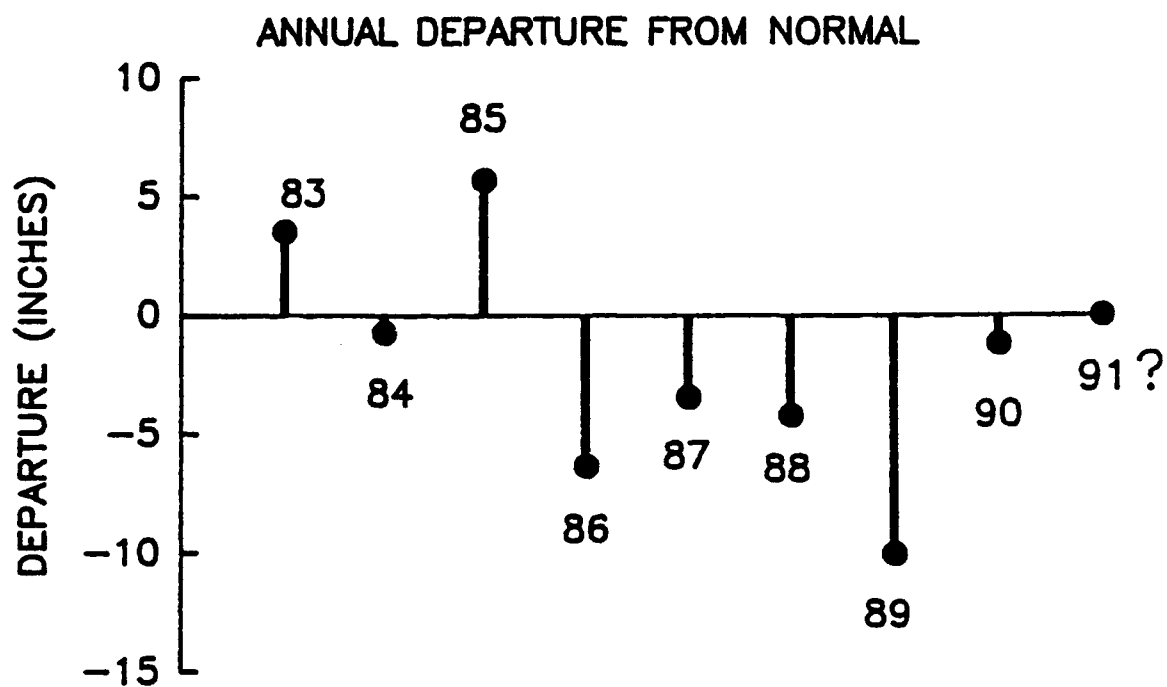
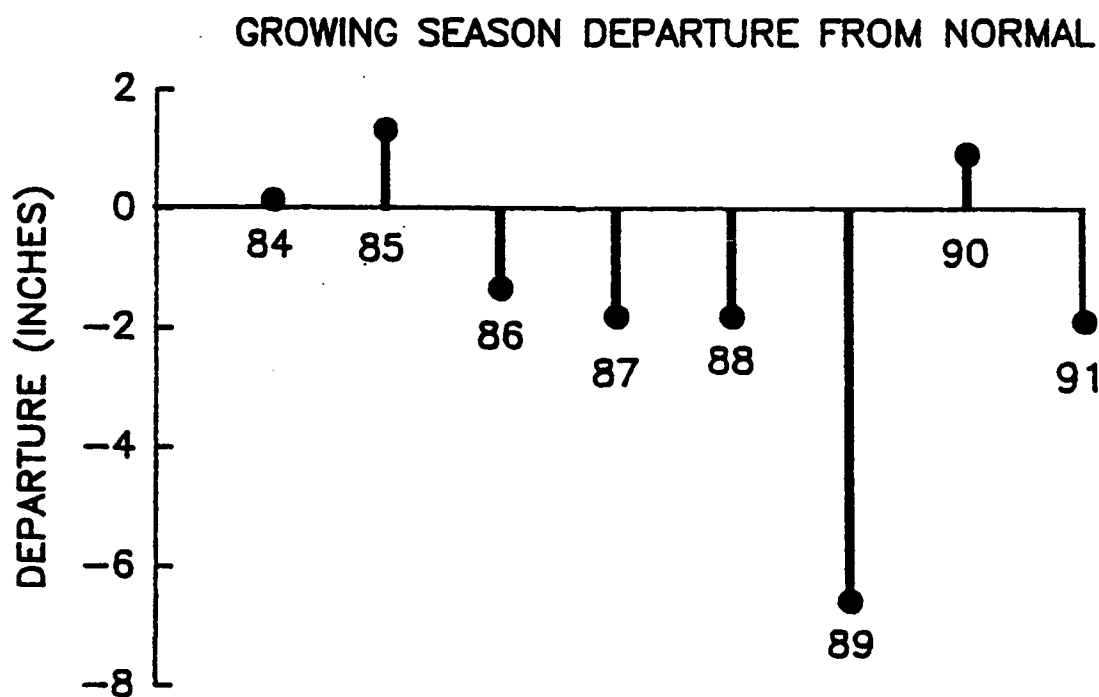


Figure 7. Annual departure from normal rainfall, and growing season.



Data from NOAA CD for Iron Mountain, Michigan



Data from NOAA CD for Iron Mountain, Michigan

Figure 8. Pooled temperature records showing mean daily temperatures with S.D. error bars, plotted every third day (top); annual summary (bottom).

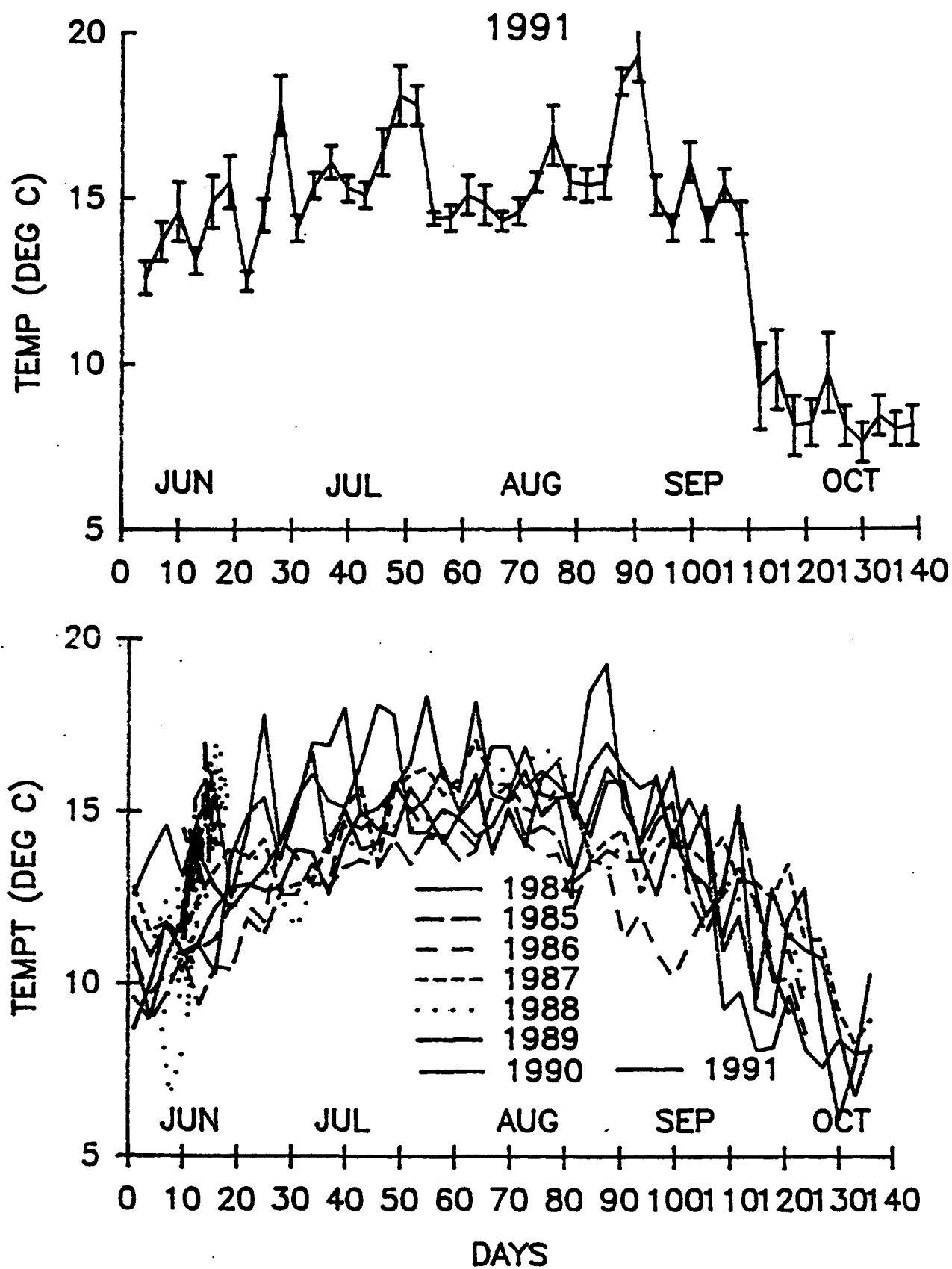
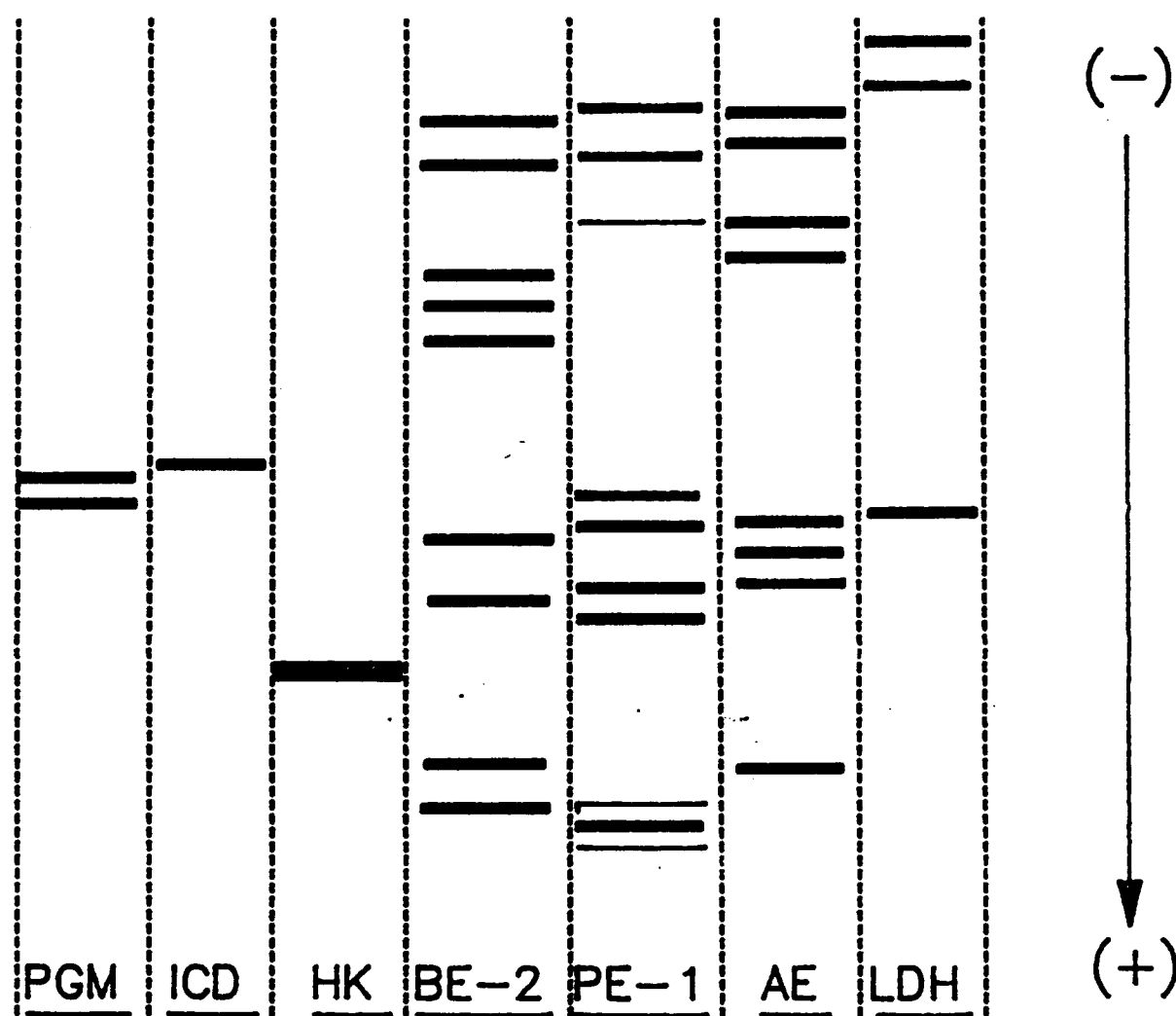


Figure 9. Isozyme patterns for Acanthamoeba polyphaga clone used in soil submerged cultures.



PGM = phosphoglucomutase
 ICD = isocitrate dehydrogenase
 HK = hexokinase
 BE-2 = butyryl esterase-2

AE = acetyl esterase
 LDH = lactate dehydrogenase
 PE-1 = propionyl esterase

Subcontractor: Michigan State University

East Lansing, Michigan 48824

Subcontract No. E06595-88-C-004

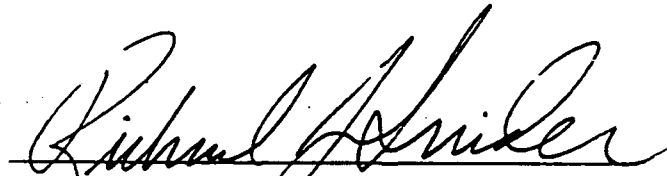
ELF Communications System Ecological Monitoring Program

Arthropoda and Earthworms

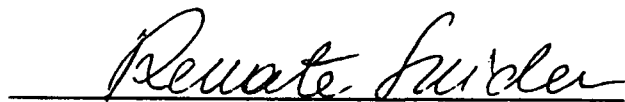
Tasks 5.3. and 5.4.

Annual Report

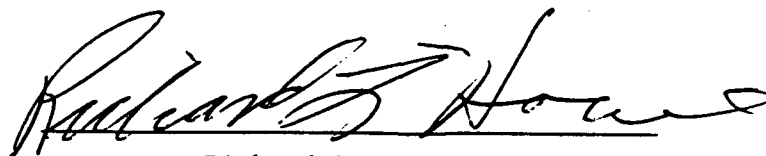
1991



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Arthropoda and Earthworms

Tasks 5.3. and 5.4.

Annual Report

1991

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ABSTRACT

Depending on the status of progress peculiar to each project element, data are now available for two or three operational years. We define the pre-operational period as spanning 1984-1988, except for elements in which the methodology was not finalized until 1985 (surface-active arthropods) or 1986 (soil-dwelling arthropods). Since the ELF antenna became fully operational in May of 1989, 1989 represents the first operational year.

Most soil- and litter-dwelling arthropods we monitor showed no detectable response to ELF operation. Community diversity, abundance of selected species, as well as seasonal frequencies of developmental stages (from larva to adult) seemed unaffected. Where statistical significance between pre-ELF and operational periods occurred, their biological significance was not clear-cut: we suggest that conclusions based on two operational years' data are as yet questionable, and need to be tested further. Given the generally high variability in arthropod numbers encountered in both Test and Control sites, additional data may well negate these preliminary findings.

Among eleven species of surface-active arthropods belonging to Collembola, Acari and carabid beetles, none showed significant deviations in 1989-90. Seasonal activity patterns in Test and Control have continued to "track" each other well. With a single (questionable) exception, diversity and equitability of night- and day-active arthropods also showed no response to ELF activation.

Among earthworms, species living in the leaf litter and the uppermost soil horizon were not noticeably influenced by EM fields. For the dominant soil-dwelling species in the Test site, however, we detected probable effects of EM fields: reproductive performance of adults seemed curtailed

during operational years. These conclusions were based on continued sampling of the natural population as well as on an experimental procedure in which earthworms were isolated in mesh-containers, incubated in Test and Control, and periodically retrieved and examined.

Inputs of leaf litter from the forest canopy, and seasonal fluctuations of litter mass on the forest floor, remained consistent with respect to pre-operational years. Monitoring of litter breakdown rates, using leaves confined in mesh bags, showed that differences between Test and Control data during pre-ELF years remained consistent in 1990-91. At the system-level, no effects of ELF operation were thus detectable.

SUMMARY

Sampling and extraction protocols of previous years were adhered to in 1991, from May 6 to October 21. Earthworms, litter and soil moisture, and litter and soil arthropods were sampled at intervals of 2 weeks; arthropod surface-activity was monitored weekly by pit-trapping; temperature, rainfall, litter input and decomposition data were obtained at intervals appropriate to each work element. An experimental procedure was developed for isolating earthworms in retrievable mesh bags embedded in the field. The method proved viable for monitoring development and reproduction of earthworms under near-natural conditions.

With the exception of data on population structure of Isotoma notabilis (available through 1989), all arthropod data were completed through 1990. Information on earthworms, litter inputs and decomposition is available through 1991.

Data bases were divided into a pre-ELF (all years through 1988) and an operational period (1989 onward). BACI (Before and After Control and Impact) analysis of differences between sites was the main procedure used to test results to date. Serial correlation over time, a characteristic of many of this project's data, was eliminated by appropriate transformations or manipulations. Where data could not be normalized, non-parametric Kruskal-Wallis Anova was performed. For variables unique to the Test site (some earthworm parameters), regression models were developed based on various independent variables, and the fit of operational years' to pre-ELF data formed the basis for conclusions.

In keeping with earlier reports, the following summary is divided into three main categories:

1. Seasonal and yearly fluctuations in population abundance:

Most arthropod species showed no detectable differences in abundance fluctuations during the 1989-90 period. Where results were significant, they must at this time be considered questionable. Given the wide variability characteristic of arthropod data, continued monitoring may well negate these preliminary conclusions. For litter-dwelling species, typically recovered in low numbers from forest floor samples, and for species showing numerical increases in the Test site, interpretation of results must be particularly cautious.

Earthworm population data yielded no particular surprises. The tendency of rare endogeics (A. trapezoides in Test and A. tuberculata in Control) to gradually increase over the years was again observed in 1991. This trend may indicate that, as these forest systems mature, their earthworm communities may slowly become more similar in composition and structure. Numbers of D. octaedra in Test, already low in 1989-90, decreased even further in 1991; at this point, the paucity of data obtainable on this species makes their usefulness to project goals questionable.

In general, while population densities are important parameters to monitor, they themselves are the end result of phenological events peculiar to each species. It is these events which are the main object of inquiry and analysis.

2. Population parameters other than abundance per se:

a. Community composition and structure: Diversity and equitability indices are commonly used descriptive community parameters. Analysis of site differences showed no evidence of ELF effects, be it on soil-litter Collembola or surface-active Collembola and Carabidae. In both cases, one

or two additional years' worth of data are expected to support our general conclusion that large-scale effects on community structure are unlikely to occur. In the case of earthworms, only between-year analyses of the Test community are meaningful: significant differences did occur, but were attributable to climate-related (e.g., the 1988 drought) fluctuations in numbers of the constituent species.

b. Population structure: among three species of arthropods in which we identify developmental stages, only one, Isotoma notabilis, showed possible ELF effects in terms of seasonal stage frequencies (higher proportion of hatchlings in Control). These results, however, are based on a single operational year and are considered tentative.

Seasonal structure of earthworm populations can generally not be subjected to rigorous analysis, even where an unusually abundant cohort of recruits can be traced through successive weight classes. Documentation of this parameter is essential, however, since it is the direct consequence of reproductive events, usually during the preceding year. Growth of many lumbricids is slow. Large-bodied species may require 2-3 years to mature, so that several years may be required to assess the effect of reproductive rate on population development, structure and persistence.

c. Behavioral traits: trap catches of arthropods are used to quantify the degree of "tracking" of seasonal activity patterns in Test and Control. While correlation coefficients are useful descriptors for single-year data, BACI analysis of site differences allows us to contrast pre-ELF and operational periods. Results for 4 collembolans, 2 mites and 5 carabid species all were non-significant. Activity patterns, which can be strongly seasonal in all species and depend partly on environmental variables and partly on life cycle events, thus appear unaffected by ELF operation.

Vertical migration of earthworms in response to moisture and temperature is a survival mechanism. The preferred stratum of a species is also, generally, that in which it feeds (e.g., leaf litter for D. octaedra, A horizon for endogeic Aporrectodea spp.). Pre-ELF regression models applied to operational data showed that no significant perturbation of vertical movement patterns was caused by ELF operation, for all species of interest (D. octaedra, L. rubellus and A. tuberculata).

d. Reproductive parameters: we have yet to complete data on carabid fecundity. Partial data for operational years suggest, however, that ELF effects are not likely to occur.

Regarding earthworms, the three most important parameters are cocoon density, clitellate abundance, and the proportion of adults in the clitellate state. Using appropriate independent variables, neither data for L. rubellus (the species is virtually impervious to environmental fluctuations) nor for D. octaedra yielded indications of adverse ELF effects.

For A. tuberculata, we were able to support earlier contentions that EM fields may curtail reproductive activity. Multiple regression explained up to 83% of variation in clitellate densities during pre-ELF years, but only 14% in operational years (1989-91): in particular, the previously significant relationship between soil moisture and clitellate density no longer existed. Results for cocoon densities were more ambiguous, the explanatory power of multiple regression dropping from 84% to 47%.

Given that significant pre-ELF relationships existed between A. tuberculata and its sister species A. turgida in Control, we subjected seasonal differences between them to BACI analysis. For both cocoon densities and proportion clitellate, results indicated a significant influence of EM fields on reproductive success of A. tuberculata.

Finally, we implemented a new method in 1991 which allows monitoring groups of earthworms confined to retrievable, field-incubated mesh bags. The mesh fabric reduced electric field intensities to 46% of those in surrounding soil. Preliminary results indicate that A. tuberculata incubated in Control exhibited significantly higher reproductive rates than those incubated in Test. We conclude that continued monitoring of lumbricid field populations, as well as refinement and repetition of field-incubation experiments, are advisable.

3. System-level parameters:

Neither litter inputs nor seasonal standing crop estimates have so far (through 1991) proven to be discrepant from pre-ELF values. We propose that the current 1992 season should allow us to finalize conclusions in this respect.

Anova of litter decomposition rates through 1991 (large-mesh litterbags) showed neither significant ELF effects nor site x ELF (site x year) interactions. However, we propose to continue this project element, because it is the only statistically tight system-level parameter available and feasible. Furthermore, we can now show that variations in breakdown rates are closely linked to biomass variations in lumbricid decomposers. Litterbag studies thus furnish the link between lumbricid phenology and one of the major functional attributes of our forested sites.

INTRODUCTION

In this 1991 annual report, we restrict the amount of information given to the major objectives of project ELF and pertinent analyses. Detailed data are shown only where they are necessary for understanding of results, statistical procedures, or interpretation. The time span available for data summaries and analyses is short, due to the relatively long field phase of the project, and we needed to allocate a greater proportion of it to preparation of long-overdue manuscripts.

Emphasis is here placed on statistical detection of potential ELF EM field effects. To this end, data were divided into a pre-operational and an operational group, the size of each being dependent on methodology (e.g., barrier-trapping was not begun until 1985) and current status of data completion (e.g., earthworm data include 1991, arthropod data are available only through 1990).

We define the pre-operational period as encompassing the years 1984-88. The ELF antenna became fully operational on May 14, 1989, at 76 Hz and 150 Amps. During the preceding three years, it had been tested at various combinations of frequencies and current. Testing was most extensive in 1988, during which a total of 500 hours were accumulated. However, if expressed in 24 hour periods, no more than 2.5 days were accumulated in any given month, and usually much less.

I. STATISTICAL APPROACH AND INTERPRETATION

Most of the data we obtain may suffer from lack of true replication precluding, according to Hurlbert (1984), use of parametric ANOVA or other inferential statistics. We have therefore extensively used the BACI method (Stewart-Oaten et al 1986), for those variables which are derived from replicate samples over time in Test and Control sites. If necessary, data were transformed to remove serial correlation and achieve normality. Where data could not be normalized, a non-parametric rank test (Kruskal-Wallis, Mann-Whitney U test) was employed.

Weekly captures of surface-active arthropods presented a peculiar problem. In the past, we often used correlation to quantify the degree of "tracking" of seasonal activity patterns in Test and Control. Strictly speaking, while coefficients of determination (R^2) are descriptively useful, specification of alpha levels (Type I error) is statistically incorrect due to serial correlation over time. Since seasonal fluctuations in activity are the main parameter of interest, we calculated ratios of numbers trapped $[(N \text{ on date}_i)/(N \text{ on date}_{i-1})]$ and used the BACI method to tests differences between Test and Control data.

For variables unique to the Test site (phenology of some earthworm species) regression models were developed based on the first three pre-ELF years (1984-86). They were applied to 1987-88 and to the operational period of 1989-91; significance levels and explanatory power formed the main basis for conclusions.

Decomposition of leaf litter with respect to initial mass at time zero yields data which are also serially correlated. This correlation was

alleviated by a simple manipulation: rather than relating remaining mass at time x to mass at time 0, individual sample data were subtracted from the mean observed at time (x-1), the preceding sampling date. Parametric ANOVA was then performed, interactions between sites and ELF (years) being of greatest value for interpretation of results.

Interpretation of results was graded into three categories:

- No detectable effect: either absolute values, or the magnitude of between-site differences did not change detectably following ELF activation;
- Possible ELF effect: indicates very tentative conclusions requiring additional data and/or analyses; or, indicates the occurrence of changes which may be traceable to factors other than ELF;
- Probable ELF effect: evidence for influence of ELF EM fields appears relatively strong, particularly where effects are detectable in more than one variable or by means of more than one statistical procedure or study technique (this last category is so far restricted to Aporrectodea tuberculata).

II. SUMMARY OF RESULTS TO DATE

Results to date are summarized in Table 1. We have included coefficients of variation (based on pre-operational data) and detection limits (in percent of pre-operational means) as measures of the variability of each parameter under consideration. Detection limits seemed preferable to calculating the power of a given statistical procedure: they do not require specification of the degree of difference which is considered biologically significant, i.e., a value judgment for which there is often no sound basis in knowledge. We do not list detection limits for data analyzed by the Kruskal-Wallis test; although they can be calculated, they are based on a complicated statistic (Conover 1980) with no practical interpretation in biological terms.

Table 1. Summary of results to date, Tasks 5.3. and 5.4. (Arthropoda and Earthworms).

VARIABLE	TEST PROCEDURE	FINDINGS THROUGH (YEAR)	CV ^{a)}	DETECT LIMIT ^{b)}	AVAIL. PRE-OPER.	PROPOSED OPERATIONAL
SOIL/LITTER ARTHROPODA						
Seasonal abundance (soil):						
Collembola:						
<u>I. minor</u>	BACI	No detectable effect (90)	531.6	301.2	86-88	89-92
<u>I. notabilis</u>	BACI	Possible ELF effect (90)	268.1	127.3	86-88	89-92
<u>T. granulata</u>	BACI	No detectable effect (90)	105.8	53.0	86-88	89-92
<u>T. mala</u>	BACI	No detectable effect (90)	42.1	21.0	86-88	89-92
Acari:						
Mesostigmatid sp. A	K-W ^{c)}	No detectable effect (90)	305.6	-	86-88	89-92
Seasonal abundance (litter):						
Collembola:						
<u>I. notabilis</u>	K-W	No detectable effect (90)	106.8	-	84-88	89-92
<u>O. hexfasciata</u>	K-W	Possible ELF effect (90)	173.5	-	84-88	89-92
<u>S. henshawi</u>	K-W	Possible ELF effect (90)	138.4	-	84-88	89-92
<u>T. flavescens</u>	K-W	No detectable effect (90)	113.5	-	84-88	89-92
Acari:						
<u>A. aphididoides</u>	K-W	No detectable effect (90)	325.3	-	84-88	89-92
<u>Nanorchestes sp. A</u>	K-W	Possible ELF effect (90)	882.8	-	84-88	89-92

a) Coefficient of variation = (SD / mean) x 100, based on pre-operational years

b) Detection limit = $\pm (SD_{\text{pooled}} \times t_{0.05, n_1 + n_2 - 2}) / ((\text{pre-ELF mean}) \times 100)$; $SD_{\text{pooled}} = \sqrt{S_1^2/n_1 + S_2^2/n_2}$, where 1 = pre-ELF, 2 = operational.

c) K-W = Kruskal-Wallis non-parametric test

Table 1. cont'd:

VARIABLE	TEST PROCEDURE	FINDINGS THROUGH (YEAR)	CV	DETECT. LIMIT	AVAIL. PRE-OPER.	PROPOSED OPERATIONAL
SOIL/LITTER ARTHROPODA						
Population structure:						
<u>I. notabilis</u> : Instar I	BACI	Possible ELF effect (89)	1001.8	803.7	84-88	89-92
Adults	BACI	No detectable effect (89)	3522.6	2200.4	84-88	89-92
Mesostigmatid sp. A	K-W	No detectable effect for any of 4 stages (90)	196.1 ^{a)} 2225.6 ^{a)}	- -	86-88	89-92
<u>A. aphidioides</u>	K-W	No detectable effect for any of 4 stages (90)	364.4 ^{a)} 678.9 ^{a)}	- -	84-88	89-92
Collembola:						
Community diversity	BACI	No detectable effect (90)	53.6	301.6	86-88	89-92
Community equitability	BACI	Possible ELF effect (90)	57.8	29.4	86-88	89-92
SURFACE-ACTIVE ARTHROPODA						
Community diversity:						
Collembola nocturnal	BACI	No detectable effect (90)	777.6	203.2	85-88	89-91
Collembola diurnal	BACI	No detectable effect (90)	320.7	117.2	85-88	89-91
Carabidae nocturnal	BACI	No detectable effect (90)	166.0	56.5	85-88	89-91
Carabidae diurnal	BACI	No detectable effect (90)	394.3	172.1	85-88	89-91
Community equitability:						
Collembola nocturnal	BACI	No detectable effect (90)	214.0	69.8	85-88	89-91
Collembola diurnal	BACI	No detectable effect (90)	665.5	215.8	85-88	89-91
Carabidae nocturnal	BACI	No detectable effect (90)	339.7	105.8	85-88	89-91
Carabidae diurnal	BACI	Possible ELF effect (90)	231.1	90.2	85-88	89-91

a) Minimum and maximum CV observed among 4 developmental stages

Table 1. cont'd:

VARIABLE	TEST PROCEDURE	FINDINGS THROUGH (YEAR)	CV	DETECT. LIMIT	AVAIL. PRE-OPER.	PROPOSED OPERATIONAL
SURFACE-ACTIVE ARTHROPODA						
Seasonal activity patterns:						
Collembola:						
<u>S. henshawi</u>	BACI	No detectable effect (90)	1164.7	414.3	85-88	89-91
<u>S. lepus</u>	BACI	No detectable effect (90)	3621.8	1228.2	"	"
<u>O. hexfasciata</u>	BACI	No detectable effect (90)	13797.2	4720.3	"	"
<u>T. flavescens</u>	BACI	No detectable effect (90)	687.7	309.2	"	"
Acarid:						
<u>T. auroraense</u>	BACI	No detectable effect (90)	577.1	210.8	"	"
<u>Nanorchestes sp. A</u>	BACI	No detectable effect (90)	574.2	181.5	"	"
Carabidae:						
<u>P. melanarius</u>	BACI	No detectable effect (90)	2848.6	1774.1	"	"
<u>P. pensylvanicus</u>	BACI	No detectable effect (90)	1953.3	992.5	"	"
<u>P. coracinus</u>	BACI	No detectable effect (90)	829.3	275.7	"	"
<u>S. impunctatus</u>	BACI	No detectable effect (90)	1535.6	3764.5	"	"
<u>H. fuliginosus</u>	BACI	No detectable effect (90)	769.9	366.5	"	"

Table 1. cont'd:

VARIABLE	TEST PROCEDURE	FINDINGS THROUGH (YEAR)	CV	DETECT. LIMIT	AVAIL. PRE-OP.	PROPOSED OPERAT.
EARTHWORMS						
Community diversity (TEST)	t-tests	No detectable effect (91)	10.0 $\pm$ 1.7 ^{b)}	-	84-88	89-93
<u>A. tuberculata</u> vs. <u>turgida</u>						
Proportion clitellate	BACI	Probable ELF effect (91)	113.0	39.5	84-88	89-93
Cocoon abundance	BACI	Probable ELF effect (91)	114.0	39.8	84-88	89-93
<u>A. tuberculata</u> (TEST)						
Vertical distribution	MR ^{a)}	No detectable effect (91)	-	-	84-88	89-93
Clitellate density	MR	Probable ELF effect (91)	-	-	84-88	89-93
Cocoon density	MR	Possible ELF effect (91)	-	-	84-88	89-93
<u>A. tuberculata</u> isolation exp.						
Clitellate numbers	t-tests	Probable ELF effect (91)	25.3, 20.6 ^{c)}	47.6	-	91-93
Cocoon production	t-tests	Probable ELF effect (91)	108.6, 63.5 ^{c)}	116.7	-	91-93
<u>L. rubellus</u> (TEST)						
Vertical distribution	MR	No detectable effect (91)	-	-	84-88	89-93
Reproduction	MR	No detectable effect (91)	-	-	84-88	89-93
<u>D. octaedra</u>						
Vertical distribution	MR	No detectable effect (91)	-	-	84-88	89-93
Clitellate density	MR	No detectable effect (91)	-	-	84-88	89-93
Cocoon density	MR	No detectable effect (91)	-	-	84-88	89-93

a) MR = multiple regression; see text for details

b) Mean CV $\pm$ SN for 5 pre-operational years

c) CV for Test and Control data respectively

Table 1. cont'd:

VARIABLE	TEST PROCEDURE	FINDINGS THROUGH (YEAR)	CV	DETECT. LIMIT	AVAIL. PRE-OP.	PROPOSED OPERAT.
LITTER INPUTS AND DECOMPOSITION						
Seasonal litter inputs:						
Maple	BACI	No detectable effect (91)	1060.5	432.2	84-88	89-92
Basswood	BACI	No detectable effect (91)	1263.4	516.9	84-88	89-92
Total	BACI	No detectable effect (91)	3553.9	155.1	84-88	89-92
Seasonal litter standing crops:						
Oven-dry mass	BACI	No detectable effect (91)	92.2	36.1	85-88	89-92
Ash-free dry mass	BACI	No detectable effect (91)	58.7	42.7	87-88	89-92
Decomposition:						
Mass loss over time (AFDW)	ANOVA	No detectable effect (91)	180.1	54.6 ^{a)} 41.0 ^{b)} 108.7 ^{c)}	86,89	90-93

a) Detection limits for ELF effects

b) Detection limits for site effects

c) Detection limits for ELF x site interactions

III. ENVIRONMENTAL MONITORING

1. Precipitation

Total rainfall during the 1991 field season came closer to long-term means than in most of the preceding years, but was somewhat unevenly distributed: a brief deficit in August was preceded by well-above-average precipitation in July (Table 2). Weekly totals recorded in both sites are illustrated in Fig. 1.

Table 2. Monthly precipitation totals in Test and Control, 1991, and 30-year means for the area at large (Crystal Falls Weather Station).

	May	June	July	Aug	Sept	Oct	Total
Control	52.0	77.8	161.7	33.6	89.8	78.8	493.7
Test	38.9	53.6	168.4	33.9	85.7	94.3	474.8
30-yr mean	81.0	105.4	91.4	98.5	84.6	52.8	513.7

2. Soil and litter moisture

Moisture estimates for Test and Control forest floor strata tracked each other very well in 1991 (Fig. 2). A horizon moisture, higher in Control much as in previous years, briefly declined to below 20% in August, concomitant with low rainfall (Table 2).

While litter moisture will continue to be obtained gravimetrically, we intend to use permanently installed TDR (Time Domain Reflectometry) sensors for monitoring soil moisture, beginning in 1992. More frequent records can thereby be obtained, and procedural error will be reduced.

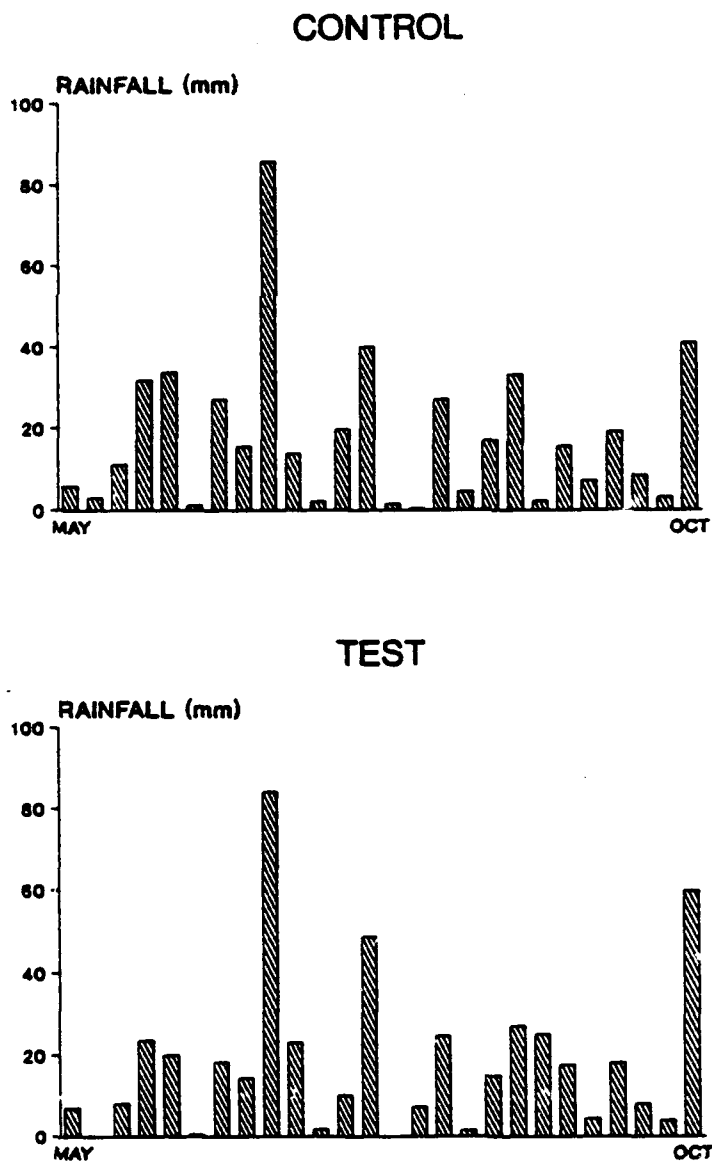


Fig. 1. Weekly precipitation totals in Test and Control, 1991.

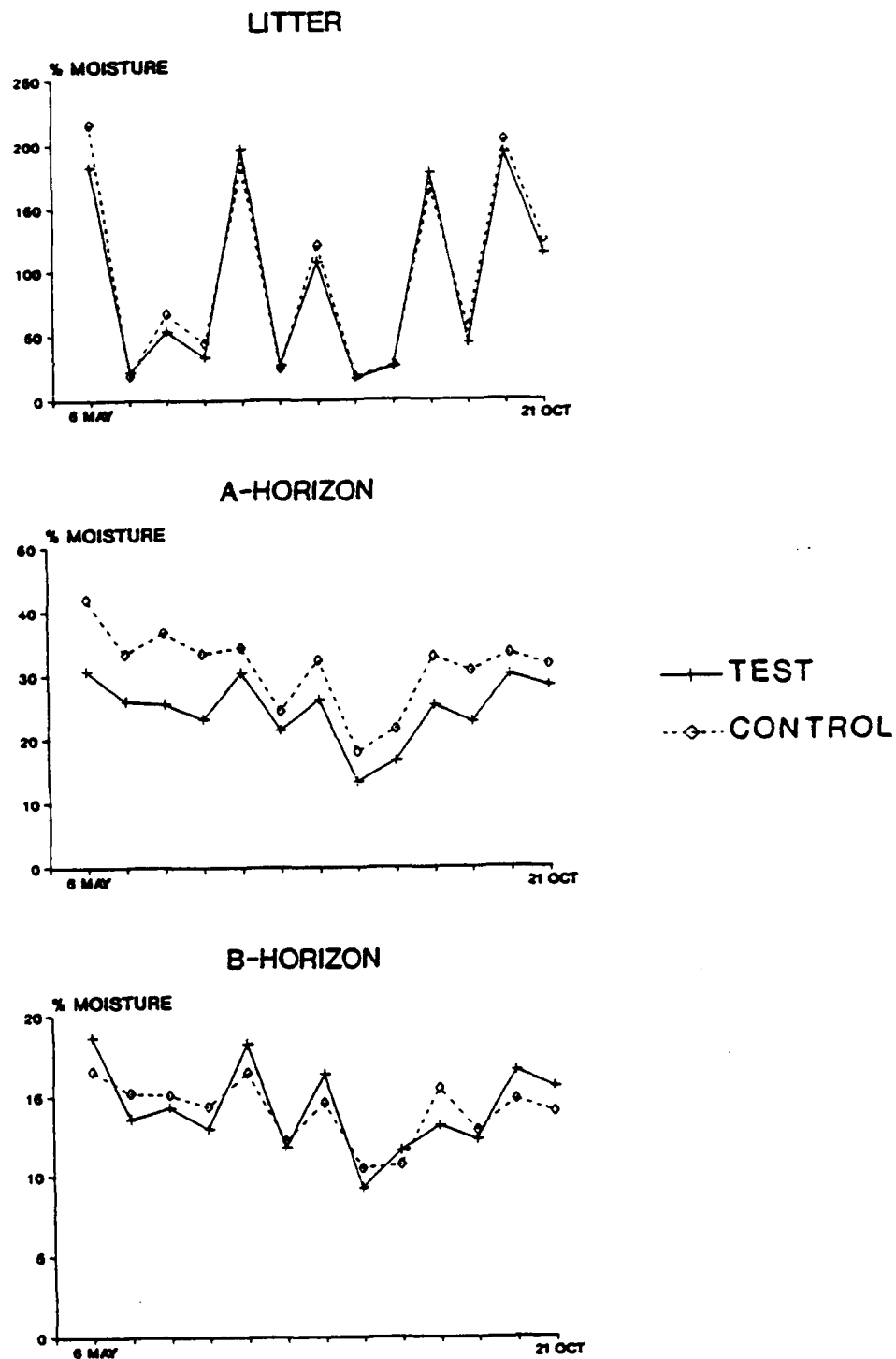


Fig. 2. Litter and soil moisture estimates (in % of dry weight) obtained at intervals of 2 weeks in Test and Control, 1991.

3. Temperature

Temperature patterns, exemplified by mean weekly air temperatures in Fig. 3, presented no unusual features in 1991. Seasonal fluctuations in Test and Control site records again coincided almost exactly.

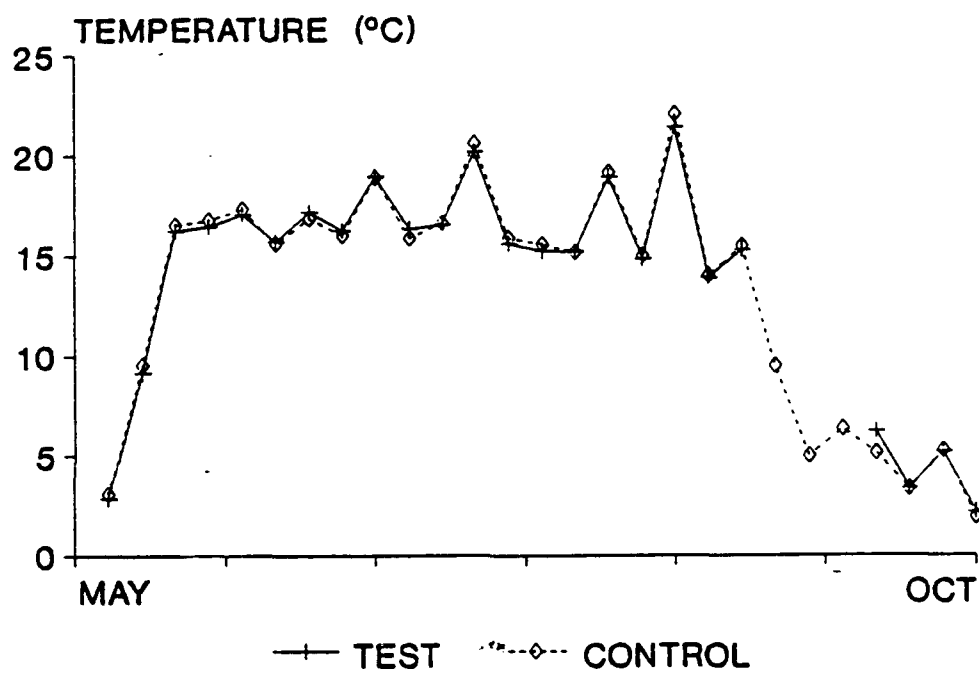


Fig. 3. Average weekly air temperatures in Test and Control sites, 1991.

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IV. SOIL AND LITTER ARTHROPODA

1. Collembola

For the most abundant taxa (selected species and family totals), annual mean abundances are listed in Table 3, providing an overview of long-term trends in both sites. There appeared to be no striking surprises in 1990. Although most species are recovered from both litter and soil (Table 3 lists summed densities from both strata), analyses were only performed for the stratum in which a given species occurs with reasonable frequency in both sites.

BACI or Kruskal-Wallis tests of seasonal density fluctuations yielded significant results for three species: soil-dwelling Isotoma notabilis, and litter-dwelling Orchesella hexfasciata and Sminthurinus henshawi (Tables 4-5). However, if we examine mean annual abundances in these species (Fig. 4), numerical relations between sites are seen to have changed beginning either in 1988, the last pre-ELF season, or in the first operational season. Thus a consistent reversal of Test/Control differences was observed for O. hexfasciata in 1988 through 1990, when densities in Control were higher than in Test. Incidentally, this trend was clearly mirrored in pit-trap catches of O. hexfasciata (section V.1.). For S. henshawi as well, equal or near-equal abundance was observed in 1989-90, as opposed to predominating Control numbers in 1984-88 (Fig. 4). Statistical results (Table 4) simply reflect these changed relationships which are, at this point, not clearly attributable to ELF antenna operation.

For the first time in 1988, and again in 1990, numbers of I. notabilis in Test exceeded those in Control (Fig. 4), resulting in significant

(Control-Test) differences (Table 5). An additional bit of information is slightly puzzling: R^2 for date-specific densities in Test and Control were not very high in pre-ELF years (range 0.30 - 0.67); in 1989 and 1990, however, the relationship between sites was lost entirely ($R^2 = 0.02$ and 0.001 respectively).

With respect to population structure of I. notabilis (seasonal frequencies of developmental stages, numbers in litter and soil summed), instar I exhibited significant discrepancies between sites: proportions of hatchlings in the population were higher in Control (Table 6). These results are, however, based on only one operational year.

Average diversity of collembolan communities, based on indices calculated for each date, was not detectably affected by ELF activation ($P = 0.26$). Equitability in Test decreased slightly in operational years (BACI $P = 0.04$), but Lloyd-Ghelardi indices may be a somewhat insensitive measure of community structure.

In summary, further data will be needed to clarify current results. In view of the wide variations typical of all arthropods, additional operational years' data may well negate results obtained to date. Most importantly, interpretation of any changes in arthropod numbers as an effect of EM fields must keep in mind that slow maturation of these forested sites is bound to be accompanied by changes in their fauna.

Table 3. Mean annual abundance (litter + soil) of selected species and family totals of Collembola in Test and Control; estimates for 1984 and 1985 not corrected for extraction efficiency.

	1984		1985		1986		1987		1988		1989		1990	
	T	C	T	C	T	C	T	C	T	C	T	C	T	C
<u>S. henshawi</u>	153	186	259	301	224	357	198	321	356	325	180	201	305	240
<u>S. lepus</u>	8	1	18	8	13	9	54	27	40	23	18	18	21	5
<u>A. benitus</u>	68	23	146	146	34	58	40	0.2	16	1	22	16	16	5
SMINTHURIDAE	268	247	473	495	299	490	418	471	453	400	311	319	423	324
<u>I. notabilis</u>	1141	1628	1684	2940	1782	2690	2220	3739	1076	1542	1661	2210	2383	2138
<u>I. minor</u>	242	375	158	143	408	292	304	541	137	200	393	224	350	323
<u>F. bisetosa</u>	-	4	162	259	171	193	94	280	34	114	66	222	46	433
<u>F. nivalis</u>	9	223	90	194	97	178	232	179	80	127	12	427	146	429
ISOTOMIDAE	1537	2727	2263	3936	2586	3571	3099	4996	1400	2175	2219	3271	3031	3473
<u>T. flavescens</u>	219	34	440	51	495	59	876	24	277	142	175	12	246	37
<u>O. hexfasciata</u>	107	50	195	39	234	28	528	73	170	95	42	70	124	101
<u>E. comparata</u>	19	80	37	82	84	34	128	58	72	222	46	255	39	265
ENTOMOBRYIDAE	822	218	1065	189	1416	173	2563	213	1035	514	708	424	945	503
<u>W. intermedia</u>	-	-	58	86	236	270	428	616	221	287	266	266	247	609
<u>W. similis</u>	-	-	77	0.4	162	69	281	227	183	237	308	246	327	693
<u>N. muscorum</u>	14	24	31	107	48	26	71	165	69	16	21	27	50	94
HYPOGASTRURIDAE	32	254	213	387	529	726	874	1642	539	728	695	851	816	1792
NEELIDAE	257	225	157	177	19	293	81	281	13	116	57	148	94	154
<u>T. mala</u>	1080	5850	1708	4382	2343	17870	4554	24347	4055	17138	5177	17935	1896	13746
<u>T. granulata</u>	1332	1421	1286	1459	3551	5658	5563	11254	4547	7721	4476	6166	3400	7027
<u>T. iowensis</u>	-	-	359	193	1554	589	2449	4188	2356	2767	1879	6693	2123	7096
<u>T. clavata</u>	104	196	246	204	746	673	723	1989	321	742	681	535	535	519
ONYCHIURIDAE	2854	7884	3819	6442	8538	25603	13756	43425	11893	28860	12995	31739	8505	28992
TOTAL COLLEMB.	5770	11555	7990	11626	13387	30856	20791	51028	15333	32793	16985	36752	13814	35238
TOTAL N SPECIES	36	41	46	37	46	55	46	47	45	44	46	48	49	53

Table 4. Results of Kruskal-Wallis test of seasonal abundances of two collembolan species in Test and Control leaf litter.

Species	Periods	N	Rank sum	P
<u>S. henshawi</u>	84-88	63	3119.5	
	89-90	26	885.5	0.01
<u>O. hexfasciata</u>	84-88	63	2428.5	
	89-90	26	1576.5	0.0002

Table 5. Results of BACI test of seasonal abundances of soil-dwelling Isotoma notabilis (Control - Test).

Periods	DF	Mean diff.	SD	t	P
86-88	38	0.8579	2.3004		
89-90	26	-0.3462	2.0344	2.1533	0.035

Table 6. Results of BACI tests of (Control -Test) differences in seasonal proportions of instars I and adults of Isotoma notabilis.

Stage	Period	N	Mean diff.	SD	t	P
Instar I	84-88	63	0.0114	0.1142		
	89	13	0.0938	0.1577	-2.2124	0.03
Adults	84-88	63	0.0465	0.1638		
	89	13	-0.0282	0.1698	1.4876	0.14

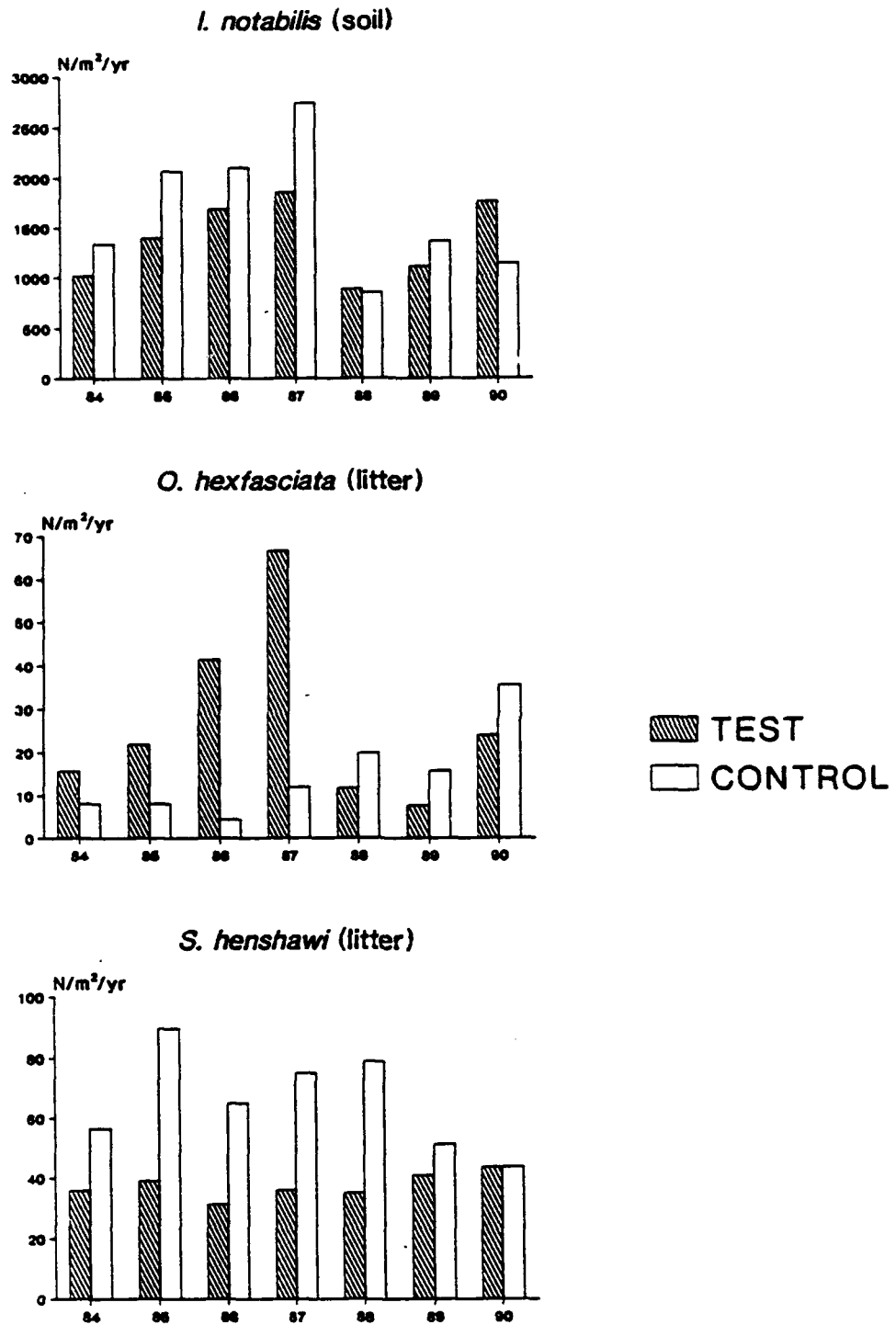


Fig. 4. Mean annual abundance of three collembolans, 1984-1990.

2. Acari

The single significant result of statistical tests pertained to seasonal abundances of litter-dwelling Nanorchestes sp. A (Table 1), among three species analyzed. In analogy to some species of Collembola, 1989 and 1990 were years in which Test populations were higher than Control populations (in 3 of 5 pre-ELF years, the reverse was observed) (Fig. 5). Once again, pending further data, we cannot attribute these changes to EM field effects.

In general, visual examination of mean annual abundances of selected Acari does not reveal any clear changes in long-term trends (Figs. 5-6). In none of the four developmental stages of Asca aphidioides and Mesostigmata sp. A could influences of ELF fields be detected (Table 1).

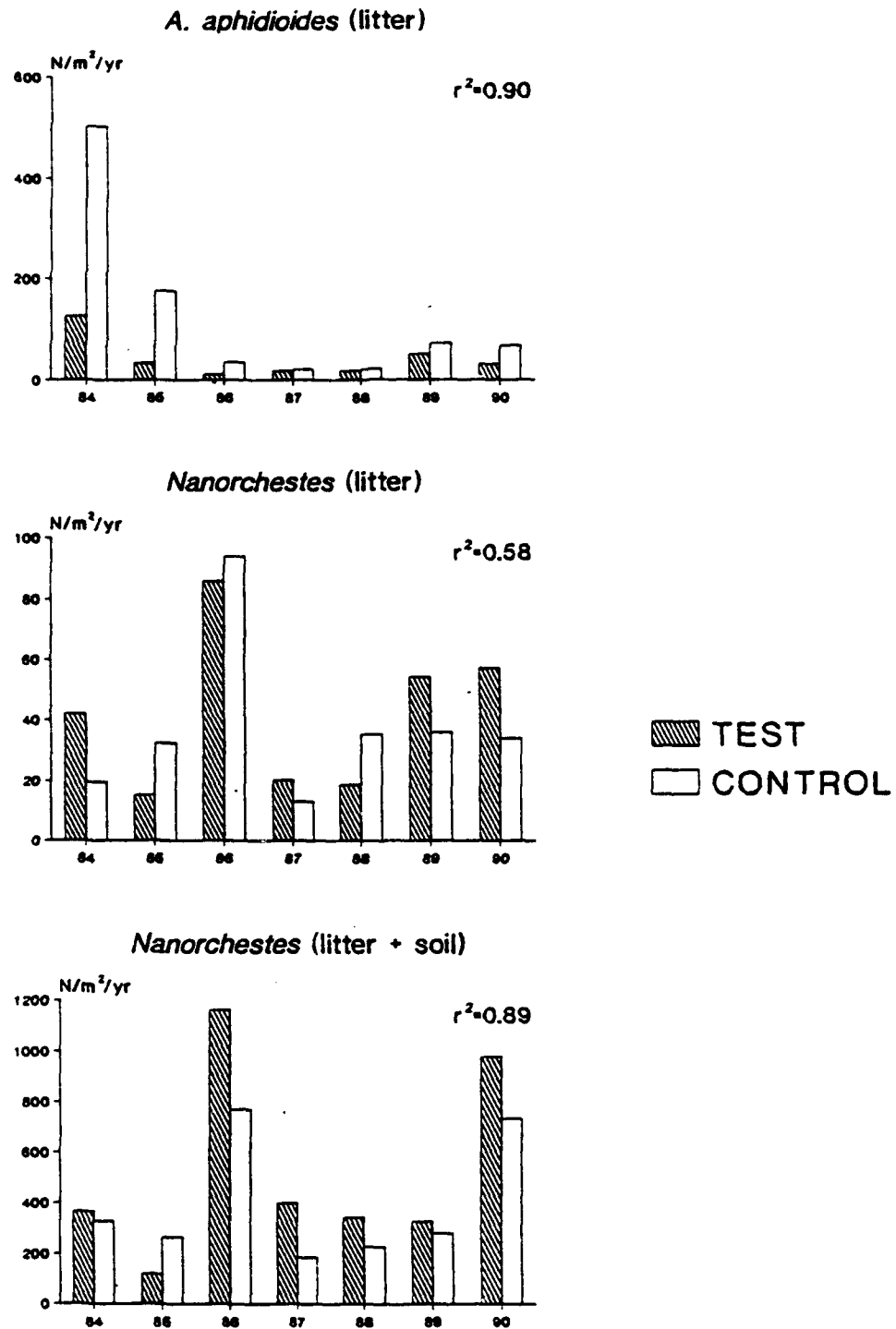


Fig. 5. Mean annual abundance of two mite species in Test and Control, 1984-1990.

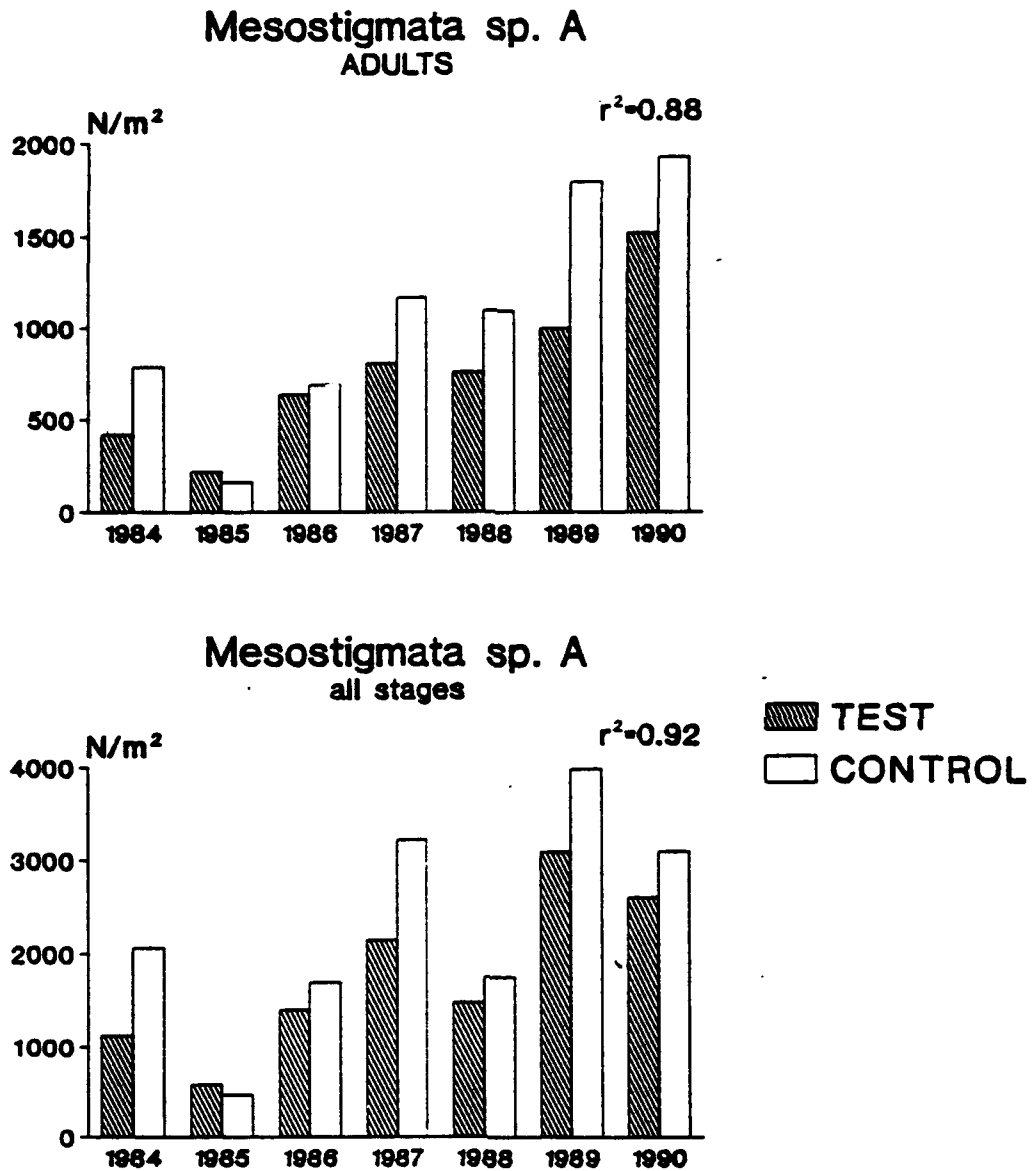


Fig. 6. Mean annual abundance of mesostigmatid sp. A (adults alone and total population) in Test and Control, 1984-1990 (1984 and 1985 not corrected for extraction efficiencies).

V. SURFACE-ACTIVE ARTHROPODA

Preface

None of the 11 species of arthropods trapped frequently enough for analysis have shown detectable responses to ELF activation (Table 1). The main parameter of interest in these data is the degree of "tracking" of activity patterns in Test and Control. Although quite variable in both sites (ref. high CV's and detection limits in Table 1), data through 1990 indicate that that these patterns are still roughly coincident in both sites; i.e., that species-specific activity in response to environmental conditions and/or developmental and reproductive stimuli has been unaffected by EM fields.

In the following, we simply tabulate or illustrate examples of these data, in order to provide a general exposé of progress and conclusions to date.

1. Collembola

After dividing collembolan data into day- and night-active components (there is of course considerable overlap in species composition), diversity and equitability indices were calculated for each date and subjected to BACI analysis. Neither of these community descriptors showed significant changes following ELF antenna activation (Table 1).

Total numbers captured (Table 7) were in no way unusual in 1990, given the variations encountered in previous years. Unlike abundance estimates, pit-trap catches continued to show an interesting trend: i.e., increasing numbers of Sminthuridae and decreasing numbers of Entomobryidae in Test, while in Control, Entomobryidae began outnumbering Sminthuridae in 1988.

Table 7. Total annual pit-trap catches of selected taxa of Collembola in Test and Control, 1985-1990.

	T E S T					C O N T R O L						
	1985	1986	1987	1988	1989	1990	1985	1986	1987	1988	1989	1990
<u>S. henshawi</u>	1637	1435	1992	2811	3065	3196	2606	2934	4123	5084	3675	2666
<u>S. lepus</u>	669	236	1049	503	1438	1375	397	375	1019	824	724	505
SMINTHURIDAE	2423	1709	3124	3398	4841	4870	3593	4379	7607	6770	5368	3627
<u>T. flavescens</u>	4213	1965	2429	1684	641	1033	842	242	280	165	237	170
<u>O. hexfasciata</u>	3201	3402	4137	3426	738	1767	1099	421	1180	3549	1672	2976
<u>E. comparata</u>	35	80	119	150	57	90	287	87	157	1493	440	731
<u>E. nivalis</u>	531	1057	294	291	218	326	4	14	34	77	104	243
ENTOMOBRYIDAE	8433	7238	8209	7186	2275	3843	3479	1752	4495	8100	6308	8578
HYPOGASTRURIDAE	80	90	191	196	420	269	2122	292	456	463	798	964
ISOTOMIDAE	582	513	486	292	484	318	751	392	562	188	485	295
TOTAL ALL SPP.	11518	9550	12010	11072	8020	9301	9946	6815	13120	15522	12959	13467
TOTAL N SPECIES	36	29	32	33	36	35	30	28	32	33	33	36

Most of the collembolans we trap are poorly represented in soil or litter samples. Whether these approximately mirror-image trends (of Sminthuridae vs. Entomobryidae) are indicative of long-term system development and associated faunal changes may not be answerable without decades' worth of data.

2. Acari

The specimen collection of Leptus and Abrolophus is still being reviewed in order to correct past identifications, and efforts to correctly relate immature stages to their respective adults are continuing. As an example of velvet mites' seasonal activity in operational years, Fig. 7 shows 1989 and 1990 data for the spring-active Trombidium auroraense.

3. Carabidae

With a single exception, differences between Test and Control community indices have not been significant through 1990 (Table 1). Equitability of the diurnal species assemblage increased in Control in 1989-90 (BACI, $P = 0.007$). We submit, however, that we may be artificially altering community structure by the activity of trapping per se. Since 1988, total numbers caught in Control have been consistently low, and a few species seem to have been gradually "depleted" (e.g., P. pennsylvanicus, Calathus spp., and particularly P. adstrictus) (Table 8).

These data, as well as the general conclusion re unaffected activity patterns (Table 1), suggest that trapping should be discontinued. Data for 1991 will thus bring this project element to its conclusion.

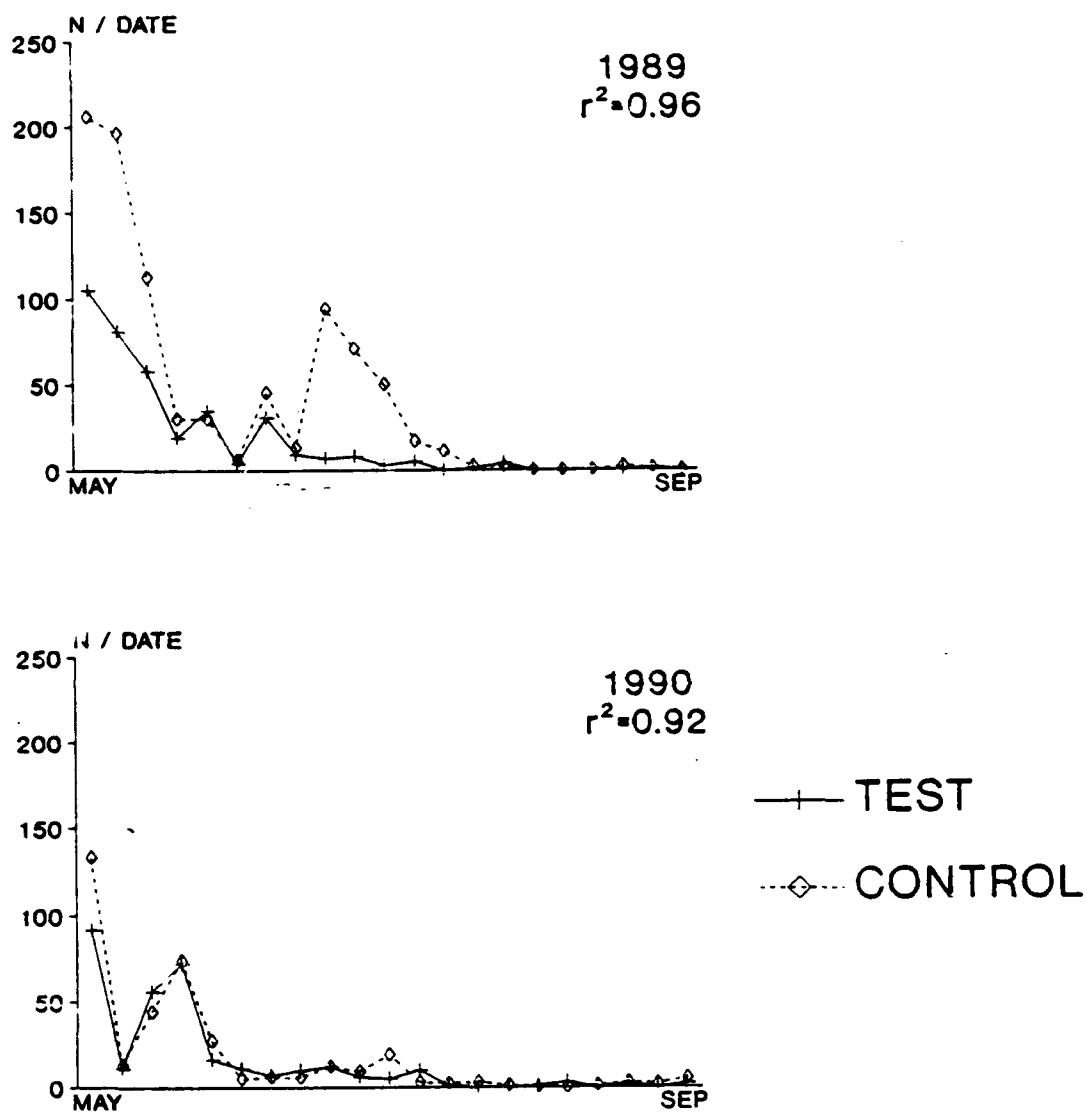


Fig. 7. Total weekly catches of *Trombidium auroraense* in Test and Control sites during operational years.

Numbers of relatively common species, and total numbers captured, are listed in Table 8. Examples of seasonal activity of carabids are illustrated for two moderately abundant species in Figs. 8 and 9. Although coefficients of determination tended to be relatively low in operational years, BACI tests did not detect any significant differences between sites and periods (Table 1).

Although we do not tabulate the data here, there have been no indications that diel preferences or sex ratios have undergone any changes during operational years.

Table 8. Total annual catches of the most common species of Carabidae in Test and Control, 1985-90.

	T E S T						C O N T R O L					
	1985	1986	1987	1988	1989	1990	1985	1986	1987	1988	1989	1990
<u>P. melanarius</u>	1087	1163	643	1528	1066	851	183	222	356	299	161	177
<u>P. coracinus</u>	146	163	134	61	85	70	263	450	335	306	321	303
<u>P. pensylvanicus</u>	206	179	102	74	93	135	278	247	176	130	122	105
<u>P. adstrictus</u>	19	6	11	3	2	-	253	172	106	18	-	-
<u>P. mutus</u>	232	203	210	102	153	182	24	15	26	12	57	25
<u>Calathus spp.</u>	81	40	32	23	31	41	290	157	130	71	72	44
<u>C. frigidum</u>	67	139	406	132	12	2	29	107	185	31	5	6
<u>S. impunctatus</u>	103	261	104	74	49	145	700	894	367	157	88	293
<u>H. fuliginosus</u>	76	139	71	124	79	88	55	116	61	88	83	84
TOTAL ALL SPP.	2168	2506	1913	2261	1744	1637	2307	2639	1936	1222	996	1162
TOTAL N SPECIES	21	20	20	24	24	23	20	20	18	20	18	20

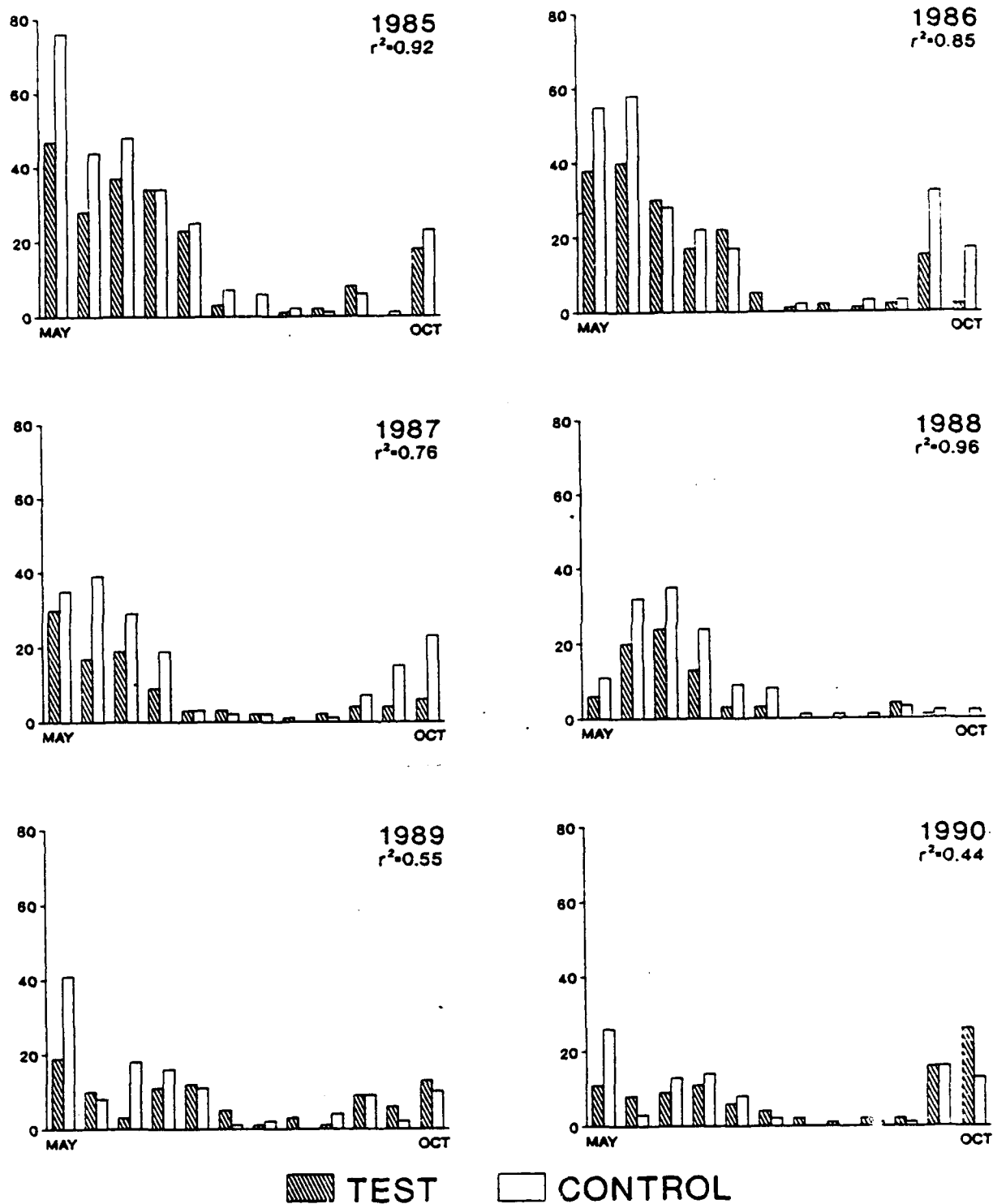


Fig. 8. Bi-weekly total catches of *Pterostichus pensylvanicus* in Test and Control, 1985-1990.

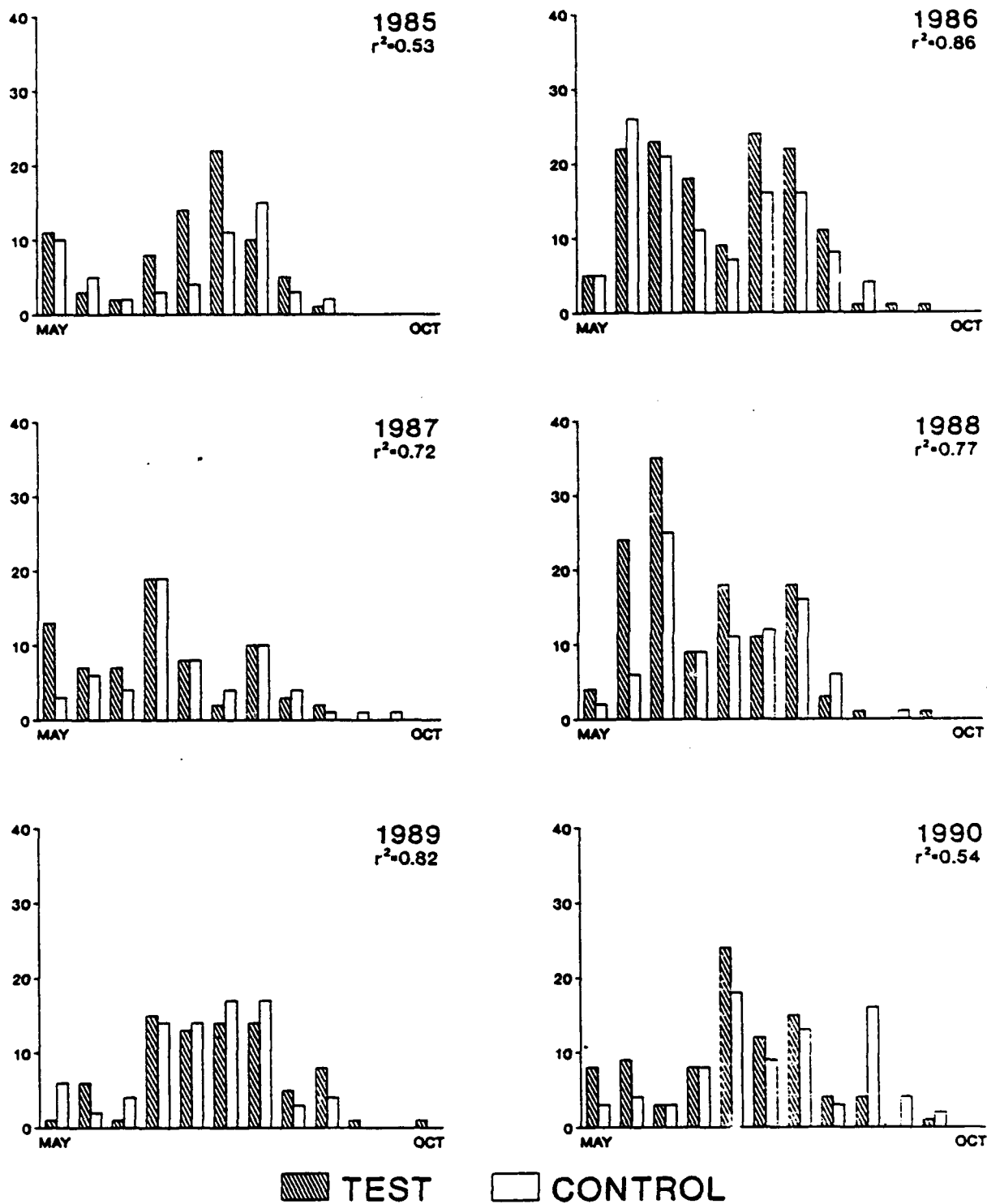


Fig. 9. Bi-weekly total catches of *Harpalus fuliginosus* in Test and Control, 1985-1990.

VI. EARTHWORMS

Preface

We have restricted presentation of earthworm data to parameters of direct relevance to project objectives, i.e. those which we have subjected to relatively rigorous statistical analyses (mainly reproductive parameters). By now, the lumbricid data base is voluminous. Detailed descriptions of species phenologies, including earthworm and cocoon mass, population structure, and annual and seasonal fluctuations in these and other variables, are the subject of manuscripts in preparation. At this time, we simply illustrate annual densities and biomass of the most common lumbricids in Test and Control, in order to provide a general overview of year-to-year variations observed to date (Figs. 10 and 11). Among species not included in these Figures, two endogeics are of further interest: Aporrectodea trapezoides in Test and A. tuberculata in Control. Since 1983, when both were extremely rare, they have been gradually and steadily increasing in numbers. It is conceivable that the two lumbricid communities are slowly becoming more similar as the two forested sites mature.

1. Community structure

Following an initial description of community parameters based on samples taken August 1983 to July 1985 (Snider and Snider 1988), we discovered that all species were actually shared between sites (with the exception of A. longa, still unique to Test). Relative numbers of shared species, however, are so highly discrepant that between-site testing of community indices is not strictly valid except for descriptive purposes.

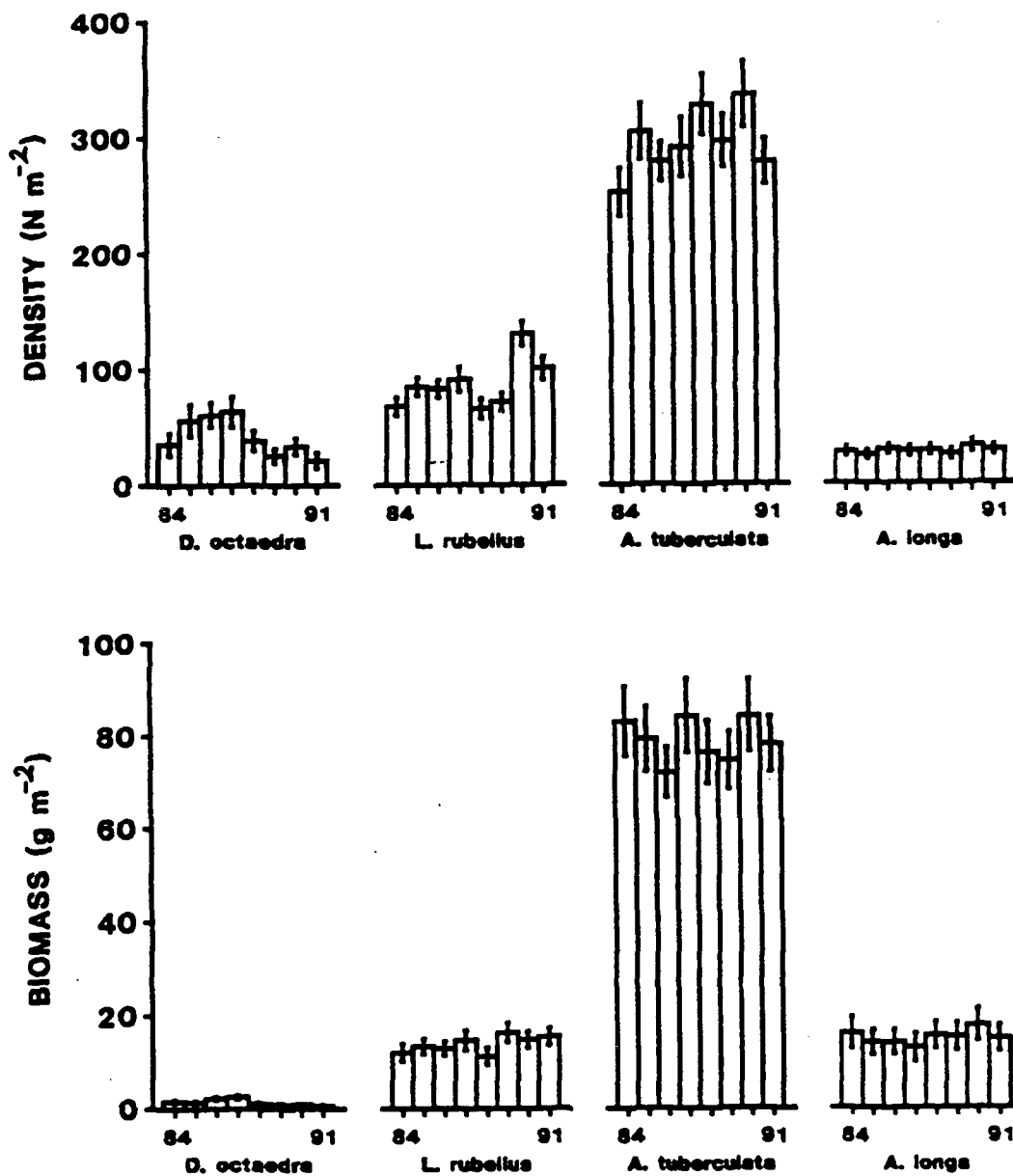


Fig. 10. Mean annual density and biomass of the most abundant lumbricid species in the Test site, 1984-1991. Error bars are 95% confidence limits.

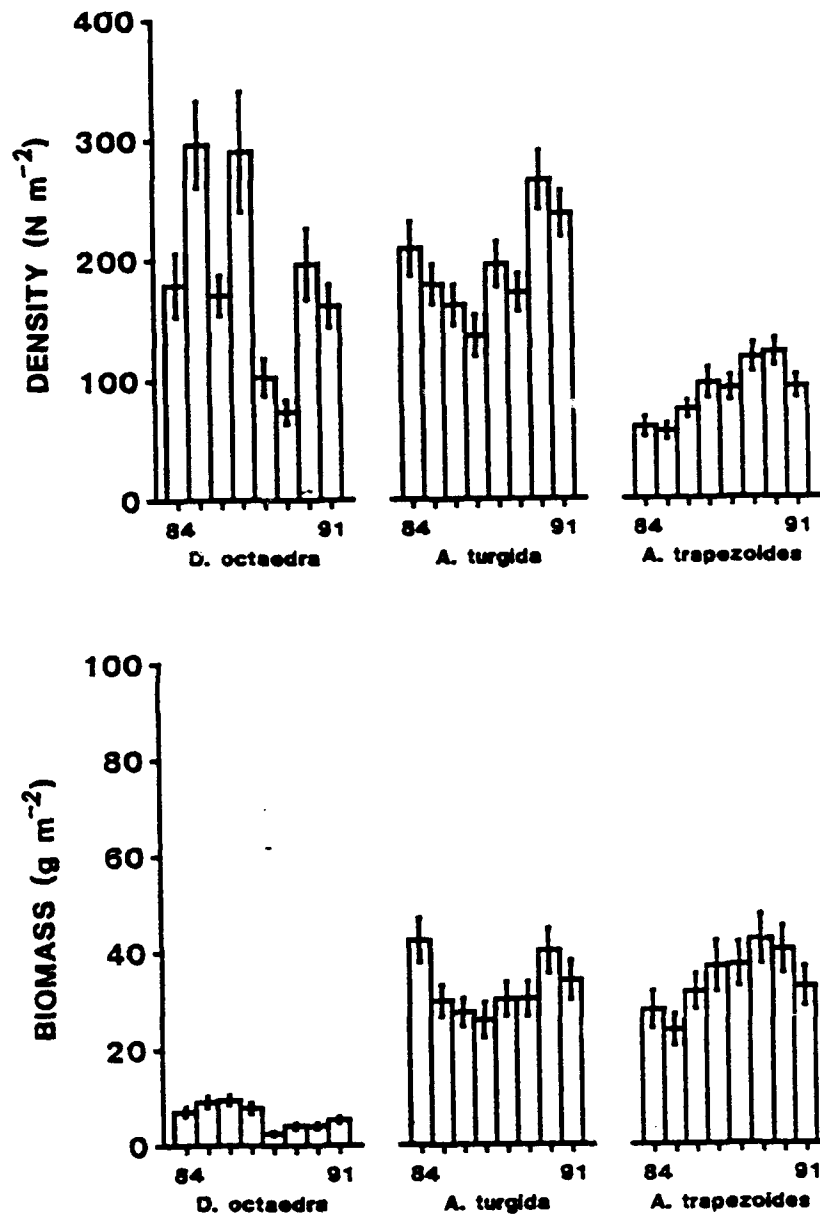


Fig. 11. Mean annual density and biomass of the most abundant lumbricid species in the Control site, 1984-1991; error bars are 95% confidence limits.

It so happened that average diversity of both communities was almost equal in the first four pre-ELF years (Fig. 12). Beginning in 1988, the two communities diverged drastically: Control persisted in a gentle increase, while H' in Test decreased. By means of paired t-tests, 1989 in particular was shown to differ significantly from all 1984-87 estimates, as well as from H' in 1990.

Diversity estimates obviously are a direct result of numerical fluctuations of the community's constituent species. In Control, where three species occur in appreciable numbers (D. octaedra, A. turgida and A. trapezoides), the effects of drastic variations in D. octaedra abundance (Fig. 11) are tempered by two or more other species; while A. turgida remained numerically dominant in most years, increasing H' is due to a gradually increasing A. trapezoides population, subtly enhanced by larger numbers of L. terrestris and the initially very rare A. tuberculata.

In Test, where A. tuberculata is the single dominant, the sharp drop in H' in 1988-89 is attributable to effects of the 1988 drought on L. rubellus and D. octaedra, coupled with all-time peak numbers of A. tuberculata due to high cocoon production in 1987. In 1990, L. rubellus numbers almost doubled over previous years (Fig. 10), raising H' again by counteracting the dominance effects of A. tuberculata.

These yearly fluctuations in diversity may be ecologically of appreciable interest; in terms of ELF project goals, they are useful only if their magnitude can be shown to be dependent on effects of EM fields on the community's constituent species.

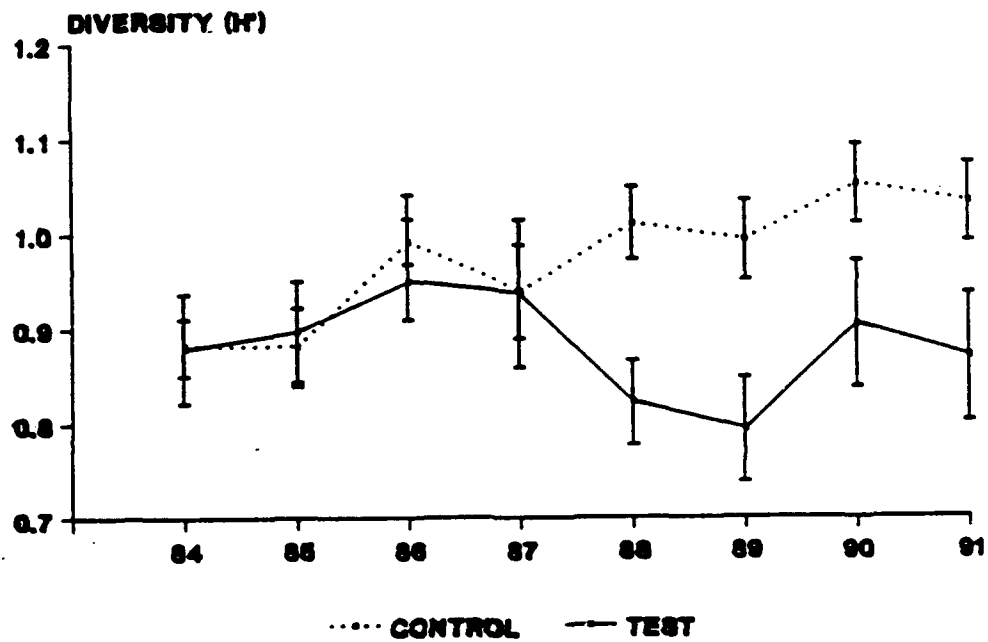


Fig. 12. Mean annual diversity ($\pm$ 95% CL) of Test and Control lumbricid communities, 1984-1991.

2. Aporectodea tuberculata vs. A. turgida

We have previously shown that relatively tight relationships existed between these two species with respect to reproductive parameters (Fig. 13, illustrating cocoon densities and clitellate percentages, may aid recall). We therefore felt justified to perform BACI analyses of date-specific differences in these variables. As shown in Table 9, mean differences (Control - Test) in operational years were indeed discrepant with respect to pre-ELF years, strongly indicating curtailment of A. tuberculata reproduction following ELF activation.

Table 9. Results of BACI tests of seasonal new cocoon densities and proportion of adults clitellate (Control A. turgida - Test A. tuberculata).

Variable	Period	N	Mean diff.	SD	t	DF	P
Cocoon density	84-88	60	0.358	1.234			
	89-91	39	1.662	1.544	-4.647	97	0.000
Prop. clitellate	84-88	60	0.177	0.200			
	89-91	39	0.310	0.149	-3.572	97	0.001

3. Regression models for Aporectodea tuberculata

Regression models were developed using 1984-86 as the original data subset, and were applied to the following two pre-ELF years of 1987-88, as well as to the 1989-91 operational period. Significance levels and coefficients of determination are here used to summarize results.

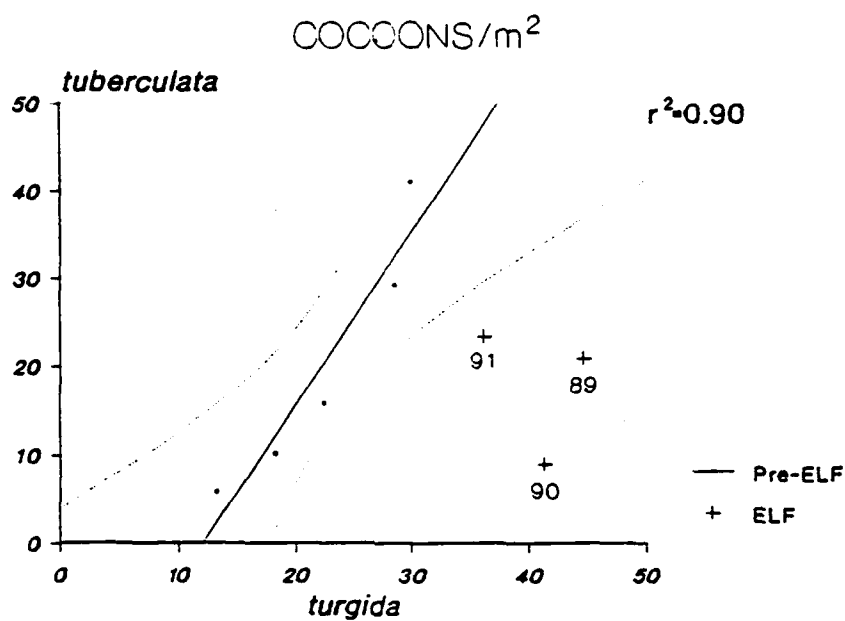
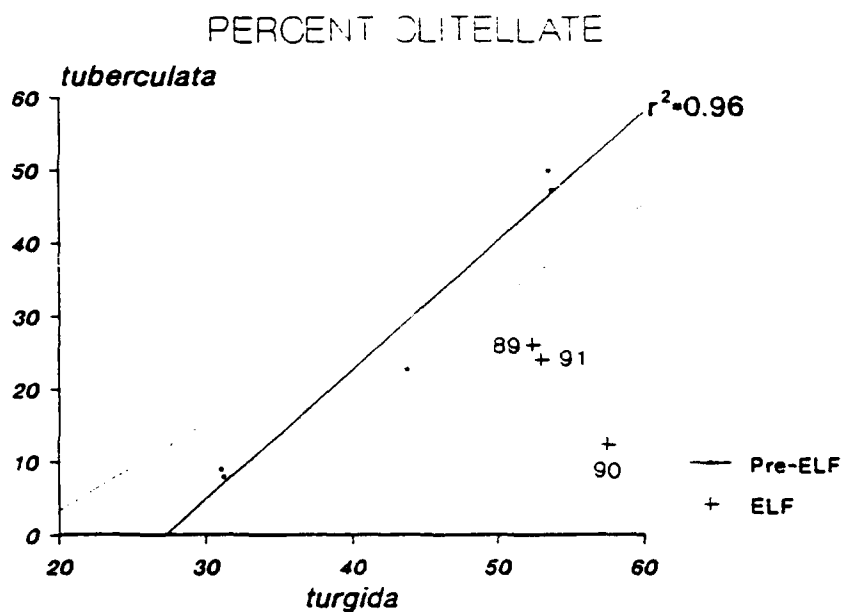


Fig. 13. Correlation of *A. turgida* and *A. tuberculata* percent clitellate and cocoon abundance during pre-ELF years (1984-88); and annual means obtained for operational years.

A. Vertical distribution:

The proportion of A. tuberculata in the A horizon (their preferred stratum) was regressed on A horizon moisture and temperature. Although R^2 was not particularly high, there was no clear evidence that vertical distribution, a behavioral response to edaphic conditions, was altered by ELF activation (Table 10).

Table 10. Anova table for regression analysis of the proportion of A. tuberculata in the A horizon on A horizon moisture and temperature.

Source	Period	SS	DF	MS	F-ratio	P	R^2
Regression	84-86	0.6905	2	0.3452	29.31	0.000	0.64
Residual		0.3887	33	0.0118			
Regression	87-88	0.4720	2	0.2360	7.68	0.004	0.46
Residual		0.5532	18	0.0307			
Regression	89-91	0.2850	2	0.1425	9.22	0.001	0.36
Residual		0.5098	33	0.0154			

B. Clitellate densities and proportion clitellate:

Both of these parameters, particularly clitellate densities, are potentially affected by the total size of the adult pool (including a clitellates and postclitellates). Examination of adult numbers showed, however, that they have remained quite constant over the years; in particular, adult abundances in 1989-91 fell within the center of the range of numbers observed in 1984-88.

Clitellate densities, regressed on A horizon moisture and "lagged"

clitellate densities (numbers on date_{i-1}, thereby alleviating serial correlation over time), gave highly significant results for the two pre-ELF data subsets (Table 11). While the relationship was still significant for 1989-91 ($P = 0.04$), the explanatory power of the regression dropped from 83 and 73% to 14% in the operational period (Table 11). The relation with A horizon moisture in particular lost its significance ($P = 0.04$ and 0.02 in pre-ELF periods, $P = 0.45$ in 1989-91).

Table 11. Anova table for regression analysis of A. tuberculata clitellate densities on lagged clitellate densities and A horizon moisture.

Source	Period	SS	DF	MS	F-ratio	P	R ²
Regression	84-86	7386.4	2	3693.2	78.32	0.000	0.83
Residual		1414.7	30	47.2			
Regression	87-88	8739.6	2	4369.8	29.15	0.000	0.73
Residual		2847.8	19	149.9			
Regression	89-91	799.4	2	399.7	3.62	0.04	0.14
Residual		3310.3	30	110.3			

Similar results were obtained for proportion (of all adults) in the clitellate state: explanatory power of regression on A horizon moisture and lagged proportion clitellate dropped from 78 and 86% to 27% in 1989-91 (Table 12).

C. Abundance of new cocoons:

Densities of newly deposited cocoons are dependent on clitellate densities and, because attainment of the reproductive state is not imme-

diately translated into the presence of cocoons, on lagged clitellate densities. Together, these variables explained 83 and 84% of observed variation in pre-ELF periods, and 47% of variation in cocoon abundance during 1989-91 (Table 13), all regressions being highly significant.

Table 12. Anova table for regression analysis of A. tuberculata proportion clitellate on A horizon moisture and lagged proportion clitellate.

Source	Period	SS	DF	MS	F-ratio	P	R ²
Regression	84-86	1.3213	2	0.6606	58.50	0.000	0.78
Residual		0.3388	30	0.0113			
Regression	87-88	0.9847	2	0.4923	64.40	0.000	0.86
Residual		0.1453	19	0.0076			
Regression	89-91	0.2154	2	0.1077	6.96	0.003	0.27
Residual		0.4642	30	0.0155			

Table 13. Anova table for regression analysis of A. tuberculata cocoon densities on clitellate and lagged clitellate densities.

Source	Period	SS	DF	MS	F-ratio	P	R ²
Regression	84-86	7498.5	2	3749.2	77.25	0.000	0.83
Residual		1456.0	30	48.5			
Regression	87-88	8505.3	2	4252.6	55.81	0.000	0.84
Residual		1447.7	19	76.2			
Regression	89-91	2876.7	2	1438.3	15.30	0.000	0.47
Residual		2820.6	30	94.0			

Results (Table 13) thus support earlier conclusions: numbers of cocoons produced are not significantly or detectably affected by EM fields, given the number of clitellates present in the population. It is the attainment of the reproductive state which appears hindered by ELF operation. By corollary, of course, lower numbers of clitellates will result in fewer cocoons. Reduced R^2 for operational years (Table 13) may, however, indicate some change in the rate of cocoon production and/or changes in the length of time A. tuberculata remains in the clitellate state once it is attained.

4. Earthworm isolation experiments

The 1991 season was used to develop a field-incubation technique that would allow observation of A. tuberculata confined under near-field conditions. Below, a brief description and evaluation of the method, as well as preliminary results, are given.

A. Basic method:

Flat-bottomed, cylindrical bags (20 cm diameter) made of fiberglass windowscreening are buried to a depth of 20 cm in tightly-fitting holes in Test and Control sites. They are filled with dried, sieved and re-moistened soil taken from the Test site, by means of a watering-in procedure which ensures good contact with surrounding soil (necessary for highest possible penetration by EM fields). Bags are stocked with a known number of A. tuberculata, and are retrieved at 4-5 week intervals in order to monitor earthworm development and reproductive activity.

B. Preliminary results:

a.) Electric fields inside wormbags were reduced to 46% of ambient field intensities in both sites (mesh fabric effect); average field intensity in Test bags was 24 mV/m.

b.) Soil moisture in Test and Control bags was essentially equal on each sampling date, seasonal fluctuations reflecting moisture conditions in the sites at large.

c.) Loss of experimental animals was most pronounced in the second half of the season. We postulate that near-quiescent earthworms lose so much body mass that escape through the mesh fabric becomes possible. In June and July, when rainfall was ample and all animals were active, no losses occurred at all. Later in the season, a maximum loss of 24 of 300 earthworms was observed, which is not considered severe enough to endanger interpretation of results.

d.) The bags were initially stocked with only a clitellates and post-clitellates. After a slow rise in reproductive activity, Test and Control treatment groups diverged significantly: in September and October, less than 30% of Test animals were clitellate, vs. 66-69% of Control animals (data refer to A. tuberculata of Test site provenance).

Tentatively, we conclude that the method is basically sound for assessing EM field effects, and that preliminary results support conclusions derived from field populations of A. tuberculata; i.e., that low-level EM fields have the capacity to curtail reproductive performance.

C. Recommendations for continued experiments:

a.) Soil moisture estimation was only feasible at the time of sampling, at inadequately long intervals. We propose to use TDR (Time Domain Reflectometry) sensors, re-installed on each sampling occasion, to monitor moisture frequently; and to develop an irrigation program designed to keep moisture at non-limiting levels (say, 22-26%) at all times. The purpose of this program will be to remove moisture stress as a potential factor influencing reproduction, so that results will be unambiguous with respect to EM field effects. In addition, maintaining high moisture levels may eliminate the problem of loss of earthworms due to decreased body mass and concomitantly increased escape capability.

b.) Initial stocking of bags will be done with a mixture of developmental states which mimic the ratios of clitellate: a clitellate: postclitellates observed in the field population of A. tuberculata at time zero.

c.) In order to alleviate the statistical problem of serial correlation, earthworms will be pooled on each date, after all data have been recorded. They are then randomly re-distributed over replicate bags such that each bag receives equal numbers of worms of each developmental state.

d.) The following additional variables will be monitored (as far as available manpower allows):

-- biomass of A. tuberculata over time: all experimental groups are weighed and returned to mesh bags within 24 hours of retrieval; a reference group from each site will be weighed, allowed to void their gut contents, and weighed again before return to the field. Correction factors will thus be derived for estimation of live biomass (gut voided) of experimental A. tuberculata.

-- Temperature inside mesh bags will be monitored at least once/week by means of a YSI telethermometer. Although A horizon temperatures during the field season have so far not proven to be critical for reproduction, these records may become useful for confirming the validity of Test/Control comparisons of field-incubation data.

-- Invasion of mesh bags by root systems can be considerable. Care will be taken in selecting specific burial locations in each site such that immediate bag surroundings (in terms of ground cover density and proximity) are comparable in Test and Control. On dates when root invasion appears significant, an approximate estimate of root mass/bag will be obtained.

5. Lumbricus rubellus

Lumbricus rubellus is not a true epigeic, dwelling mainly in the A horizon and almost never descending below it. The degree to which the species invades leaf litter is partly dependent on population structure: small immatures are more frequently found in leaf litter than large-sized immatures or adults.

A regression quantifying the proportion of L. rubellus in the A horizon therefore used both litter moisture and small immature proportions as independent variables (Table 14). The model's explanatory power was relatively weak in all periods, but significance levels remained high for operational years. There is thus no evidence that EM fields influenced vertical distribution of L. rubellus.

With respect to reproductive parameters, descriptive summaries are provided in Tables 15 and 16. Ratios of annual cocoon : clitellate densities were in no way discrepant during operational years (Table 15). We re-evaluated

mean proportions of adults clitellate based on single sampling dates (Table 16): although the lowest average proportions were obtained for 1990 and 1991, a high mean of 84.2% in 1989, the first operational year, makes conclusions difficult. In 1991, significantly fewer adults were reproductive when tested against 1984, 1987, and 1989. When tested against years of mild (1985) or severe drought (1986, 1988), differences were not significant. There is some indication that L. rubellus, in moist operational years, reproduces at rates equivalent to those in dry pre-ELF years, but results to date are far from conclusive.

Table 14. Anova table for regression analyses of proportion of L. rubellus in the A horizon on litter moisture and small immature proportions.

Source	Period	SS	DF	MS	F-ratio	P	R ²
Regression	84-86	0.3380	2	0.1690	18.53	0.000	0.53
Residual		0.3010	33	0.0091			
Regression	87-88	0.3108	2	0.1554	19.53	0.000	0.68
Residual		0.1433	18	0.0080			
Regression	89-91	0.3356	2	0.1678	13.70	0.000	0.45
Residual		0.4041	33	0.0122			

Table 15. Ratios (means $\pm$ SD) of annual cocoon/clitellate densities of L. rubellus; N = 11 dates/year.

	1984	1985	1986	1987	1988	1989	1990	1991
Ratio	6.76	9.61	8.37	8.31	4.99	6.07	9.09	7.17
$\pm$ SD	4.35	8.08	4.78	3.39	2.43	1.53	5.59	3.98

Table 16. Mean percent $\pm$ SD of all adult L. rubellus in the clitellate state, 1984-1991; (N dates in parentheses).

	1984	1985	1986	1987	1988	1989	1990	1991
Mean %	85.3	69.0	69.1	79.1	69.3	84.2	60.9	56.9
$\pm$ SD	14.3	26.3	17.4	22.8	21.4	15.1	19.4	24.4
(N)	(12)	(13)	(13)	(10)	(12)	(13)	(13)	(13)

We sought to develop some predictive models for L. rubellus reproduction, but not one of several variables tested gave satisfactory coefficients of determination (all explained much less than 20% of observed variation). We were thus unable, so far, to test reproductive parameters during operational years. The relative insensitivity of the species to climatic variables, coupled with typically low adult numbers in all years (immature: adult ratios are twice as high in L. rubellus than in any other species) foiled all efforts to predict its reproductive behavior.

6. Dendrobaena octaedra

In analogy to L. rubellus, the proportion of small immatures present in D. octaedra populations was found to be significantly related to the species' vertical distribution. In conjunction with litter moisture, 72 to 51% of observed variation was thereby explained, and the relationship remained significant in operational years (Table 17).

Table 17. Anova table for regression analyses of proportion of D. octaedra in litter on litter moisture and small immature proportions.

Source	Period	SS	DF	MS	F-ratio	P	R ²
Regression	84-86	2.2181	2	1.1091	42.94	0.000	0.72
Residual		0.8524	33	0.0258			
Regression	87-88	1.1994	2	0.5997	21.14	0.000	0.70
Residual		0.5107	18	0.0284			
Regression	89-91	1.5487	2	0.7743	17.15	0.000	0.51
Residual		1.4903	33	0.0452			

Using independent variables found to be important for both Control and Test D. octaedra (clitellate density, clitellate density lagged, and A horizon temperature), a significant relationship with new cocoon densities was observed for all periods (Table 18). No effects of ELF EM fields were detectable.

Table 18. Anova table for regression analyses of D. octaedra new cocoon densities on clitellate and lagged clitellate densities and A temperature.

Source	Period	SS	DF	MS	F-ratio	P	R ²
Regression	84-86	11314.9	3	3771.6	10.23	0.000	0.51
Residual		10689.0	29	368.6			
Regression	87-88	14736.0	3	4912.0	28.05	0.000	0.85
Residual		2627.0	15	175.1			
Regression	89-91	8353.4	3	2784.5	15.34	0.000	0.61
Residual		5624.1	29	181.5			

With respect to clitellate densities or proportion clitellate, we find that numbers recovered from samples are now so low as to preclude meaningful analysis and interpretation. Unlike Control D. octaedra (Fig. 11), the Test population has continued to decline, reaching an all-time low in 1991 (Fig. 10). Occurrence of clitellate individuals, never numerous to begin with, may now be greatly influenced by random chance, making conclusions tenuous.

VII. LITTER INPUTS AND DECOMPOSITION

1. Litter inputs

Seasonal patterns of leaf-fall have remained tightly synchronized between sites (Fig. 14), and total inputs in 1991 fell well within the range of previous years (Table 19). We believe results of the current 1992 season will permit firm conclusions with respect to these parameters, which have not shown any effects of ELF antenna operation (Table 1).

Table 19. Annual litter inputs (g dry/m²), 1983-1991, by the dominant Acer saccharum and by all species together in Test and Control.

		1983	1984	1985	1986	1987	1988	1989	1990	1991
Maple	T:	189	177	203	176	161	191	180	169	167
	C:	221	179	199	189	180	198	162	172	187
Total	T:	278	259	286	252	231	276	269	246	261
	C:	305	264	289	284	275	301	258	261	296

2. Litter standing crops and turnover

Seasonal fluctuations in standing crops during operational years are illustrated in Fig. 15. Standing crops have been consistently slightly higher in Control in all years; differences between sites were not significant when pre-ELF and operational periods were contrasted (Table 1).

Turnover times have been variable over the years, and were relatively high in 1991 for both sites (Table 20). We propose that these estimates incorporate a significant amount of error, due to point-sampling and spatial variability, to be of much rigorous use. However, we have found that litterbags provide more precise (and explainable) data on variations in litter decomposition rates.

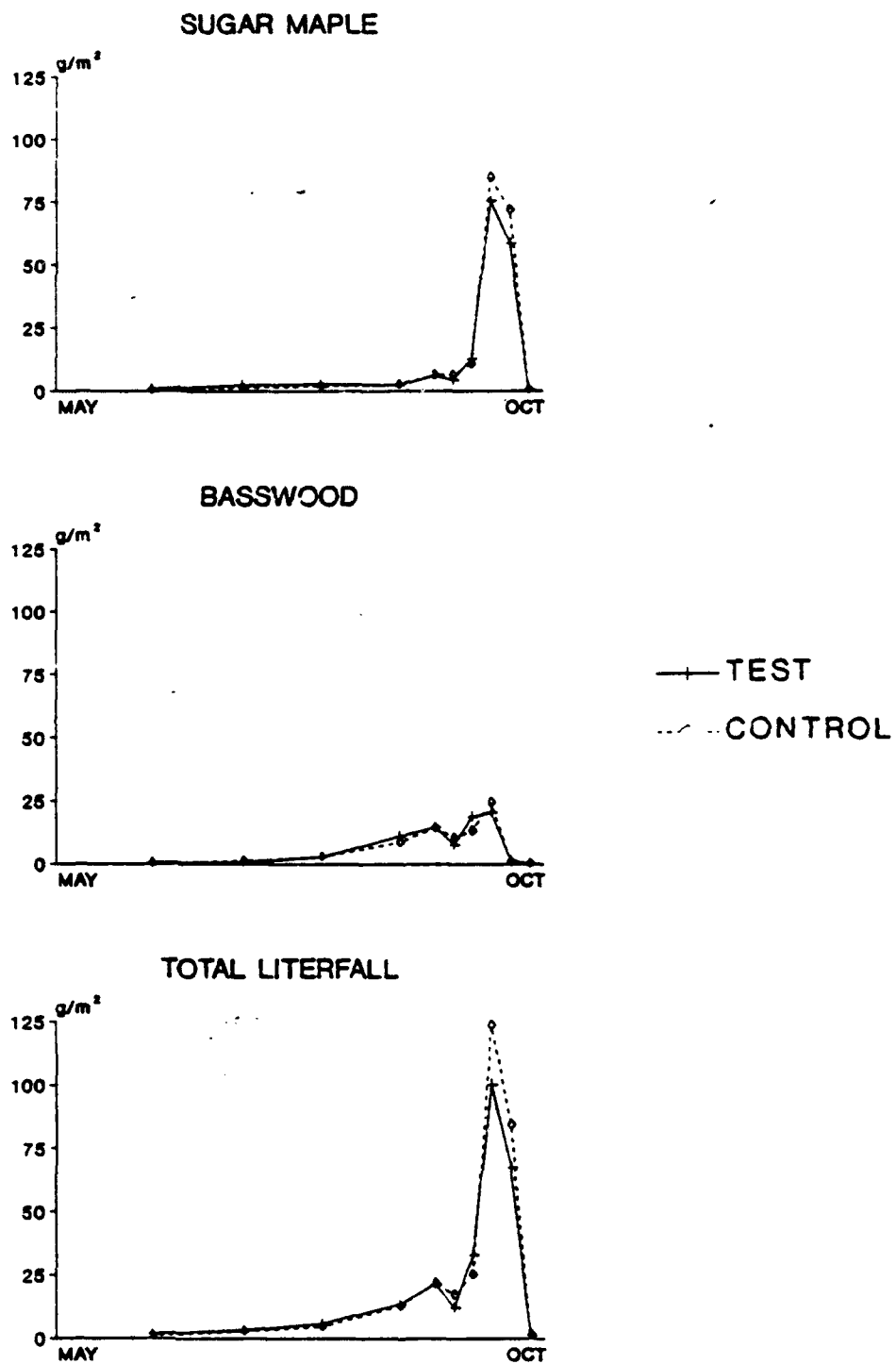


Fig. 14. Seasonal litter inputs (g dry / m^2) in Test and Control, 1991.

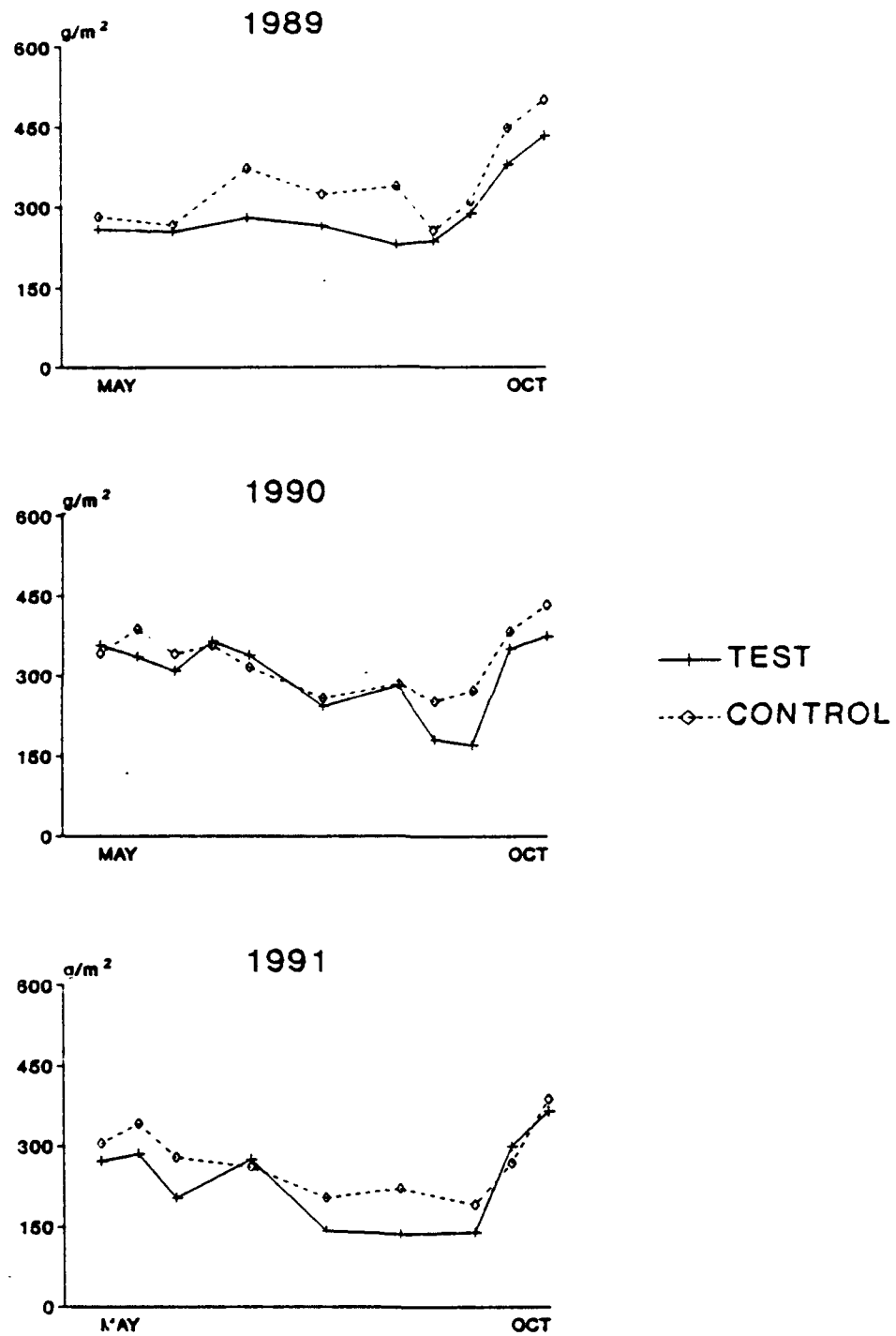


Fig. 15. Seasonal litter standing crops in Test and Control during operational years (g dry /m²).

Table 20. Turnover times for leaf litter standing crops in Test and Control.

	1985	1986	1987	1988	1989	1990	1991
TEST	0.99	0.97	1.22	0.82	1.03	0.93	1.26
CONTROL	0.97	1.00	1.28	1.00	1.37	1.08	1.15

Note: turnover time = $1/k$; $k = -\ln(1-k')$; $k' = \text{input}/\text{max. standing crop}$.

3. Litterbags

Patterns of decomposition in 1991 (Fig. 16) (litterbag series IV, initiated in November 1990) followed much the same pattern as in previous years. The "exchange series" (Test litter in Control and vice versa), implemented to test whether litter quality, e.g., ratio of sun and shade leaves, influenced observed discrepancies between sites, simply mimicked the data obtained from regular litterbag series (Fig. 16).

Using both 1986 and 1989 as pre-ELF years (the first six months of decay of the 1988 series fell into the pre-operational period), ANOVA of differences between sites showed significant site effects, as expected ($P = 0.008$), but non-significant ELF effects ($P = 0.12$) and site x ELF interactions ($P = 0.74$).

Turnover times for the four available litterbag series which all employed the same methodology (large-mesh, flexible fabric) are given in Table 21.

Almost equal turnover times in the pre-ELF year 1986 had led us to believe that this parameter would allow valid between-site comparison. Subsequent litterbag data were discrepant and somewhat puzzling, although we have previously alluded to fluctuations in lumbricid decomposer densities as the main cause for variations in decomposition rates.

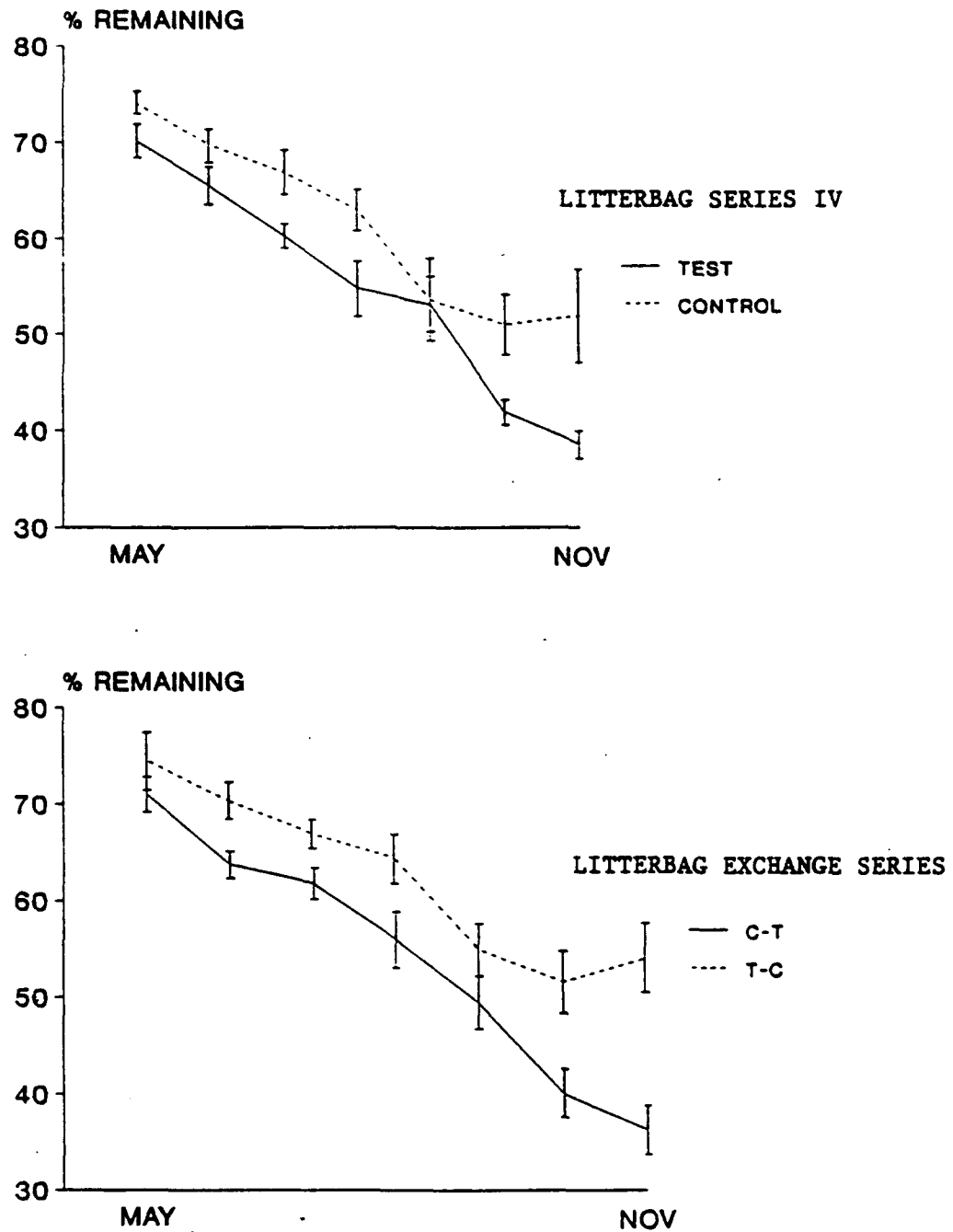


Fig. 16. Litterbag series IV (initiated November 1990) and "exchange series": mean % remaining mass $\pm$ SD (AFDW) during 1991.

Table 21. Decomposition constants (k) and turnover times (1/k) for litterbag series I to IV in Test and Control.

		Litterbag series			
		I (11/20/85 to 10/20/86)	II (11/10/88 to 11/6/89)	III (11/10/89 to 11/8/90)	IV (11/13/90 to 11/2/91)
TEST	k	0.997	0.808	0.918	0.984
	1/k	1.003	1.237	1.089	1.016
CONTROL	k	1.038	0.566	0.673	0.678
	1/k	0.963	1.767	1.485	1.475

Note: $k = (365/t) * \ln(100/m_t)$, where t = days exposure, m_t = % of initial mass remaining at time t (approximately 1 year after field placement).

Yearly variations in litter decay are indeed related to lumbricid macrodecomposers (Fig. 17). In Control, biomass of [D. octaedra + L. terrestris] explained 92% of observed variation in turnover times. In Test, biomass of [D. octaedra + L. rubellus immatures] explained 88% of observed variation, immature L. rubellus having a much more pronounced propensity to invade leaf litter than adults. Increased turnover times in both sites in 1989 are thus directly traceable to effects of the 1988 drought on earthworm populations. And equal Test and Control turnover times obtained for 1986 are traceable to unusually high earthworm biomass, mainly of D. octaedra in Control (Fig. 11).

The low turnover time of approximately one year in Control, 1986, appears to be the exception rather than the rule for that site. It may recur only if climatic circumstances allow one or more cohorts of D. octaedra to survive and grow to large immature and adult sizes, resulting in peak biomass, and/or if L. terrestris continues its gradual numerical increase.

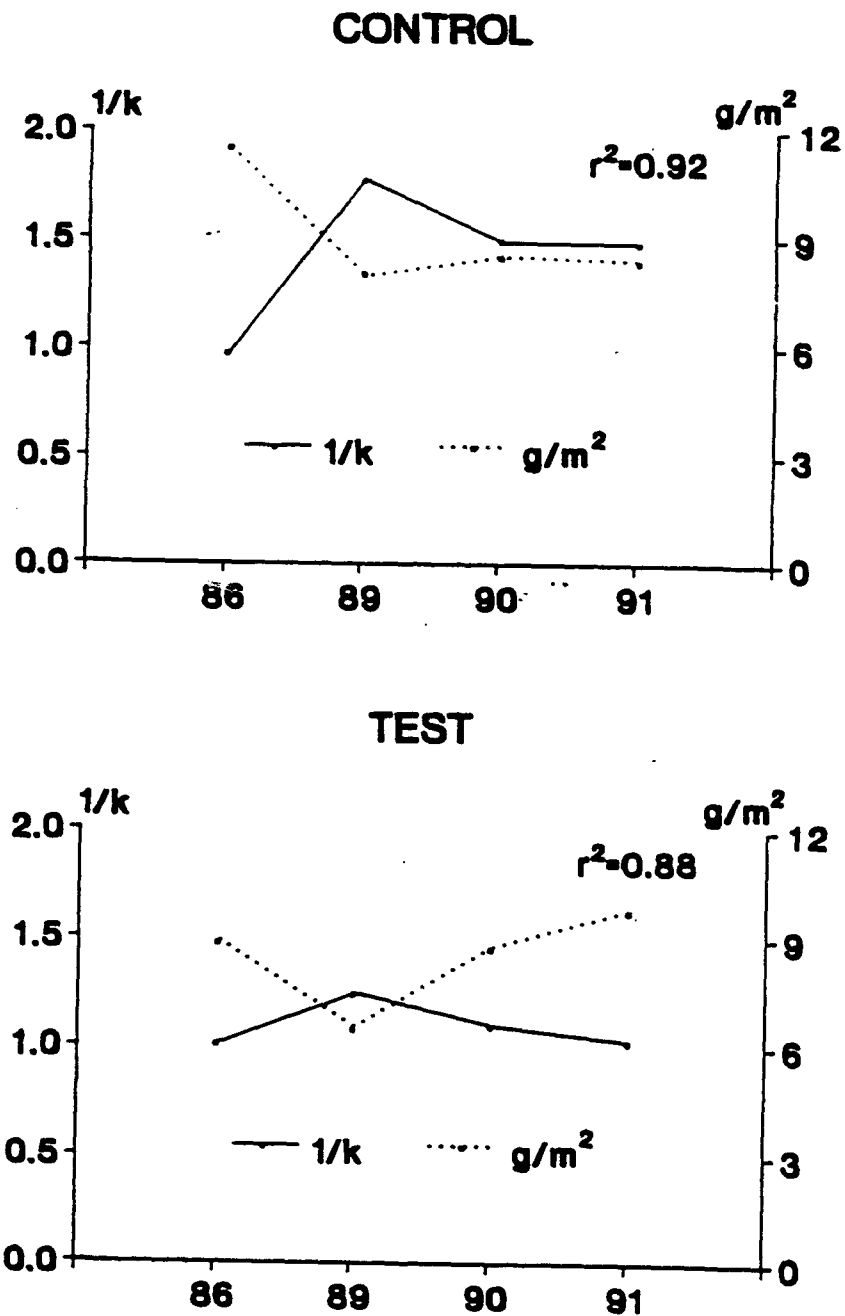


Fig. 17. Litterbag series I through IV (1986-91): turnover rates (1/k) and biomass of lumbricid decomposer species in Test and Control (ref. to text for details).

Generally higher turnover times in Control with respect to Test (Fig. 17) explain the frequently higher litter standing crops encountered there.

On the other hand, relatively greater stability of decomposition rates in Test are attributable to the relative stability of L. rubellus biomass (Fig. 10), which is not subject to the drastic fluctuations characteristic of the purely epigeic D. octaedra. In Test, the contribution of D. octaedra to decomposer biomass is minor, though not negligible.

We are planning to develop models to further quantify these relationships, using date-specific turnover times (remaining mass related to preceding sampling dates) and various combinations of decomposer biomass and environmental data. We intend to continue monitoring breakdown of confined litter because the data provide a check on system function, and can be related to lumbricid phenologies as they respond to climatic events. It is evident, however, that interpretation with respect to potential ELF effects rests not on decomposition data themselves, but on detection of effects on the lumbricid macrodecomposers which promote the disappearance of litter in Test and Control.

References

- Conover, W.J. 1980. Practical non-parametric statistics, 2nd ed.,
John Wiley and Sons, 493 pp.
- Hurlbert, S.H. 1984. Pseudoreplication and the design of ecological
field experiments. Ecol. Monogr. 54 (2): 187-211.
- Snider, R.M. and R.J. Snider. 1988. ELF ecological monitoring in Michigan.
II. The earthworm communities of test and control sites. Pedobiologia
32: 335-342.
- Stewart-Oaten, A., W.M. Murdoch and K.R. Parker. 1986. Environmental
impact assessment: "pseudoreplication" in time? Ecology 67 (4): 929-940.

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GLOSSARY AND LIST OF ACRONYMS

C5: Camp 5 control site

CATMOD: Categorical data modeling procedure in SAS.

CL: County Line control site

ELF: Extremely Low Frequency

EM: Electromagnetic

Exp: Variable indicating whether the data were from an experimental or a control area.

Exp*Year: Interaction effect of the Exp and year variables in the GLM, ANOVA, or CATMOD model.

Expected Sex: The actual or predicted sex of the bee offspring in a cell. Predicted sex is based on the order of the cell in the nest, and the presence of at least one cell of known sex. Females are found in the innermost cells, males in the outermost cells (see p. 14,16).

F1: Ford 1 (north Ford) experimental site

F2: Ford 2 (south Ford) experimental site

GLM: General Linear Modeling procedure in SAS.

LO: A round leaf piece used to cap a cell or plug a nest. Occasionally an LO is found at the base of a cell or is part of the construction of a cell lining, along with LRs. The bee carries an LO in her mandibles.

LR: An elongate, oblong leaf piece used to line a cell. The bee carries an LR rolled between her legs.

Measurer: variable indicating the person who observed or measured data.

Primary sex ratio: The sex ratio that would have been produced if all cells had yielded an offspring.

SAS; Statistical software package on the VAX computer, used in analysis of data.

Season (early vs. late): Nests were classified as "early season" if they were begun on or before the date on which half of the nests of that species were begun during that year. Nests begun on later dates were classified as "late season" nests.

Secondary sex ratio: The ratio of male to female adult and pupal offspring, which could be sexed with certainty.

Site [exp]: Site variable nested in experimental areas.

Trip Rank: The number of LO leaves already collected by a bee, including the current LO, in a series of LO trips to cap a cell. Usually the duration of the first 5 such trips are recorded for a given cell cap. These LO trip durations are given Trip Ranks of 1,2,3,4, and 5 respectively.

Yr: Year

I ABSTRACT

High voltage transmission lines and magnetic fields have been shown to affect honeybee reproduction, survival, orientation, and nest structure. ELF EM fields could have similar effects on native megachilid bees.

Two species in the genus Megachile have been abundant in artificial nests at experimental and control sites in Dickinson and Iron Counties in Michigan. Data on their nest architecture, nest activity, and emergence/mortality have been collected since 1983. Five hypotheses concerning the possible effects of ELF EM fields are considered using these data. The ELF antenna has been at 100% power since the summer of 1989. Exposure to ELF EM fields could be reflected in nest activity data for 1989 - 1991, and in nest architecture and mortality for nests constructed in 1989 and 1990.

Our hypotheses have involved monitoring changes in cell length, number of cells per nest, number of leaves per cell, orientation of nest entrances, and time to collect a round leaf piece to cap a cell. Thus far during operational years we have not detected significant changes in nest architecture or nest activity at experimental areas that could be attributed to ELF EM fields. Nest Architecture data will continue to be collected and analyzed for 1991 and 1992 nests to see if current results are confirmed in the final years of the project.

One possible effect of ELF EM fields was detected in the 1989 analysis. M. inermis prepupal (overwintering) mortality in nests oriented along a NS axis was lower in experimental than in control areas for 1988 nests. 1988 was the first year with significant testing of the antenna during the winter, and the first year that the nests were overwintered in the direction that they were constructed. This year, three out of ten analyses of prepupal mortality had a significant effect that suggests greater mortality at experimental sites in full power years, and/or reduced mortality for nests oriented NS relative to nests oriented EW at experimental sites in full power years. These significant effects were very weak compared to other effects on prepupal mortality such as weather, and the effects may represent random yearly fluctuations that have nothing to do with ELF EM fields. We will collect emergence/mortality data for two more seasons (nests constructed in 1991 and 1992) to see whether such effects persist.



II INTRODUCTION

Project Rationale and Overall Objectives.

High voltage transmission lines and fluctuations in the earth's magnetic field have been reported to affect honeybees (Greenberg et al. 1981; Gould 1980). In addition, honeybees have been shown to have an organ in the abdomen consisting of magnetite particles that could be used to detect the earth's magnetic field and thus could be used as a compass in orientation (Gould et al. 1978). This organ appears to be involved in the detection by foraging honeybees of localized magnetic anomalies associated with nectar rewards (Walker and Bitterman, 1989; Kirschvink and Kirschvink, 1991). Honeybees appear to use the earth's magnetic field as a reference system for orientation based on polarized light, and the presence of an artificial magnetic field causes a positive deviation in the angle of the waggle dance for bees orienting their dance on a horizontal hive where skylight but not the sun is visible (Leucht and Martin, 1990). Because such effects of electric and magnetic fields have been demonstrated, it is possible that ELF EM fields may alter a bee's ability to orient or may otherwise affect its behavior.

Honeybees, however, are rare in the state forest where the Michigan ELF antenna is located (personal observation), and are unable to overwinter in the harsh climate of Michigan's Upper Peninsula (Fischer, 1983 Annual Report). Therefore, native bees are a better choice for ecological studies of the resident bee fauna. Native bees are particularly important in ecological communities such as those in the vicinity of the ELF antenna because they are pollinators of flowering plants, and are therefore important to the reproductive success of these plants.

With the exception of bumblebees and some halictids, native bees are solitary, meaning that each female constructs and provisions her own nest rather than having a special queen caste responsible for reproduction. Solitary bees have several advantages for ecological studies. As "mass provisioners", they create a discrete cell for each offspring, and fill it with a provision mass of pollen and nectar prior to laying the egg. The bee does not add more provisions after the egg is laid. A series of such cells, each with a provision mass and egg, are created in succession by each female. The provisions that go into each cell are a direct measure of parental investment in an offspring (Strickler 1979; Cowan 1981; Johnson 1983; Danforth 1990). The size of the adult bee that emerges from each cell is correlated with the amount of provisions provided it, and with the size of the cell in which the larva

develops (Krombein 1967; Klostermeyer et al. 1973; Trivers and Hare 1976; Alcock 1979; Torchio and Tepedino 1980; Johnson 1983; Danforth 1990). However, there is a tradeoff between the investment per offspring and the rate at which offspring are produced. The more the bee invests per offspring (ie, the larger the offspring), the fewer offspring she will produce. If bees are disoriented, agitated, or slower at foraging, they may invest less per offspring, produce fewer offspring per unit time, or both. Solitary bees are unusual in having this direct relationship between parental investment per offspring, adult size, and reproductive output.

The nesting biology of some species of solitary bees in the family Megachilidae is especially easy to study because they accept artificial nests placed in the field. These bees typically nest in abandoned beetle bores in dead logs. "Trap nests" of drilled blocks of wood are also used by bees as nest sites. Such artificial nests can be placed in habitats where bees are expected to nest, in order to increase the sample of nests available for study, and to standardize such characteristics of the nest as bore depth and diameter (Krombein, 1967). Trap nests are used in the management of the Alfalfa Leafcutting Bee, Megachile rotundata, for pollination of alfalfa (Stephen, 1962, 1981; Bohart and Knowlton, 1964; Johansen et al., 1969; Bohart, 1972; Gerber and Klostermeyer, 1972; Hobbs, 1972; Baird and Bitner, 1991), and the Blue Orchard Bee, Osmia lignaria for the pollination of fruit trees (Torchio 1981a,b; 1982a,b,c; 1984a,b; 1985). Thus there is an extensive (though largely unreviewed) literature on megachilid biology. Literature relevant to the ELF project is discussed throughout this report.

Although the effects of electromagnetic fields on solitary bees had not been studied previous to the ELF project, research on the effects of high tension wires and magnetic fields on honeybees suggested working hypotheses on which to base our analyses of megachilid nesting biology. Of possible relevance to megachilid behavior are an alleged greater tendency for dispersal, and greater levels of activity (Wellenstein, 1973), as well as reduced reproductive output, lower overwintering survival, and modifications of nest structure (Greenberg et al., 1981a,b) when colonies were exposed to electromagnetic fields from high voltage transmission lines. Disturbance of colonies under transmission lines can be attributed to electric shock from induced hive currents, especially under wet conditions (Bindokas et al., 1988). Although induced currents are less likely in trap nests than in honeybee hives, the possibility of stress or disturbance from electromagnetic fields should be appraised. In addition, disorientation due to fluctuations in ELF magnetic fields is possible if megachilids share the honeybee's ability to detect magnetic fields. (Gould et al., 1978, 1980; Gould 1980; Tomlinson et al. 1981; Walker and

Bitterman, 1989; Kirschvink and Kirschvink, 1991). No data exist on the ability of megachilids to detect magnetic fields.

Nesting Biology of Megachilid Bees

A decision to restrict our study to two species of leaf-cutting bees, Megachile (Megachile) relativa Cresson and Megachile (Megachile) inermis Provancher, was made in the fall of 1986 (1986 Annual Report). M. inermis and M. relativa have similar nest architecture in that both line their cells with pieces of cut leaves. However, the two species differ in size, and may therefore partition their time and the space in their nests differently. Aspects of the biology of both species have been described generally for populations in Wisconsin and Canada (Medler, 1958; Medler and Koerber, 1958; Stephen, 1955, 1956; Longair, 1981).

The general structure of the nests of the two species is depicted in Fig. 1. The bee may leave some space at the base of the nest (the basal space) unoccupied by cells for offspring. She may then cut and bring to the nest a few round pieces of leaf that are added one at a time to form the base of the first cell. Next she cuts and brings to the nest several elongate pieces of leaf (LRs) in succession. These are used to line a tube- or cup-shaped cell that is slightly longer than her body. Next she makes a series of pollen and nectar foraging trips to fill the cell with the discrete provision mass that will be the larva's food supply. When provisioning is complete, the female lays an egg. Fertilized eggs become females while unfertilized eggs become males. The female has voluntary control over fertilization and thus the sex of the offspring in each cell (Klostermeyer and Gerber, 1970). After laying the egg, she cuts more leaves, this time round in shape (LOs), to cap the cell. Sometimes she adds chewed leaves, dirt, or bits of wood to separate the cells. Next she cuts more elongate leaves for the second cell, and repeats the process. Thus a linear series of cells is constructed in the nest bore. Typically, the cells at the base of the nest are more likely to contain females and the cells near the entrance are more likely to contain males (Krombein, 1967). Since females are usually larger than males in these bees, cells at the base of the nest tend to be larger than cells near the entrance. When she has completed the last cell that she is going to put in the nest, she constructs a series of plugs of round leaves, chewed leaves, dirt, chewed wood, and possibly other material. M. relativa frequently includes empty "vestibular" spaces between segments of plug. M. inermis and some M. relativa create one long mass of plug material after completing the reproductive cells. In nests of both species there may also be space between the outermost plug and the opening of the nest, called an "indentation".

Each female may construct several such nests over her life time. Some nests are abandoned before they are finished because the bee has died, or for other unknown reasons. The adult life span is no more than one season; adults do not overwinter.

Inside each cell the egg hatches, and the young larva feeds on the provisions prepared by its mother. Both Megachile species at our sites are univoltine (with a few exceptions; see Emergence Results), and both overwinter as prepupae. Pupation occurs in spring, and adults emerge soon after, in June and July at our study sites. A variety of parasites may emerge from the cell instead of the original bee. Oviposition by parasites of the genus Coelioxys (Megachilidae) often occurs while the cell is being provisioned, when the mother host bee is out of the nest on a pollen foraging trip, or on a round-leaf foraging trip just after laying her egg. Other parasites may lay their eggs in empty nests holes (Anthrax spp., Diptera:Bombyliidae) or in complete nests (chalcids; Hymenoptera:Chalcidoidea).

Hypotheses Tested

During the first four years of the project, 1983-1986, data on nest architecture, nest orientation, emergence/mortality and nest activity were collected. Based on these data, six tentative hypotheses concerning the effects of ELF EM fields on Megachile behavior were specified in the 1986 Annual Report. The initial hypotheses were modified in subsequent reports based on our ability to gather sufficient sample sizes to detect differences between experimental and control areas. The modified hypotheses are expressed in the following sections as null hypotheses, ie., hypotheses of no difference between experimental and control areas, that we will try to disprove statistically. The "Rationale" sections explain the possible effects of ELF EM fields that may cause a rejection of the null hypothesis.

Hypotheses Involving Nest Architecture:

Hypothesis 1: The average length of cells for each offspring, and/or the average number of cells produced per nest is unchanged by exposure to ELF electromagnetic fields.

Rationale

Honeybee reproductive output decreased on exposure to high voltage transmission lines. Capped brood, which normally averaged 12,000 per hive, decreased to as low as no brood after 8 weeks of exposure (Greenberg, et al., 1981b). ELF EM fields may have a similar effect on the number of cells produced by megachilids. Furthermore, ELF electromagnetic fields may

affect cell size and nest architecture in various ways. For example, if bees are disoriented by the fields, they may gather resources (leaves, pollen) more slowly when exposed to the fields than when not exposed. As a result, they may produce new cells at a slower rate, or they may produce smaller cells.

Previous studies have found that the weight of offspring of the generalist megachilids, Osmia lignaria and O. cornifrons, is lower if their cells were produced late in the season rather than early in the season (Torchio and Tepedino, 1980; Sugiura and Maeta, 1989). These species also showed an increase in the proportion of male offspring (the smaller sex) produced late in the season. A reduction in offspring size late in the season is related to reduced foraging rates due to aging of the bee (Torchio and Tepedino, 1980, Tepedino and Torchio, 1982; Sugiura and Maeta, 1989). Similarly, ELF EM fields may slow the foraging of M. relativa and M. inermis, resulting in smaller bees produced in smaller cells. A size reduction could affect cells with offspring of both sexes, or it could reflect the production of a greater proportion of male offspring, since males are the smaller sex in both Megachile species. An additional complication is that female sizes decrease more than male sizes late in the season (Torchio and Tepedino, 1980). Thus we might expect female cells to be affected more than male cells by stresses from ELF EM fields.

In contrast to the generalist megachilids, the pollen specialist Hoplitis anthocopoides did not show a reduction in offspring weight late in the season, in spite of reduced foraging rates (Strickler, 1982). Rather, it was hypothesized that slower foraging rates led to fewer offspring per nest late in the season as compared with early in the season for this species. Similarly, M. relativa and M. inermis may produce fewer cells per nest in response to slow foraging rates due to ELF EM fields.

In testing hypothesis 1 we are interested in determining whether there are differences between experimental and control sites in cell lengths and number of cells per nest. Ideally, we hope to find no differences between experimental and control sites, and between years, prior to the 1989 season when the ELF antenna was operational at full power. Then, if significant differences between experimental and control sites appear after the antenna is functioning at full power, we can attribute these differences to the effect of ELF EM fields.

Hypothesis 2: Bees exposed to ELF EM fields, and bees not exposed, will make nest plugs of the same thickness and will devote the same proportion of nest space to reproduction.

Rationale

Abnormal deposits of up to 48g of propolis were present at honeybee hive entrances under high voltage transmission lines, presumably in response to stress connected with electric fields at the nest entrance (Greenberg et al, 1981b). This suggests the possibility that megachilid bees will respond to disturbance from ELF EM fields by increasing the amount of nest lining material in the bores. This may be reflected in larger cells (tested in hypothesis 1) and/or increased nest plug length. More generally, there could be an increase in the nest space that does not include cells for offspring (ie. basal and vestibular spaces, nest plugs and indentations).

Hypothesis 3: The number of leaves used to line a cell is unchanged when bees are exposed to ELF EM fields.

Rationale

Bees may pad a cell with extra leaves as a result of stress due to electromagnetic fields, just as they may pad a nest with plug material. We can easily determine the number of elongate leaves used to line a cell by taking the cell apart after bee emergence and counting leaves.

Hypothesis 4: The relative acceptability of nests oriented in a NS direction vs. nests oriented in an EW direction does not change when bees are exposed to ELF EM fields.

Rationale

Honeybees may use the earth's magnetic field under special circumstances to orient their comb (reviewed in Gould, 1980). The fluctuating ELF magnetic fields could disturb any biases that megachilids normally have for nest orientation, or could cause greater acceptance of nests oriented in certain directions in order to reduce disturbance by the fields.

Hypotheses Involving Nest Activity

Hypothesis 5: The duration of round leaf (LO) foraging trips remains the same when bees are exposed to ELF EM fields.

Rationale

Honeybee activity, measured by honey production, allegedly doubled under high voltage electromagnetic fields in one study (Wellenstein, 1973). In contrast, colony weight, a measure of rate of honey accumulation and brood production, decreased by as much as half for colonies exposed to high voltage transmission lines in a different study (Greenberg et al., 1981b). In a third study, there were dose-related lags in colony weight gain, with the maximum difference being a doubling of exposed hive weights compared with more than a six fold increase in control colonies in 5 weeks (Greenberg et al., 1981a). Foraging rates were decreased by as much as half in exposed colonies in this study (Greenberg et al., 1981a). Honeybees also had an increased tendency to sting under high voltage transmission lines (Wellenstein, 1973). ELF EM fields might similarly affect megachilid bee activity by disorienting or agitating the bees so that the duration of leaf- and pollen-foraging trips is altered. Interference with magnetoreception might play a role in disorientation. Changes in electric potential of the bees, or of the plants on which they forage (Erickson, 1975), or changes in the electric potential of antennal chemosensilla that detect plant odors (Erickson, 1982) might also affect the bees' foraging rate.

Leaf-foraging trips for M. inermis are easy to recognize behaviors, usually lasting less than a minute in duration. Many of these trips are taken in succession, so within and between bee variability can be analyzed, and a potentially large sample of leaf collecting trips can be timed. In the 1986 Annual Report we demonstrated that the collection of LO leaves was the most consistent behavior of the leaf-cutting bees under study. We argued that this is probably because it is adaptive to close the cell as quickly as possible after the egg is laid to avoid parasitism. Thus, our analysis focuses on LO trip durations.

Hypotheses Involving Emergence:

Hypothesis 6: Overwintering mortality of megachilid bees is unchanged by exposure to ELF EM fields.

Rationale

Overwintering mortality of honeybee colonies under high voltage transmission lines increased from 29% when hives were

shielded to 71% when they were fully exposed to electrical fields. (Greenberg et al., 1981b). We would like to test for a similar effect in megachilid bees. To do this requires comparing control and experimental sites in the proportion of cells that suffer mortality during the prepupal (overwintering) stage, relative to the number of cells that survive to the prepupal stage or beyond (pupa and adult) (see results section for further explanation).

According to Brodeur (1989, p.58), studies of the effects of ELF EM fields on chicken embryos suggest that teratological effects depend on the orientation of the embryo relative to both an artificially pulsed field and the earth's magnetic field. I have not found an original reference for this result, although Leal et al. (1986) and Berman (1990) imply that such a relationship may be important. However if true, this suggests that overwintering mortality (as well as mortality of eggs and developing larvae) may be different for nests oriented in a north-south vs. nests oriented in an east-west direction.

III METHODS AND TYPES OF DATA COLLECTED

Nest architecture and nest orientation are obtained by placing trap nests in the environment, and allowing bees to construct nests in their choice of traps during the summer. The following spring, various parameters of their nest architecture are measured. Bee and parasite emergence and larval and pupal mortality are also recorded in the spring. Nest activity data are gathered during the summer season while the bees are constructing their nests.

The methods discussed below will compare, where appropriate, changes in protocol over the years, especially pre- and post-1987. Where no such comparisons have been made, no significant changes in protocol have been made.

Trap Nesting Methodology

Bees are provided with fresh trap nests each year. Trap nests consist of elongate white pine pieces 19x19x153 mm. Most of these nests were drilled lengthwise to a depth of 142mm. Exceptions were the largest diameter nests pre-1987, and half of the 1987 large diameter nests. These nests were drilled to only 107mm.

Prior to 1987, drill bits with seven different diameters were used to create trap nests (Table 1). The maximum diameter was limited by the dimensions of the trap nest, and by availability of long drill bits.

In 1987 only the 5.5mm bit and the 11.0mm bit were used because these diameters were accepted most often in 1985 by the two *Megachile* species under study (see 1986 annual report). In 1988-1991 small nests were made with both 5.5 and 6.0mm drill bits because analysis of 1986 nests indicated that the 6.0 mm diameters were common, and because it was feared that 5.5 mm diameters would skew the sex ratio in favor of male offspring and thus bias the cells towards shorter lengths. Bore diameter has been shown to influence sex ratio for other trap nesting species (Stephen and Osgood, 1965; Krombein, 1967; Cowan, 1981; Tepedino and Torchio, 1989).

Prior to 1987, twelve nests, two of each bore diameter, were bound together with plastic strapping into a "block", so that one of each bore diameter faced each direction, and no two bore entrances were adjoining (Fig. 2). Starting in 1987, two 11mm bores and four 5.5mm bores were arranged randomly in each direction (Fig. 3). In 1988-1991, three of the small nests were 5.5mm and one was 6.0mm in each direction. We did not realize that the 1987 random arrangement of nest entrances differed from the 1983-86 pattern of no adjoining entrances

until blocks for 1987 had already been prepared. However, we do not believe that this change in nest arrangement affected the bee's behavior.

"Hutches" consisting of a wooden frame with four shelves and a roof were used to hold the blocks of trap nests (Fig. 4). Four blocks of nests were placed randomly on each shelf, making a total of 192 nests present at any one time. The hutch was open on both sides, so half of the nests opened in each direction. The shelves were roughly 0.1, 0.4, 0.8, and 1.1 meters from the ground.

Four study sites were selected by 1984 for placement of hutches. Two are experimental sites along the ELF antenna: Ford 1 and Ford 2 (F1 and F2), and two are control sites: Camp 5 and County Line (C5 and CL). The study sites are described in the section titled "Description of Sites", p. 20. Further information can be found in the 1985 annual report. Three sets of two hutches, making a total of six hutches, were placed at each of the four study sites. In each set of two hutches, one hutch was oriented in a north-south direction so that its nests open to the east or west, and one hutch was oriented in an east-west direction so that its nests open to the north or south. The two hutches in each set were placed close together in edge habitats between open areas where there are abundant flowering plants, and woods where natural nest sites are available. In 1983, only the F1 site had been chosen for study in the spring. The CL and F2 sites were added in mid-season. Generally, only one or two sets of hutches were in place that year.

When a nest was occupied by a megachilid bee, it was given a number that included site (C5, CL, F1, or F2), hutch direction (NS or EW), nest entrance orientation (E, W, N, or S) and shelf height (1-4, top to bottom). This number was written on the side of the nest. Position on the shelf and in the block of nests was not recorded. Starting in 1987, a computer data base was created to help us manage nest numbers and progress of the nesting bees.

Once a nest in progress was identified, the depth of empty tunnel space was recorded daily (pre-1987) or every 2-7 days (1987-91). This information, coupled with nest architecture measurements taken the following spring, allowed us to estimate which cell the bee was constructing on the day the nest was first located. Assuming that the bee takes approximately one day to complete a cell, we estimated the dates on which the nest was begun and finished. Nests were classified as "early season" if they were begun on or before the date on which half of the nests of that species (pooled over all sites) were begun during that year. Nests begun on later dates were classified as "late season" nests. When the nest was completed, it was

removed from the block, and replaced with an empty nest of the same bore size.

Each completed nest was stored in a large centrifuge tube with cloth covering the opening. Tubes were placed in wooden overwintering boxes built to fit the hutch shelves. Prior to 1987, completed nests were brought to Channing to overwinter, in order to avoid vandalism and marauding animals. However, starting in 1987, nests were left in overwintering boxes at the site where they were constructed. Starting in 1988, we took care to insure that nests were oriented in their original direction. Overwintering boxes were not left on hutch shelves as in the past, but rather were elevated about a foot off of the ground and camouflaged with branches, bark, and leaves in order to avoid vandalism. Fortunately, overwintering boxes have not been vandalized at any of the sites, although hutches have been damaged and have disappeared during the winter.

Beginning with nests constructed in 1990 and continuing in 1991, a manipulative experiment was initiated to compare overwintering mortality of nests constructed at one site but overwintered either at an experimental or a control site. The results of this experiment cannot determine unambiguously whether ELF EM fields affect overwintering mortality, but the experiment may offer further evidence in conjunction with broader comparisons between all sites and years. For the manipulative experiment, each year one third of the nests constructed at the F2 experimental site were moved to the C5 control site in mid-September for overwintering. The nests that were moved were chosen to represent hutches and dates of nest initiation in the same proportions as the nests that remained at the F2 site. The number of F2 nests overwintering at C5 approximately equaled the number of C5 nests overwintering at C5. Nests from both sites were placed in overwintering boxes in the same directions as they were constructed, but C5 and F2 nests were mixed and positioned randomly with respect to bottom vs. top, right vs. left side of the overwintering boxes. The reciprocal experiment, overwintering C5 nests at F2, could not be conducted in 1990 or 1991 because there were insufficient C5 nests. If nest numbers at C5 are sufficiently large in 1992 we will perform the reciprocal experiment. However, the control sites tend to have lower M. inermis nest numbers than the experimental sites, and 1990-91 had peak nest numbers at all sites (Table 3) so we do not expect that the opportunity will arise.

Nest Architecture Measurements

Nests constructed by M. relativa during 1983 were measured in the spring of 1984 prior to emergence. Nests constructed by M. relativa during 1985 were measured after bee emergence, in

November and December, 1986. Nests constructed during 1985 by M. inermis were measured after emergence in August, 1987. Most 1986 M. relativa nests were measured before emergence in 1987, so that we would know with certainty the species and sex of the occupant of each cell. The 1986 M. inermis began to emerge in spring 1987 before we began measuring their nests, so most M. inermis nests were measured after bee emergence. The 1987-90 nests were measured sufficiently early in May of 1988 - 1991, that we were able to complete nest measurements of both species before they emerged in June and July.

After recording nest number and bore diameter, nests were split open lengthwise with a chisel. Total bore depth, non-reproductive spaces (basal space, vestibular spaces, associated caps, nest plugs, and indentation) were measured with the cells intact. Each cell was then removed and measured from the base of the cell to the position of the outermost leaf in the cell cap (Fig. 5). Cell lengths measured after emergence are likely to be somewhat more variable than cell lengths measured before cell emergence, because emergence damages the cell cap. Thus it is sometimes difficult to determine where the edge of the cell cap starts.

The nest number that is written on each nest includes information on the site where the nest was created, so nest architecture measurements of pre-1988 nests were not blind to site. We doubt that knowledge of the nest site affected our measurements. However, in response to reviewer concern, our measurements of the 1988 - 1990 nests were made blind to site. Before nest measurements were made, students who did not measure nests spent a day crossing out nest numbers and replacing them with a random number independent of site. A data base not available to the nest measurers recorded the original nest number, and the random code number assigned to it. Nests were then measured without knowing at which site they were constructed. After all measurements were complete, the random number was associated with its original nest number, including site.

Since more than one person measures nests, we attempt to divide the nests equally by site and date of nest initiation among all measurers. Thus individual biases in measurement are distributed evenly between sites and dates. In addition, in 1987 thirty-nine M. relativa cells were re-measured to determine within- and between-individual measurement error. Twenty cells were measured three times by each of the four individuals measuring nests. An additional 19 cells could only be measured 1 or 2 times by each measurer, because they were damaged by the multiple measurements. Similar experiments were repeated in 1990 and 1991, with 3 measurers and 39 M. inermis cells from nests constructed in 1989 and 1990. Each cell was measured 3 times.

Emergence Data

Nests created in 1985 were checked daily in the spring of 1986 for bees that had emerged from the nest and were in the tubes. For nests created in subsequent years, after measurement in the spring, cells from which nothing had yet emerged were placed in individual plastic culture tubes or 2 oz. transparent plastic "Solo" rearing dishes, and labeled with nest and cell identification numbers. In 1987 and 1988 tubes were kept in the Crystal Falls Laboratory at room temperature (approx. 68°F) until emergence. However, 60hz EM fields are relatively high in Crystal Falls due to the presence of numerous power lines. In the laboratory, electric lights and wiring in the walls also create relatively high EM fields (ELF Communications System Ecological Monitoring Program: Electromagnetic Field Measurements and Engineering Support - 1990). Therefore, beginning in 1989 unopened nests and rearing tubes were kept at a holding site constructed by the ELF Small Mammal and Bird Project in woods 5 miles south of Crystal Falls. Nests were brought to the Crystal Falls lab only briefly for measurement. There they spent up to 6 hours outside the house where 60 hz fields were low, and no more than 2 hours in the lab for measurements. In addition, starting in 1990, measurements were made in wire mesh Faraday cages constructed by IITRI to minimize exposure of developing bees to electric fields (Fig. 6). Just before and just after measurements, nests and cells were stored in another Faraday cage on the front porch of the Crystal Falls Lab (Fig. 7).

After nest architecture measurements were complete, cells in tubes were returned to the holding site. Cells were checked daily for emergence. In all years, date of emergence, species, and sex of offspring were recorded. Live weights were also obtained for most bees from 1988 - 1990 nests (see below).

Some bees were saved for dry weight measurements (see below) and identification. Bees were identified by G. Dahlem, V. Scott, and K. Strickler based on Mitchell (1962), and by comparison with reference specimens provided by T. Griswold, ARS Bee Laboratory, Utah State University, Logan, Utah.

The remaining adult bees were released at the sites where their nest had been constructed the previous summer. The Faraday cages mentioned above are intended to insure that released bees were not affected by 60 hz electric fields when nest architecture measurements were taken. Effects of 60 hz fields might be mistaken for (or might mask) effects of the ELF antenna's 76 hz fields, and affected bees might alter the genetic makeup of natural populations. Parasites were collected and not released. Also, F2 nests that had overwintered at C5 were not released at the research sites.

Cells that showed no signs of emergence were opened in August (1986-90 nests), or when the nest was measured (1985 nests). Contents were recorded to indicate at what stage mortality had occurred.

Offspring Weights. Whenever possible, two or three bees from each 1986 - 1990 *M. relativa* nest were saved for dry weight measurements and for confirmation of species identification. In 1988-91, *M. inermis* individuals from 1987-90 nests were similarly saved for dry weight measurements. Dry weight may be a more appropriate measure of parental investment per offspring than is cell length. Dry weight depends directly on the amount of provisions in the cell (see introduction, p. 2), and provisioning the cell typically takes much more time than constructing a cell. A larger cell with more leaves may have less provisions and thus yield a smaller offspring than a smaller cell with more provisions, which cost more in time and energy to gather than the leaves.

Some authors (eg., Cane, 1987) and one of our reviewers have suggested that measurement of hard body parts is a better indicator of body size than is weight, although the two are correlated (Cane, 1987). Field collected bees, which vary in age and foraging status, may be especially variable in weight. Since bees in this study were collected within hours of emergence without being released, their crops were empty. Thus much of the variability in weights that would be expected from a sample of field collected bees was eliminated. Measurement of hard body parts may still be a better measure of body size, but since we have weight data for our bees from a number of years, since it is relatively easy for us to make weight measurements, even in the field, and since we would have to remeasure many pinned specimens to get measurements of hard body parts, we prefer to continue taking weight measurements at this time. We will, however, try to measure a sample of bees to see how closely correlated dry weight is with measurements of body parts such as intertegular distance.

Weights were obtained by drying bees in a desiccator over P_2O_5 to constant weight. Constant weight was defined as two weights taken 48 hours apart that were within 0.5mg of each other. The lower of these weights was used in analyses.

Offspring sex, expected sex of a cell, and sex ratio. Previous analyses indicate that the offspring's sex contributes significantly to variance in cell length and leaves per cell (1989 and 1990 Annual Reports). However, the sex of the offspring was known only for a small proportion of the cells, since many offspring die in the larval and prepupal stages, which can't be sexed. Furthermore, parasites emerge from some

cells rather than M. inermis or M. relativa. In an attempt to increase our sample size, we create a new variable in our data set that indicates the expected sex of a cell. We can predict the expected sex for many of the cells that did not have a bee emerge. Emergence data for 1987-1989 nests indicate that when a nest contains females, they are almost always in inner cells relative to cells containing males. Very few males have ever emerged from cells that were deeper than a female cell: only 4 male M. relativa and 7 male M. inermis in 1987, and one male M. relativa and 9 male M. inermis in 1990. Therefore, cells of unknown sex deeper in the nest than a cell with a female offspring can be assumed to be female. Conversely, cells with unknown sex that follow a male cell can be assumed to be males. Similar deductions have been used in analysis of sex ratio in other studies of trapnesting bees and wasps (Cowan, 1981; Sugiura and Maeta 1989).

The expected sex of a cell is the predicted sex of the cell when sex can be deduced, or the actual sex when sex is known. In statistical analyses where female and male cells are treated separately, expected sex increases the number of cells that can be included in the analysis by 2.6 fold for 1985 M. relativa, by 2.4 fold for 1985 M. inermis, by 1.3-1.6 fold for M. relativa in subsequent years, and by 1.2-1.8 fold for M. inermis in subsequent years.

Expected sex of a cell is a useful variable in analyses of cell length and leaves per cell. However, it is not a good variable to use in estimates of sex ratio of the population. This is because expected sex cannot be deduced in nests that have only a single dead cell, or in nests that have no emergence in the innermost cell and only males in subsequent cells. Since the innermost cell has the highest proportion of female offspring, using expected sex of a cell to estimate sex ratio will bias the sex ratio toward males. Instead, we calculate two estimates of sex ratio. First, the "secondary" or actual sex ratio is the ratio of male to female adult and pupal offspring, which could be sexed with certainty. The "primary" sex ratio is the sex ratio that would have been produced if all cells had yielded an offspring. Primary sex ratios were calculated according to the method of Frolich and Tepedino (1986). Cells of unknown sex were assumed to contain males and females in the same proportions as cells of known or expected sex for a given cell position. The unknown cells at each cell position were multiplied by the proportions of known males and females, and these numbers were summed over all cell positions and added to the cells for which actual or expected sex was known.

Leaf Counts

The number of elongate leaves that were used to construct a cell was determined for 1985-1990 M. inermis cells and 1986-1990 M. relativa cells that were still in good condition once emergence was complete. Leaves lining M. inermis cells overlapped, but were easy to tease apart and count. Leaves lining M. relativa cells were smaller, and were fastened together so that a microscope was often needed to determine where one leaf ended and the next began. When in doubt, leaf counts for M. relativa cells were not recorded.

Data Entry for Nest Architecture, Emergence, and Leaf Count Data

Nest architecture measurements, emergence records, and leaf counts are recorded manually in the spring and summer on data sheets for each nest. In the fall, these data are typed into an R-Base file on a Zenith personal microcomputer, where an initial check for errors is made. The R-Base file is then down-loaded to the VAX 11/730 computer (VAX/VMS operating system) in the Department of Entomology at MSU. Here they are checked further for errors, and loaded into several files in INGRES, a relational data base management program on the VAX. Finally, relevant subsets of the data are transferred from INGRES to SAS data files for statistical analysis.

Nest Activity

One or more observers have gathered data on behavior of individual bees at the nest every year since 1983. In the 1986 Annual Report, we decided to focus on the collection of round pieces of leaf (LO trips) used in capping a cell. Analysis (1986 Annual Report, p. 20-21) suggested that this was the most consistent of the three main behaviors in nest construction (collection of pollen, collection of elongate leaves for cell lining, and collection of round leaves for cell caps). LO trips probably involve fewer extraneous behaviors such as sunning or taking nectar than do pollen or elongate leaf collecting trips. Thus residuals for the transformed duration of LO trips could be normalized for statistical analysis. Consistency in LO trip durations probably results from the necessity to cap the cell rapidly to avoid parasitism after laying an egg.

Prior to 1987 each observer watched a single bee for several days in succession, until the nest was complete. This protocol generated a great deal of information on the variability in behavior within a bee, but less information on between-bee variability. In 1987 - 1991 field seasons we maximized the

number of bees timed per day, rather than timing one bee for long periods of time. Observers became adept at locating a bee that was about to lay her egg, and were able to focus on timing the first few LO trips that the bee made after laying her egg. Generally, we tried to time 5 such trips in succession before searching for another bee that was about to collect LO leaves. Occasionally the bee would complete a cap in fewer than 5 timings. The observer sometimes would time more than 5 LO trips if no other bees were active. Number of trips timed for a bee on a given day ranged between 1 and 18. In 1987 we did not try to record the number of LO trips that the bee made before we began timing. Our 1987 analysis suggested that this "trip rank" number is important (1987 Annual Report), because LO trips tend to increase in duration with each successive trip. Thus, during the 1988-1991 field seasons we attempted to record this number when timings were made. Only LO durations for which this trip rank order was known are used in the current analysis. Furthermore, no more than the first three trips are included in statistical analysis, because this minimizes the variability in the duration of a given bee's cell capping trips.

During the 1987 - 1991 field seasons, four observers were rotated between sites every 3 to 4 days, so that biases between observers would be distributed evenly between sites and dates. On a given day, two observers visited a control site and two an experimental site.

Prior to 1987, the duration of LO trips was determined by using a watch to record the hour, minute, and second that the bee left the nest and returned to the nest. Since 1987, we have used portable Tandy 102 computers that are programmed as event recorders. When the program is activated, the observer is prompted for information on the nest number and site, and some weather data (see below). The program automatically numbers the observed activities in sequence. Hitting the space bar records the time to the nearest second at which the bee leaves the nest or returns to the nest. A single letter code is used to indicate what cargo (e.g., LOs), if any, the bee brings back to her nest. An editing feature allows the observer to correct errors made during the timings, or to delete times that result from hitting the space bar inappropriately. These data were down-loaded to a Zenith personal computer at our field headquarters, and later transferred to an INGRES data base file on the VAX computer in the Department of Entomology at MSU. Duration of each trip was calculated in INGRES by subtracting the time when the bee left the nest from the time when the bee returned.

Weather Data

Because behavior of insects is often affected by such environmental factors as temperature and wind speed, foraging trip durations might be correlated with weather conditions. Some weather data were recorded in the event recorders as each bee was timed during the 1987-1991 field seasons. This included sun conditions (sunny, partly cloudy, cloudy, rain), temperature in the shade on the same shelf as the bee's nest, shading of the block in which the bee's nest was found, relative humidity calculated with a sling psychrometer, average wind speed and speed of wind gusts measured with a Dwyer Portable Wind Meter (hand held). These weather data are downloaded from the Tandy computers to the Zenith, and then to an INGRES file on the VAX computer (as described above for LO durations). However, lack of time due to problems with the VAX computer have delayed us in adding weather data to our SAS data set.

Data on long-term trends in temperature and precipitation were also obtained from the ELF Herbaceous Plant Cover and Tree Studies project, based at MTU. Dr. Hal Liechty of the MTU project kindly provided us with an asci file of daily summaries of average, 3 hr. minimum, and 3 hr. maximum air temperatures, and total daily precipitation. Ambient monitoring of air temperature and precipitation (among other variables not of interest to us) takes place at MTU's Red Pine Plantation sites: a treatment site under the ELF antenna, 10 miles North of our F1 site; and a control site 9 miles south of Crystal Falls. Despite the distance between the MTU sites and the sites that we are using in the Native Bee ELF project, major climatic trends and differences between years in temperature and precipitation are representative for the region. Climatic trends correlate with floral resources and thus with bee population size, cells per nest, offspring weight, and percent mortality. For further information on the MTU ambient monitoring system, see Appendix B of the 1985 Herbaceous Plant Growth and Tree Studies Project Annual Report.

Description of sites

Figure 8 shows the location of the study sites relative to the ELF antenna. Three sites are located on Copper County State Forest Property in Dickinson Co. in the Upper Peninsula of Michigan. A fourth site (C5) is located in Iron Co. on property leased by the Michigan Department of Natural Resources to Champion Paper Company. Permission to use these sites is gratefully acknowledged.

The C5 site is located 6.7 km south of Route 69 and about 0.8 km west of Camp 5 road in Iron County, Michigan (Township 42N, Range 31W, Section 14). The area has recently been logged, and nearby forests continue to be logged within a km. of our hutches. An abandoned railroad bed runs N-S through the site. Camp 5 creek runs through the site, creating a cut-over swamp and flood plain. Two hutches are located at the south edge of this flood plain, and two hutches are located in an open depression next to the abandoned railroad bed. Until mid July 1990 the last two hutches were at the north edge of the flood plain, north of C5 creek. This site was not close to Cirsium palustre populations, and attracted few M. inermis.

In spring, 1990 we discovered that a beaver had made a dam across C5 creek, making access to the north hutches impossible by crossing the creek next to the railroad right-of-way. For several months we walked around the edge of the flood plain to reach the north hutches. However, as the water behind the dam increased, the flood plain turned into a shallow lake. On July 25, when water was within 10 feet of the north hutches, we moved them to the south side of C5 creek. The hutches were relocated to an elevated site about 20 feet west of the railroad right-of-way, near a large patch of Cirsium palustre. The bee population that uses nests at these hutches should be the same as in the original location. However, being closer to flower populations, more bees are nesting at the new location.

Nearby woods consist primarily of Populus tremuloides, with occasional Larix decidua, Picea glauca, and Prunus serotina. Shrubs in the vicinity include Alnus rugosa, Vaccinium sp., Salix sp., Spirea alba, and Rubus allegheniensis. Herbaceous plants include Cirsium palustre, Fragaria virginiana, Hieracium spp., Trifolium spp., and Solidago spp.

The CL site is located about 1.7 km north of Route 69 on the east side of County Line Road, in Dickinson Co., (Township 43N, Range 30W, Section 19). Logging continues within a km or so of the hutches. This site has very sandy soil and is the driest of our sites. Hutches are located at the edge of clearings in Populus tremuloides woods, with occasional Acer saccharum, Betula papyrifera, Abies balsamea, and Pinus resinosa. Two hutches are adjacent to a patch of trees north of a logging road through the sandy clearing. Two are east, and two west of a marshy, low lying area south of the logging road. Hieracium aurantiacum carpets the ground at this site in June, if rain has been sufficient. Bracken fern is common near the east hutches which are in a shadier location than the others. Other flowering plants that are common in the area include Cornus canadensis, Campanula rotundifolia, Fragaria virginiana, Rubus spp., Solidago spp., Vaccinium spp., and Prunus pensylvanica. Small patches of Cirsium palustre grow in the marshy area south of the logging road. Epilobium angusti-

folium was abundant at this site in 1983, but decreased rapidly thereafter. Only a couple of stems were present in 1987, and none in subsequent years.

Low numbers of M. inermis nests at the CL site, especially in 1986, prompted us to transplant about 90 Cirsium spp. plants (a common pollen source at other sites) to the CL site in April, 1987 and 50 plants in June 1989 to try to increase the numbers of M. inermis that nested there.

The F1 site is located south of Turner Road, and north of the Ford river, 20 km east of Channing. (Township 43N, Range 29W, Section 14). The hutches are located at the edge of a flood plain, bordered on the north by a Red Pine plantation, and the south by vegetation along the river consisting of Populus balsamifera, Populus tremuloides, Fraxinus nigra, and Alnus rugosa. A corridor has been cut through the pine plantation to allow for the construction of the ELF antenna, which runs NE-SW through the site. Two hutches are east of the antenna, at the north edge of the flood plain. Two are a similar distance west of the antenna. Two are in a shady clearing further west of the antenna at the northwest edge of the flood plain. Flowering plants near the hutches include several species of Cirsium, especially C. palustre and C. arvense, Urtica dioica, Solidago spp., Hieracium aurantiacum, Hypericum perforatum, Aster spp., Rubus spp., Humulus lupulus, Linaria vulgaris, and Vaccinium spp.

The F2 site is located about 0.8 km south of the Ford River and the F1 site, along the clear cut for the ELF antenna. The soil is sandy. Three of the hutches are located on top of a hill at the edge of the clear cut west of the antenna, and along an old logging/hunting trail running west from the antenna. Three hutches are located in a valley east of the antenna. Nearby woods consist of Populus tremuloides, with occasional Picea glauca, and Pinus resinosa. Centaurea maculosa has increased since 1983 until it is now the most abundant flowering plant on the hill. Also abundant are Cirsium palustre, Fragaria virginiana, Hieracium aurantiacum, Coronilla varia, Prunus virginiana, Rubus idaeus, Solidago spp., and Trifolium spp.

Floral Resource Levels

We noted in the 1989 Annual report that some aspects of the biology of our study populations of M. relativa and M. inermis, such as number of cells per nest and population sizes, seem to be related to the availability of floral resources. Floral resources in turn are affected by climatic variability such as temperature and precipitation. However, no direct measures of floral resources were made between 1987 -1989. In

order to obtain direct evidence of the relationship between weather, floral resources, and population size, in 1990 we monitored inflorescences in bloom for three different species in the Compositae at all four of our sites. These species are thought to be important pollen sources for the two Megachile species under study, especially for M. inermis. They were Hieracium aurantiacum, Cirsium palustre, and Centaurea maculosa. Monitoring was continued in 1991, though at a reduced level because of time constraints.

In this report we present the results of monitoring of C. palustre. This plant is visited by M. inermis, but not by M. relativa. We counted every plant in five discrete patches of C. palustre (one each at CL, F1, and F2, and two at C5). The patches generally consisted of small clearings near one pair of hatches at each site. An additional sample of C. palustre was made at C5 (C5-S), by establishing a 50m transect in a large patch of thistle, and counting the number of plants that intersected the transect. The identical thistle patches and transect were sampled in both 1990 and 1991, so the number of blooming plants can be directly compared between years.

In addition to counting plants, the total number of thistle capitula (inflorescences) on each plant in the patch or transect were counted midseason, in late July or early August. Total capitula counts included all capitula currently in bloom, setting seed, or in bud stage. Buds were counted only if they were pink at the tip, indicating that they were large enough to successfully bloom. By mid season, some buds are too small to bloom before the plant senesces. Some of the pink-tip buds that were counted may not have bloomed successfully either, but such counts should give a consistent relative estimate of capitula per plant between years and sites. To insure consistency, the same researcher (KS) made total capitula counts in both years.

When other patches of thistle were present nearby, a rough estimate of additional thistle plants was made by counting stems in bloom.

ELF Antenna Operations

In interpreting results of this project it is important to know the pattern of antennal operations in past years (Table 2, Fig. 9, 10). The Michigan Transmission Facility (MTF) began testing at 10% power (15 amperes) periodically during the summer (March - October) of 1986, and with increasing regularity from May - November, 1987 and January - July, 1988. Starting July 6, 1988 and lasting until May, 1989, testing continued at 50% power (75 amperes).

In June 1989, the ELF antenna began testing periodically on full power (150 amperes). Continuous full power operation did not begin until October, 1990.

Magnetic fields to which the bees were exposed are plotted in Figs. 9 and 10, based on measurements provided by IITRI (Technical report, ELF Communications System Ecological Monitoring Program: Electromagnetic Field Measurements and Engineering Support). Unlike electric fields, magnetic fields are not blocked by trees, hutches, or trap nests. Thus magnetic fields are more likely than electric fields to affect the bees. Fig. 9 plots Gauss-Hours of magnetic field exposure of foraging bees during June, July and August. A bee sitting directly under the antenna for the entire month would experience the maximum exposure plotted. A bee sitting on the hutch farthest from the antenna at the F2 site would experience the minimum exposure plotted (stippled bars). Most bees at the experimental sites would experience intermediate magnetic field exposures. Figure 10 plots Gauss-Hours of magnetic field exposure of bee prepupae in overwintering boxes between Sept. and April at the two experimental sites. Exposure of the prepupae at the F2 site was approximately twice that of the F1 site in 1989. Insufficient data for 1990 and 1991 nests were available at the time of this writing, but magnetic field exposures were probably very similar to 1989 exposures.

In this year's analyses, 1989 - 1991 are considered full power years. Exposures during the intermediate years of 1987-1988 were considerably lower than in subsequent years, and analyses did not show any effect of experimental and control areas on nest architecture and activity. Therefore, we either pool 1987-1988 with pre-treatment years, or analyze them separately as "low-treatment" years.

Statistical Methods

The General Linear Models (GLM) procedure on SAS (Version 5) was used to analyze sources of variability in cell lengths (both species), leaves per cell (*M. inermis*) and LO trip durations (*M. inermis*). Because cell lengths or leaves per cell within a nest, and/or LO durations within a cell capping bout, are autocorrelated, we calculate a mean cell length or leaf number for each nest, or a mean LO duration for the first three LOs in a cell capping bout. GLM analysis was accomplished on these means. In this model, the error variance consists largely of between-nest variability.

In GLM analyses, means of LO duration per cell capping bout were weighted by the number of trip ranks (1-3) that were used to calculate the mean. However, means of cell lengths and

leaves per cell were not weighted by number of cells per nest. Rather, cells per nest was a covariate in the models of cell length and leaves per cell.

Incomplete cells (without a cell cap) were not included in calculations of mean cell length for a nest. Not all cells could be measured in some nests, because some of the cells were destroyed by emerging bees. This may have biased the mean cell length of the nest, if most of the unmeasurable cells were inner cells or outer cells. However, different nests with unmeasurable cells are expected to have different biases, and thus the biases should cancel each other. Thus no attempt was made to adjust for such biases.

In all analyses, experimental vs. control areas (Exp), sites nested in experimental and control areas (Site[Exp]), observers or measurers nested in year, complete vs. incomplete nests, and early vs. late season nests were treated as fixed class variables. Number of cells per nest, nest diameter, and bore depth were covariates in the analysis of cell lengths and leaves per cell. Date of the trip was a covariate in the analysis of LO trip durations. Time was tested as a second order covariate in this analysis. Significance would indicate that LO durations are faster (or slower) during the middle of the day, as might be the case if LO durations are correlated with temperature. Type IV mean squares were calculated in all GLM analyses. This model is invariant to the ordering of effects in the model.

The mean square (ms) of Site[Exp] was used as the error term for testing the significance of Exp, and interactions between Exp and other variables in the models. This insures that differences between experimental and control areas are significant only if they are greater than any differences between the sites within the areas. The ms of measurer[yr] was the error term for testing year, and interactions between year and other variables in the models. This insures that differences between year are greater than the differences between measurers who took data in any given year. For *M. inermis*, the interaction between year and bore depth was included in most models because depths of the largest diameter bores varied between years.

If significant, the interaction term Exp*Yr indicates that one area has shown a greater change between years than the other. Ideally this interaction term will not be significant before the antenna is operational. If the Exp main effect is significant but not the Exp*Year interaction, then we know that there are intrinsic differences between experimental and control areas that have nothing to do with the antenna. If the year main effect is significant but not the Exp*Year interaction, then we know that there are differences between years

that have affected both experimental and control areas equally, as would be the case for climatic changes between years. If the Exp*Year interaction is not significant before the antenna is operational, but it becomes significant after the antenna is operational, the antenna is a likely cause of the difference. If the interaction term is significant before the antenna is operational, then the problem of detecting differences between experimental and control areas is much more complex.

In cases in which sample sizes (ie, number of nests) were small in some years at some sites, the data for pre-operational years were pooled and compared with the data for pooled low power and pooled full operational years.

A Shapiro-Wilk statistic for $N < 51$ and a Kolmogorov D statistic for $N \geq 51$ in the Univariate procedure of SAS were used to test for normality of residuals in models of LO trip durations, cell lengths, and leaf counts. The data are tested against a normal distribution with mean and variance equal to the sample mean and variance. The significance level used in these tests was 0.05. Ln or lnln transformations of the data were sometimes required to meet the assumption of normality of residuals. When used, such transformations are discussed in the Results section. In some cases where residuals were significantly different from normal, a plot of the residuals revealed that a few outliers or a slight skewness of the data were responsible. In these cases the GLM results are likely to be robust, so they are reported.

Minimum detectable differences between experimental and control areas (Exp) were estimated with a modification of Cochran and Cox's (1975) formula (Zar, 1984 p.135, 137, 260). Sample size used in this formula was the harmonic mean of the treatment and control area sample sizes (Zar 1984, p. 137) based on numbers actually collected each year for the control and experimental sites. The value of population variance s^2 , used in calculating minimum detectable differences was the Site[Exp] mean square because this mean square value is used as the error term for testing Exp and Exp*Year, and thus is the denominator in the F test of the GLM analysis (Zar, 1984 p.260). Values of α and the power of the test ($1-\beta$) were 0.05 and 0.9 unless otherwise stated. We would prefer to test for the minimum detectable difference for the Exp*Year interaction, but we do not know how such a test would be made.

A two-way classification model II ANOVA was used to analyze within- and between- measurer components of cell length variability (Sokal and Rohlf, 1969, p.313). In this analysis, measurer and cells measured were random effects. The error mean squares gives within-measurer variability.

The Categorical Data Modeling (CATMOD) procedure on SAS was used to compare distributions of cells per nest. This statistical program fits linear models to functions of response frequencies for discrete data; i.e., it is an extension of the GLM procedure for continuous data that was used in the analyses of cell lengths. The program uses a Wald statistic (which approximates a chi-square distribution for large sample sizes) to test hypotheses about linear combinations of the parameters in the model. As with the GLM tests previously described, we tested for significance of experimental vs. control areas (Exp), Sites nested in Exp areas (Site [Exp]), Year, the interaction between Exp and Year (Exp*Year), and early vs late season. The level of significance of all tests was 0.05.

A log transformation of number of thistle capitula per plant was used when comparing thistle patches at different sites and in different years (1990-1991) in a two-way analysis of variance.

Proportion of nests oriented in a N-S vs. E-W direction was tested in a log-likelihood ratio contingency table analysis (Zar 1984, p. 67-68) to determine if the pattern of directions of nests was the same for all years at a given hutch set. If consistency was found between years, then data for a hutch set were pooled over years, and tested against other hutch sets at a given site. If the ELF antenna was affecting choice of nest direction, then the contingency tests should be significant at some or all of the hutch sets at experimental sites, but not at the control sites. In addition, a change in nest orientations should occur some time between 1988 and 1990. Prior to the change, nest orientation should have been consistent over pre-operational years. Similarly, any changes that occur as a result of ELF EM fields are expected to continue during subsequent operational years.

Proportion of mortality in the overwintering prepupal stage was tested with the ANOVA procedure in SAS in a randomized block design. Proportions were transformed using a Freeman and Tukey arcsine transformation (Zar 1984, p. 240):

$$P_{ft} = \frac{1}{2} \left(\arcsine \sqrt{\frac{X}{(n+1)}} + \arcsine \sqrt{\frac{(X+1)}{(n+1)}} \right)$$

Two additional transformations were tried in ANOVAs. These included Ascomb's arcsine transformation (Zar 1984, p. 240), and the Probit of Rao's transformation (Rao 1965). Since all three transformations usually gave very similar results, we

report here only the Freeman and Tukey arcsine transformation, which is preferable for small proportions. Analysis using this transformation usually had the greatest r^2 .

Resulting values were analyzed in an ANOVA to determine whether Site[Exp], Year, Exp, and Exp*Year, contribute significantly to variability in proportions. The ms of Site[Exp] was used as the error term for testing the significance of Exp, and interactions between Exp and other variables in the ANOVA. Calculation of proportion of prepupal mortality was complex, and will be explained in the results section.

CATMOD analysis was used to compare prepupal mortality for 1990 nests moved from F2 to C5 to overwinter. Nest construction site, overwintering site, and nest direction were tested in the model.

IV NEST ARCHITECTURE RESULTS

Climate, Floral Resources, and Bee Abundance

Table 3 and Figs. 11 and 12 summarize the number of nests of the two species for which we have data on cell lengths, and an estimate of the number of complete nests created in 1991. Some 1985 M. inermis nests were not included in our measurements because Dr. Fischer, who initiated this research project, used them in experiments on diapause. The 1983 nest architecture data were finally incorporated into our analysis this year. Data for the entire season are available only for the F1 site, and only at two hutches at this site. Some information is also available for late season nests at CL and F2 in 1983. Unfortunately, data for 1984 nests were either not taken, or were unreliable due to personnel problems at the time. Nests constructed in 1991 will be measured in the spring of 1992, so number of nests are estimates for this year.

Between 1985 and 1991 M. relativa has produced similar numbers of nests at all sites (32-128), with no consistent differences between control and treatment sites (Fig. 11). In contrast, M. inermis produces a consistently lower number of nests at the control sites, especially CL, than at the experimental sites (Fig. 12). Furthermore, M. inermis nest numbers at all sites were lower in 1986 and 1988 (except for F2 in 1988) than in other years. We believe that this reduction in the bee population was caused by a reduction in floral resources due to low rainfall, especially early in the season. Fig. 13 plots cumulative precipitation for 1986 - 1989. The first nests of M. relativa and M. inermis are indicated on the plots, along with first bloom (when known) of two important pollen plants for the bees: Hieracium aurantiacum, and Cirsium palustre. In 1986 and 1988, bee nesting and plant flowering began when less than 4 inches of rain had accumulated, whereas in 1987 and 1989 the same events began after 4-5 inches of rain had accumulated. Although no quantitative measures of numbers of flowers in bloom were made, we did note that H. aurantiacum, which normally creates a carpet of orange flowers during peak bloom, produced very few capitula (inflorescences) in both 1986 and 1988. Thus, newly emerged bees beginning their first nests may have been faced with a dearth of floral resources. M. inermis numbers were not affected as strongly at the F2 site in 1988 because of a substantial population of Centaurea maculosa that bloomed in late July, in spite of the drought and hot temperatures. This plant was not as abundant at the F2 site in 1986. It is absent from the CL and F1 sites, and was only found in low numbers at the C5 site in 1988.

Although monitoring of plant populations did not take place during the drought years of 1986 and 1988, some infor-

mation is available about the state of plant populations in 1990 and 1991, both years with sufficient rainfall and plentiful bee populations. Numbers of C. palustre plants that bloomed in 5 patches and along one transect at the sites are presented in Fig. 14 along with the geometric mean and standard deviation of number of capitula per plant at the sites each year. Total numbers of plants in bloom were similar between years, or somewhat higher in 1991 at most sites. Abundant additional thistle stems bloomed at all sites except CL, where only one small additional patch of thistle was located. Number of capitula per plant varied considerably, but it was significantly lower at CL-E than at any other site (ANOVA SS for site=18.8, df=5, F=41.38; P=0.0001; Tukey's Studentized Range Test, MSE=0.09 df=420 P<0.05). The low M. inermis populations at the CL site relative to the other sites is probably explained by the small number of thistle stems and few capitula per stem at this site relative to other sites.

Monitoring of floral resources has taken little of our time and provides some quantitative data that explains differences in bee populations, particularly between sites. We plan to monitor plant populations again in 1992. If 1992 happens to be a drought year, quantitative data on low plant and bee populations will provide support for our hypothesis that drought conditions reduce bee populations because of reduced floral resources.

Cumulative numbers of nests constructed over the season at the four sites are presented by year in Fig. 15. Final nest numbers are underestimates for M. inermis in 1985, as explained above. There are differences between sites and years in dates of first and last nest construction, and in rates of nest construction through the season. M. inermis generally started nesting later than M. relativa. Both species began nesting earlier in June in 1987 than other years. M. relativa began nesting later in 1985, 1989 and 1990 than in other years. Accumulation of nests was slower at most sites during the drought years of 1986 and 1988 for M. inermis. This was not true for M. relativa.

The midpoint of the season varied between years, sites and species. Vertical lines on Fig. 15 indicate the date on which 50% of the nests had been started for each species and year. This date was the last date on which nests were classified as early season nests. Early season ended later for M. inermis than for M. relativa in all years except 1988.

Hypothesis 1: The average length of cells for each offspring, and/or the average number of cells produced per nest is unchanged by exposure to ELF electromagnetic fields.

M. relativa

Mean cell length was calculated for each nest, and used in GLM analysis. If ELF EM fields have an effect on cell lengths we would expect to see mean cell lengths changing for the treatment sites but not for the control sites starting in 1989. This does not seem to be the case. There are no consistent trends of differences between experimental and control areas, either in pre-operational years, or under full power in 1989-90 (Fig. 16). Indeed, the means for control and experimental sites overlap considerably both before and after the antenna became operational. Dashed horizontal lines bracketing the means for each year in Fig. 16 indicate upper and lower limits to the minimum detectable differences between control and experimental means for that year. Difference between actual means was always less. GLM analysis (Table 4) confirms that neither Exp nor Exp*Year contribute significantly to variation in mean cell length. Therefore, there does not yet appear to be any influence of ELF EM fields on cell length for this species. We will measure cell lengths for one more year (1991 nests) of continuous full power EM fields to see if these results are confirmed.

Cells from the CL site tended to be slightly but significantly larger than cells from other sites, and cells were significantly smaller in 1985. This significant year effect is probably a consequence of the fact that bees emerged before cells were measured in 1985. Cell bases are rounded before the bee emerges, (Fig. 5), but once the bee chews through the cell in front of it, the cell base is truncated, and the cell measurement is slightly reduced.

Overall, the mean cell length per nest was 11.1mm for M. relativa. The model accounted for only 16% of the variance in mean cell lengths (see r^2 in Table 4). Between nest variability (error ms) is large. Cell lengths decreased slightly as diameter increased. In addition, cell length decreased as the number of cells in a nest increased. This may reflect in part a decrease in cell length as cells get closer to the nest entrance. Nests with few cells have large inner cells, so mean cell length is large. Nests with many cells include small cells near the nest entrance, so mean cell length will be lower than for nests with few cells. Cell lengths in early season nests and in complete nests tend to be larger than cells in incomplete or late season nests. This seems contrary to the effect of cells per nest, because early season and complete

nests tend to have more cells per nest than do late season and incomplete nests.

Past analysis indicated that expected sex contributes significantly to the variation in cell length. Therefore, mean length of cells expected to have female offspring, and the mean length of cells expected to have male offspring were analyzed in separate GLM analyses (Tables 5, 6). Neither Exp nor Exp*Year were significant in these analyses. However, separating cells by expected sex of offspring increased the proportion of the variance accounted for in the models. The model explained the highest proportion of the variance (25%) when only cells expected to have female offspring were included in the analysis, even though diameter, cells per nest and early vs. late season nests were the only effects that contribute significantly to variability in female cell lengths (Table 5). Cells expected to have female offspring averaged 0.7mm larger than cells expected to have male offspring (11.6mm vs. 10.9mm).

In the 1987 Annual Report, we expressed concern that bore diameters of 5.5 mm might bias the sex ratio towards males, since most females in 1986 nests were in larger diameters. Therefore, we added some 6.0mm nests in 1988. Our fears proved to be unfounded (Table 7, 8) since 1987 nests had sex ratios as low or lower than in previous years. Higher male biased sex ratios were produced in 1986 and 1988, when drought reduced flower populations, than in 1987 and 1989, when flowers were more abundant. These results suggest that flower resource availability is more important than nest diameter in affecting M. relativa sex ratios. The results hold whether we consider secondary sex ratios (Table 7) or primary sex ratios (Table 8). In last year's annual report we predicted that 1990 nests would have a continued low sex ratio because of an abundance of flower bloom. Much to our surprise, the 1990 sex ratio was higher at three of the four sites than in 1988 or 1989. Factors other than flower populations are apparently important in determining sex ratio. Sex ratio could be tested as a dependent variable for effects of ELF fields. However, we have not tried to do so because of variability between sites and years. There do not appear to be any systematic changes in sex ratio at the experimental sites that could be attributed to ELF EM fields.

Within and Between Measurer Variability. As mentioned earlier, differences between measurers usually contributed to the variance in mean cell lengths. Mean cell lengths for individual measurers varied from 10.6mm (ND, 1985) to 11.4mm (KS, 1988, 1989; JR 1990) (Table 9). The range of means between measurers was greatest for 1986 cells, when four measurers were involved (0.6mm). It decreased considerably for 1987 cells

(0.1mm), but increased again for 1988 - 1990 cells (0.4-0.5mm).

In order to better understand the contribution of measurer differences to cell length variability, in 1987 39 M. relativa cells were measured up to three times by each measurer after the cell was originally measured. In an initial two-way model II ANOVA there was no significant interaction between measurers and cell measured. This indicates that although the mean cell length differed between measurers, the magnitude of the differences between cells was the same for all measurers.

The interaction and error variances were pooled by rerunning the ANOVA without including the interaction term in the model. This omission had the additional advantage that the residuals from the model were normally distributed, whereas with the interaction term the residuals were not normally distributed. Each person measured each cell an average of 2.55 times; this value was used to compute the relative contribution of within- and between- measurer variance to the total variance (Table 10). 75% of the variance was between cells, while only 25% was between and within measurers. Variance within measurers (15%) accounted for more of the measurer variance than did variance between measurers (10%). In this analysis the mean cell length was 10.5mm, and the overall coefficient of variation was only 3.6%, or a standard deviation of 0.4mm. Measurer variance accounts for 25% of the total variance, and thus 50% or the standard deviation = 0.2mm. In the full analysis, the overall mean cell length was 11.1mm with a CV of 7.6%, or a standard deviation of about 0.8mm. Thus, our analysis suggests that measurer variance accounts for about 0.4mm of the total variance.

M. inermis

As with M. relativa nests, mean cell length was calculated for each nest and used in GLM analysis. However, in some years, numbers of nests are very low at some sites (eg., 1 nest at the CL site in 1986 and 1988). Therefore, cell length data were pooled for pre-operational years (1985-1986), low power years (1987-1988) and full power years (1989-1990). Only nests with diameters greater than 9.5mm were used in the analysis. Also, separate analyses were conducted on cells with male and female offspring because the residuals are usually not significantly different from normal in such analyses.

If ELF EM fields have an effect on M. inermis cell lengths, we would expect to see mean cell lengths changing consistently for the treatment sites but not for the control sites as ELF EM fields increase. This does not seem to be the case. Control sites tended to have larger cells than Experimental sites

during all years, and changes when the antenna became operational were as great or greater for control sites as for experimental sites (Fig. 17). Variability within the control areas is great, so the difference between experimental and control areas is not expected to be significant. GLM analyses (Tables 11, 12) confirm that neither Exp nor Exp*Year contribute significantly to variation in mean cell length. Therefore, there does not appear to be any influence of ELF EM fields on cell length for this species. We will measure cell lengths for one more year (1991 nests) of continuous full power EM fields to see if these results are confirmed.

M. inermis cells- expected to have female offspring averaged 1.2mm larger than cells expected to have male offspring (16.5mm - 15.3mm). The models accounted for 32% of the variance in mean female cell lengths and 37% of the variance in male cell lengths. Parameters that contributed significantly to M. inermis cell length were very similar to those that were significant for M. relativa cell length. Cells from the CL site tended to be slightly but significantly larger than cells from other sites. Cell lengths decreased slightly as number of cells in a nest increased. Cells in complete nests tended to be larger than cells in incomplete nests.

As with M. relativa, differences between measurers (measurer [yr]) made a significant contribution to cell lengths. Cells measured by KS were larger than cells measured by other measurers (Table 13). In 1990 and 1991, 39 M. inermis cells were measured three times by each measurer after the cell was originally measured. A two-way random-effects model ANOVA will be used, as for M. relativa, to partition the variance within and between measurers and between cells. We have not completed these analyses as of this writing.

Sex ratios for M. inermis vary considerably between sites and years (Table 14, 15), and do not show an influence of climate and floral resources as sex ratios for M. relativa did before 1990. During 1985 and 1986, high sex ratios may have been an artifact of short bore depths (Stephen and Osgood, 1965). Because of the variability between sites and years, there do not appear to be any systematic changes in sex ratio at the experimental sites that could be attributed to ELF EM fields, so no analysis of the effects of ELF EM fields on sex ratio as a dependent variable has been attempted.

Offspring Weights. In the 1987 Annual Report we questioned the necessity to analyze the variance in cell volumes, because volumes are highly correlated with nest diameters. We suggested that the answer to this question depended on whether offspring weights correlate best with cell length or with cell volume. In last year's annual report we showed that bee weight

is unrelated to cell length or volume, and thus does not help us resolve the question of whether we should be analyzing variance in cell volume rather than cell length. Since the two measures are correlated, and since our analyses have thus far been on cell length, we decided to continue to analyze only cell length in the future.

However, we should be able to do a separate GLM analysis of bee weight as a dependent variable, just as we have analyzed cell length, for 1987-1990 bees. Such an analysis has not yet been done. It will add an additional hypothesis to our study: **Newly emerged bees exposed to ELF EM fields are the same weight as newly emerged bees not exposed to ELF EM fields.** We hope to be able to add this hypothesis in next year's annual report. Both live and dry weights of a sample of both bee species from 1987 - 1990 nests have been measured. Dry weights for bees from 1990 nests are still being measured as of this writing. Data from 1989 bees have been added to the computer.

Tables 16 and 17 present mean dry and live weights by sex, year, and site for M. relativa and M. inermis respectively. No statistics have been accomplished with these data. However, the means for M. relativa suggest that there are differences between years for both sexes, with weights reduced during the drought years of 1986 and especially 1988, when hawkweed did not bloom. There may also be differences between sites (eg., bees from CL tend to be smaller than bees from other sites). There do not appear to be systematic differences between experimental and control areas.

After weighing, the bees were pinned and identified. All of the small Megachile bees from 1986 - 1988 nests have been confirmed as M. relativa. The 1989 and 1990 bees will be identified after they are weighed and pinned.

Number of cells per nest

Number of cells per complete nest ranged from 1 to 12 for M. relativa. In a CATMOD analysis of cells per nest we used four categories to minimize the cases in which expected frequency was less than five. The categories were: nests with 1 or 2 cells, nests with 3 or 4 cells, nests with 5 or 6 cells, and nests with seven or more cells (Fig. 18).

There were significant differences in the distribution of number of cells per nest between Sites, Years, and Exp. However, the interaction between Exp and Year (Table 18) was not significant. Examination of Fig. 18 suggests why these parameters are significant. For example, nests constructed in

the drought year of 1988 tend to have fewer cells than nests constructed in 1987 (see analysis of contrasts, Table 18); CL and F2 have fewer cells per nest than do C5 and F1. In 1989 when the ELF antenna was fully operational, cells per nest at experimental sites did not show any obvious change as compared with control sites. Analysis of contrasts confirmed that experimental sites pooled between 1985 and 1988 are not significantly different from experimental sites pooled over full power years (1989-1990).

Similar patterns can be observed when early vs. late season nests are included in a CATMOD analysis. Two categories of nests were used: 1-4 cells, and 5-12 cells (Fig. 19, Table 19). This analysis indicated that late season nests usually have fewer cells than early season nests. The effect of season on cells per nest was different in different years (Year*Season interaction is significant. Compare 1987 and 1988). In addition, pooled 1985-87 nests are significantly different from pooled 1988-1990 nests. No significant change was observed, however, for experimental nests pooled for 1985-87 vs. 1988-90, or for 1985-88 vs. 1989-90. Such contrasts would be significant if ELF EM fields were affecting cells per nest.

Number of cells per complete nest ranged from 1 to 8 for M. inermis. The deeper the nest, the more cells can be constructed. Therefore, in analyzing cells per nest for M. inermis, we compare only 1987 - 1989 nests, when bore depth was routinely 140mm and only drill bits of 11mm were used to make large diameter nests. In all years, the experimental sites have more cells per nest than do control sites (Fig. 20), as confirmed by CATMOD analysis (Table 20) using two categories (1-4 cells or 5-7 cells). No significant Exp*Year interaction indicates no effect of ELF EM fields at experimental sites after 1989.

No significant differences between years for M. inermis suggests that, unlike M. relativa, M. inermis did not produce fewer cells per nest in the drought year of 1988. This is surprising, since one might expect lack of resources to affect a large species more than a small species. Apparently these two species responded differently to the drought: The small species produced more nests in 1988 than in previous years (Table 3), but with fewer cells per nest (Fig. 18) especially early season (Fig. 19) and with smaller offspring (Table 16). The large species produced fewer nests in 1988 (Table 3), possibly with smaller offspring (Table 17), but maintained a similar distribution of cells per nest as in 1987 and 1989, non-drought years (Fig. 20).

Early vs. late season was added to the catmod analysis for M. inermis (Fig. 21, Table 21). In this analysis, nests from 1987 and 1988 were pooled because of small sample sizes.

Season was significant, with more large nests produced early season than late season. Exp was significant, presumably because nests from the experimental sites, F1 and F2, had a greater proportion of large nests than do nests from control sites. Finally, Year*season was significant, suggesting that late season nests in 1989 had a greater proportion of small nests than did late season nests in 1987-1988. The Exp*Year*Season interaction was not significant, indicating that the fully operational ELF EM fields in 1989 and 1990 did not affect early or late season nests differentially.

Hypothesis 2. Bees exposed to ELF EM fields, and bees not exposed, will make nest plugs of the same thickness and will devote the same proportion of nest space to reproduction.

No test of this hypothesis has been attempted yet, although the data are available in our INGRES database. We have begun to create a SAS data set consisting of nest plug length, the sum of lengths of all reproductive cells, and the sum of lengths of basal spaces, nest plugs, indentations, and other non-reproductive space for M. inermis. The length of nest plugs will be tested first with M. inermis, since complete nests for this species usually have a solid, uninterrupted nest plug between the last reproductive cell and the nest opening. In contrast, M. relativa nests usually have empty vestibular spaces between two or more nest plugs (Fig. 1), and are thus more complex to analyze. Because nest plug lengths for M. inermis are skewed in distribution, we will consider categorical modeling of different length classes (eg. 5-20mm, 20-35mm, 35-50mm, >50mm). Somehow, we must take into account the number of reproductive cells in the nest, since the space left over for plug decreases as the number of cells increase, and the variance in plug length decreases as the number of cells increase.

In analyzing the proportion of space devoted to reproduction, we wish to compare the sum of reproductive cell lengths with total space in the nest used by the bee. The ratio of reproductive space to used space approaches 1.0 as the length of nest plugs and vestibular spaces decreases. We can test whether the distributions of this ratio for experimental and control areas are the same, using a Goodness-of-fit test.

Hypothesis 3. The number of leaves used to line a cell is unchanged when bees are exposed to ELF EM fields.

Although the number of leaves lining a cell is discrete data, we treat it as if it were continuous, and use the GLM procedure on the mean ln of leaves per cell, instead of a

CATMOD analysis. This should increase our ability to detect differences between control and experimental areas if any exist. Only M. inermis data have been treated this way, because the range of leaves per cell (6-36) is larger than the range (3-16) for M. relativa.

As with cell lengths, a mean of ln leaves per cell was calculated for each nest and used in GLM analysis. In some years, numbers of nests are very low at some sites (eg., 1 nest at the CL site in 1986, 1988). Therefore, data on leaves per cell were pooled for pre-operational years (1985-1986), low power years (1987-1988) and full power years (1989-1990). Only nests with diameters greater than 9.5mm were used in the analysis. As with cell lengths for this species, cells with male and female offspring are analyzed separately, because the residuals are likely to be not significantly different from normal.

If ELF EM fields were having an effect on leaves per cell, we would expect to see mean leaves per cell changing for the treatment sites but not for the control sites as EM fields increase. For these data, the experimental sites do show consistent changes over time (Fig. 22). For male cells, these changes are echoed by cells from the CL control site, but not by cells from the C5 site. The changes of CL leaves per cell suggest that ELF EM fields are not responsible for changes at experimental sites. GLM analysis (Table 23) confirms that the Exp*Year interaction is not significant for leaves per male cell. For female cells, the control and experimental sites have changed in different ways (Fig. 22). The greatest contribution to a significant Exp*year interaction for female cells are the control sites in 1985 (Table 22), rather than experimental sites in 1989-90. We conclude that ELF EM fields have no effect on leaves per cell for this species. We will count leaves per cell for one, possibly two, more years of continuous full power EM fields to see if these results are confirmed.

Male cells were constructed with more leaves (13.0) than female cells (11.4) on average (Tables 22, 23). Coefficients of variation in the tests ranged from 6.8-7.0%, and 32% (females) - 37% (males) of the variability was explained by the models. Between nest variability (error ms) is large. Early season nests were constructed with fewer leaves per cell for both male and female cells. Male cells in complete nests were constructed with fewer leaves than in incomplete cells.

Hypothesis 4. The relative acceptability of nests oriented in a NS direction vs. nests oriented in an EW direction does not change when bees are exposed to ELF EM fields.

As explained in the methods section, at each site there are three sets of hutches. Each hutch set consists of two hutches in close proximity, one oriented N-S, and one oriented E-W. Nests on the N-S hutch have openings facing E or W, while nests on the E-W hutch have openings facing N or S. The directions used in this analysis refer to the direction of nest openings.

Each set of hutches is situated in a different location and has a different pattern of sun and shade during the day, and a different compliment of nearby flowering plants. These factors may be important in acceptance of nest opening direction by bees. Thus, we have analyzed nest orientation by hutch set at each site. Furthermore, since sample sizes are low at some hutches in some years, we have not tried to discriminate between nests oriented in four directions; rather we compare acceptance of nests oriented N or S vs. nests oriented E or W. Only data for M. relativa are analyzed, since sample size was very low most years for M. inermis at the control sites.

We analyzed the data with a Log-likelihood Ratio (G-test) Contingency test (Table 24). This tests whether the pattern of nest acceptability (whatever the pattern) is the same for all years at a given hutch set. When the null hypothesis was accepted for all hutch sets at a site the data were pooled over years and each hutch set was tested against the other hutch sets at that site, to test whether the pattern was consistent for the entire site.

The results indicate that there is often a consistent bias over the years at a given hutch set, but that often the bias is different between hutch sets. These biases are probably due to differences in shading and proximity to resources, which are fairly consistent between years. If ELF EM fields are beginning to affect nest orientation acceptability, one would expect changes in nest orientation within a hutch set over the years at experimental but not control areas. Two hutch sets at F1 and one at F2 have shown significant changes within a hutch set over the years. For F1-N, these differences appear to be due to differences between 1985 and subsequent years. If a G-test is repeated with 1985 data removed, the F1-N hutch has a consistent bias toward the NS direction ($G=3.214$, $df=4$ n.s.). We have no idea why nest directions were different in 1985 than in subsequent years at the F1 site, but this change cannot be related to ELF EM fields. Similarly, nest orientations at the F1-W site have changed in both pre-operational years (1983, 1985, 1988) and full operational years (1990). Thus, these changes can't be attributed to ELF EM fields. Only the F2-N

hutch set showed a change in nest orientation in 1989 that continued in 1990, both full power years. This change might be attributable to ELF EM fields. However, the F2-N hutch set is the furthest hutch set from the ELF antenna at the F2 site. If ELF EM fields are having an effect, we would expect it to affect more than one hutch set, and more than the hutch set furthest from the antenna. Two more years of data on nest entrance orientation will be collected, for nests constructed in 1991 and 1992. We will be interested to see if these patterns are consistent.

V. NEST ACTIVITY RESULTS

Hypothesis 5. The duration of round leaf (LO) foraging trips remains the same when bees are exposed to ELF EM fields.

During the 1987 field season we noticed that LO trip durations increased with each successive trip after the bee lays her egg. In 1987, however, we did not keep track of which LO trips in the capping sequence were being timed. However, we learned that the female makes a series of very rapid flights in and out of the nest just before collecting the first LO after laying her egg. Undergraduate observers refer to this behavior as "spazzing". Where rapid flights in and out of the nest, without a cargo, appear at the beginning of a series of 1987 LO timings, we have assumed that the first LO trip for the cell has been timed.

In 1988 we recorded the actual trip number for 73% of the capping sequences that were timed. In 1989 - 1991, we were even more diligent, recording actual trip numbers for every cell cap timed. In our analyses residuals fit a normal distribution when we restrict the analysis to the mean of the first 3 trips if we use a $\ln(\ln)$ transformation of LO trip durations.

Figure 23 summarizes mean LO durations for the four sites and five years, based on GLM analysis of the mean of trip ranks 1-3 for each cell capping bout. If ELF EM fields were having an effect on LO durations, we would expect to see mean durations increasing (or possibly decreasing) for the treatment sites but not for the control sites since 1989. This does not seem to be the case. LO durations tend to be greater at the experimental sites across all years, even before the antenna became fully operational. Furthermore, mean LO durations have tended to fluctuate around a narrow range of means from year to year. (There was a greater spread between sites in 1987 than in subsequent years because of smaller sample sizes.) Results of the GLM analysis of the mean of trips 1-3 are summarized in Table 25. The error variance is a measure of between bee variability. As expected, experimental vs. control areas did not contribute significantly to the variability. We now have three years of data with the ELF antenna on full power, and the most recent two years have been on continuous full power. These negative results indicate that the antenna is not affecting LO trip durations.

To further confirm these results, we tried pooling data for pre-operational and continuous operational years in a second analysis. In this analysis, 1987 - 1989 were considered pre-continuous operational years, and 1990 - 1991 were considered continuous operational years. These categories were chosen because the separation between Experimental and Control

means showed their greatest separation in 1990 and 1991 (Fig. 23). If significant changes are occurring in LO durations, we are most likely to detect them in 1990-91 data. However, the GLM analysis in Table 26, showed no significant contribution of experimental vs. control areas to the variability in LO durations, nor was there a significant interaction of Exp and Pre- vs. Full Operational years.

Minimum detectable differences between control and experimental sites were calculated separately for each year and plotted on Figure 23. Observed differences between experimental and control areas have always been less than the minimum detectable difference.

Time of day did not contribute significantly to variability in LO durations. This suggests that temperature or other weather parameters do not affect LO durations. Date of the timing was significant only in 1990.

Although 1991 was the final year for collecting data on LO durations, there are still several refinements to the analysis that we plan to make to confirm the results presented here. First, we are in the process of analyzing data collected prior to 1987 using the same GLM procedures, to be sure that no significant changes took place after 1987, when testing at 10% power had already begun. At the time of this writing, the Trip Rank variable is being created for this data.

Weather data, and presence or absence of ELF EM fields during the LO trip are variables being added to our nest activity SAS data set, so we can incorporate them into our model of nest activity in the future. During pre-operational test years (1987-1989), LOs collected at times when the antenna was on may have differed in timings from LOs collected when the antenna was off.

VI EMERGENCE RESULTS

For the most part, both species of Megachile in our study are univoltine, having only one generation per year. There have been a few exceptions: In M. relativa nests, 5 - 22% of all M. relativa and 6 - 26% of all Coelioxys moesta Cresson emergences occur in August and September (Table 27). Far fewer instances of bivoltinism occur in M. inermis nests (0 - 0.3%; Table 28). Early emergences do not overwinter, and are not included in the analysis described below.

Hypothesis 6. Overwintering mortality of megachilid bees is unchanged by exposure to ELF EM fields.

Prior to emergence as an adult in the spring, Megachile are subject to a variety of sources of mortality. The egg may fail to hatch, or the larva may die of unknown causes during the summer. The prepupa may die during the winter. The pupa may fail to eclose in the spring. A number of parasites may attack the Megachile egg, larva, or pupa at various times in its development. Parasites include the cuckoo bees, Coelioxys moesta on M. relativa and C. funeraria Smith on both Megachile spp.; the flies Anthrax irroratus irroratus Say and Anthrax pluto pluto Weidemann; chalcid and leucospidid wasps.

The percent mortality due to various causes is presented by site and year for M. relativa and M. inermis in Tables 29 and 30 and Figs. 24 and 25. Variability between years is probably due in part to a change in protocol in 1987, leaving nests to overwinter in the field rather than bringing them to Channing. For example, Pre-overwintering mortality (mortality of eggs and larvae) was greater in 1987 than in previous years, and even greater in 1988, especially for M. relativa. Weather patterns are undoubtedly also involved. High pre-overwintering mortality in 1988 nests was probably due to dry, hot summer weather. Unusually cold spring weather contributed to overwintering mortality of nests constructed in 1988 and 1989. Numerous summer rainfalls may have caused higher pre-overwintering mortality in 1987 as compared to earlier years. Similarly, proportion of adults emerging was particularly low for 1988 M. relativa nests. The proportion of cells with prepupal mortality (i.e., the overwintering mortality) was low at all sites and in all years. Prior to 1989 it varied between 0.014 and 0.134 (M. relativa) and from 0 to 0.165 (M. inermis). In 1989, prepupal mortality peaked at 0.188 for M. relativa and 0.240 for M. inermis at F2 (Tables 29 and 30). Overwintering mortality was lower for 1990 nests than for 1989 nests, perhaps because there was no cold snap in spring 1991 as there had been in spring 1990.

There are several ways that one can measure overwintering mortality, and several problems that must be dealt with in

analyzing it. First, we equate overwintering mortality with the prepupal stage, but actually the prepupa lasts for a longer time than just the winter. The prepupal stage begins several weeks after the egg is laid, when the larva has finished eating its provisions. The prepupa defecates shortly after molting, and then spins a silken cocoon for overwintering that is surrounded by fecal pellets. Thus the prepupal stage may begin as early as mid-summer. It lasts until pupation in the spring. This occurs typically in mid to late May, although we have opened few cells to find out, because this is likely to increase mortality. In spring 1989 and 1990, the prepupal stage for nests constructed in 1988 and 1989 probably lasted into June, due to cool weather and a change in protocol to a shady outdoor emergence site. Emergence was delayed in 1989 and 1990 until July. Figs. 26 - 29 compare emergence of 1987 - 1989 nests in spring 1988, 1989, 1990, and 1991 respectively.

There is no way to separate prepupal mortality that occurs during the winter from prepupal mortality that occurs in summer, fall or spring. 1987 - 1989 nests were left at the sites where they were constructed during the entire prepupal stage except for the last few weeks, when nests were returned to Crystal Falls for nest architecture measurements. Thus, the effects of ELF EM fields on prepupal mortality any time before May are tested by our protocol.

Prior to 1989, pupation and emergence took place in the lab where indoor microclimate and 60 hz EM fields could affect pupal and adult mortality. Starting in 1989, the effects of 60 hz EM fields were minimized by moving emergence of all cells to an outdoor holding site. We have no way of knowing how many adult bees would have successfully emerged at the study sites, but the number of cells that survive past the prepupal stage provides an upper limit. Therefore, we combine pupae, adults that die in the cocoon, and adults that successfully emerge, into one "post-overwintering" category.

The prepupal stage has the longest duration of all the developmental stages of these univoltine species. However, mortality is usually greater in the pre-overwintering egg and larval stages. Mortality of these early stages show differences between years and sites (Tables 33, 34, Figure 30, 31) that could make it difficult to detect differences due to ELF EM fields. Therefore, we propose restating our hypothesis as: Given that a bee survives to the prepupal stage, the probability that it will not survive past the prepupal stage does not change in the presence of ELF EM fields. Thus, we analyze proportion of mortality in the prepupal stage, calculated as the number of cells with a dead prepupa divided by the sum of cells with prepupae or post-overwintering bees. Cells containing egg and larval mortality are not included.

Parasites present another problem. It is easy to distinguish adult and pupal Megachile from adult and pupal parasites. However, we are unable to distinguish prepupae of Megachile from prepupae of the cuckoo bee, Coelioxys (also in the Megachilidae). The Coelioxys larva kills its host larva or egg, and feeds on the provisions in the cell. Like the host bee, Coelioxys overwinters in the prepupal stage. When testing the hypothesis above, the number of cells with dead prepupae should be reduced by the percentage of cells that are parasitized by Coelioxys. We can estimate percent parasitism of prepupae from the proportion of adults that are parasites. This assumes that there is no differential mortality of parasites in the prepupal stage as compared with the adult stage.

In our first attempts to analyze prepupal mortality, however, we have not tried to separate Megachile and Coelioxys data. Rather, we assume that both genera are affected in the same ways, if at all, by ELF EM fields. This assumption is more likely to be true for two bee species in the megachilid family, than for a bee and a fly or wasp parasite. We calculate proportion of cells with prepupal mortality for each site and year by dividing the number of cells containing dead prepupae (x) by all cells with Megachile or Coelioxys prepupae or post-overwintering stages (n): x/n . These proportions are graphed as percents in Figs. 30 and 31.

In 1989 nests, prepupal mortality often occurred in several cells in a row in a nest. Some of these cells had a partially formed pupa visible under the prepupa exoskeleton. These prepupae obviously died late in their development, just before pupation. We believe this occurred during the cold spring weather, particularly on May 10, when there was a snow storm. For 1989 nests in particular, prepupal mortality in a cell was probably not independent of prepupal mortality of other cells in the same nest, which were all at the same critical stage of development when cold weather occurred. Therefore, in addition to an analysis of prepupal mortality by cells, we have also analyzed prepupal mortality by nest. We calculated proportion of nests with prepupal mortality for each site and year by dividing the number of nests containing at least one dead prepupa (X) by all nests with at least one Megachile or Coelioxys prepupa or post-overwintering stage (N): X/N (Fig. 32-33). These proportions were higher than the proportions of cells with prepupal mortality (Figs. 30 - 33).

Neither Exp nor Exp*Year contributed significantly to variance in proportion of cells or nests with prepupal mortality for either M. relativa or M. inermis (Table 31 - 34). This suggests that exposure to ELF EM fields at half power during the winter of 1988-89 and at full power during the winters of 1989-90 and 1990-91, did not affect overwintering

mortality. Year was significant for both species. For M. relativa (Tables 31, 33), 1989 differed from 1985-87, and these three years were not significantly different. For M. inermis (Tables 32, 34) 1989-90 had significantly greater prepupal mortality than other years, while 1985-87 had the lowest prepupal mortality. Note, however, that in 1985-86, prepupal mortality did not take place at the site where the nest was constructed.

Nests constructed in 1988 were the first to overwinter in the same orientation as they were constructed. We analyzed 1988 - 1990 prepupal mortality by cells and nests, adding the additional variable "direction", indicating whether the nest overwintered along a north-south axis, or along an east-west axis. (It is not necessary to separate nests by hutch set, as in our analysis of acceptability of nest orientations, because nests from all hutch sets at a site were overwintered in the same place.) We are curious to determine whether direction of the nest contributes significantly to prepupal mortality, particularly at the experimental sites where nests are exposed to ELF magnetic fields that might differentially affect prepupae oriented in particular directions (see Introduction, p. 10). Thus, we are looking for a significant effect of Direction*Exp.

Analysis of 1988 M. inermis cells suggested that mortality was high at control sites but low at experimental sites for NS oriented nests (Fig. 35, 1988). This effect of nest orientation was not repeated for M. inermis with either 1989 or 1990 cells or nests (Tables 36, 38; Figs. 35, 37). However, the analysis of M. inermis prepupal mortality suggests that mortality at the experimental sites was significantly lower at experimental sites in 1988 than at control sites in 1988, or experimental sites in 1989 and 1990 (Significant Exp*Year, Table 38). This effect was not seen in the analysis of M. inermis nests without nest orientation included in the model (Table 34, Fig. 33), but the former analysis included data for 1985-86 that were not strictly comparable. Fig. 33 suggests that overwintering mortality was lower at experimental than control sites in both low power years, 1987-88, and that exposure to full power in 1989 may, indeed, have increased mortality at the experimental sites to the same level as mortality at control sites.

An effect of nest entrance orientation was barely significant for M. relativa cells ($P=0.0496$, Fig. 34, Table 35), but not for M. relativa nests (Fig. 36, Table 37). In this case, cells overwintered NS had slightly lower mortality relative to cells overwintered EW at the experimental sites than at the control sites. Interestingly, the effect is the same as was observed for M. inermis cells in 1988.

In the manipulative experiment, cells constructed at the F2 site but overwintered at the C5 site, had mortality closer to cells constructed and overwintered at C5 than to cells constructed and overwintered at F2 (Fig. 38A, Table 39). This is consistent with the hypothesis that overwintering mortality is higher at experimental than control sites. The same effect was not seen for % prepupal mortality of nests (Fig. 38B). Nest orientation was also not significant.

In summary, three out of ten analyses of prepupal mortality had a significant effect of Exp*Year or Exp*direction, suggesting that ELF EM fields may have a weak effect on overwintering mortality at the experimental sites:

1. There is one instance of slightly increased mortality at experimental sites at full power relative to low power (Table 38, Fig. 37).
2. There is one instance of slightly reduced mortality in nests oriented NS relative to nests oriented EW (Table 35, Fig. 34).
3. There is a slightly reduced mortality of cells constructed at the experimental site but overwintered at the C5 control site relative to cells constructed at F2 that overwintered at F2 (Table 39).

These significant effects are not consistent for both species, or for both percent of cells with prepupal mortality and percent of nests with prepupal mortality. The effects are just barely significant ($P=0.49$). Using an α of 0.05, we expect one out of twenty tests to be falsely significant. Three significant tests out of 10 may be more than expected for random yearly fluctuations that have nothing to do with ELF EM fields. However, at most the effects of ELF EM fields on prepupal mortality are very weak in comparison to other causes of prepupal mortality such as weather. We will be interested to see if these instances of significance persist in two more years of data, for nests constructed in 1991 and 1992.



VII SUMMARY

Studies of the effects of high voltage transmission lines and magnetic fields in honeybees suggest several ways that solitary megachilid bees might be affected by ELF electromagnetic fields. In particular, honeybees show greater levels of activity, reduced reproductive output, lower overwintering survival and modifications of nest structure in response to high voltage transmission lines. In addition, honeybees can detect magnetic fields and may use them in orientation. ELF EM fields may affect megachilid bees in similar ways.

Megachilid bees are particularly well suited for this study. Their investment per offspring and reproductive output per nest are easy to measure because they provide each offspring with a discrete cell, and because they readily nest in artificial nests. Three types of data have been gathered in past years: nest architecture, nest activity, and emergence/-mortality.

Two abundant species at the experimental and control sites, both in the genus Megachile, are the focus of our analysis. These species differ in size and degree of sexual dimorphism. Thus, they may be impacted differently by ELF EM fields.

Four hypotheses regarding the impact of ELF EM fields on nest architecture are being tested:

Hypothesis 1: The average length of cells for each offspring, and/or the average number of cells produced per nest is unchanged by exposure to ELF electromagnetic fields.

Hypothesis 2. Bees exposed to ELF EM fields, and bees not exposed, will make nest plugs of the same thickness and will devote the same proportion of nest space to reproduction.

Hypothesis 3. The number of leaves used to line a cell is unchanged by exposure to ELF EM fields.

Hypothesis 4. The relative acceptability of nests oriented in a NS direction vs. nests oriented in an EW direction does not change when bees are exposed to ELF EM fields.

Nest architecture data for M. relativa nests constructed in 1983, and M. relativa and M. inermis nests constructed in 1985-1990 have been analyzed. Cells expected to have female offspring were larger than cells expected to have male offspring. Mean cell lengths were significantly larger at the CL site, in complete nests and early season nests, and in nests with few cells. However, there did not appear to be any effect

of ELF EM fields at 100% power (1989-1990) on cell length for either species.

Number of cells per nest was significantly less for nests begun late in the season as compared with those begun early in the season. The distribution of numbers of cells per nest varied between years, sites, and treatment areas, but neither species showed any obvious changes at the experimental sites in 1989 and 1990 when the antenna was fully operational.

Mean number of leaves per cell was smaller for female M. inermis cells than for male cells. Nests begun in early season had fewer leaves per cell than did nests constructed late season. For male cells there were differences between complete and incomplete nests as well. However, there did not appear to be any effect of ELF EM fields at 100% power (1989-1990) on mean leaves per cell for this species.

Nest entrance orientation has been consistent over the years for M. relativa at control sites, but it has varied over the years at three out of six hutch sets at experimental sites. Only one hutch set has shown consistent change since the antenna became operational (F2-N), but since this is the furthest hutch set from the antenna, we do not believe that changes in nest entrance orientation are related to ELF EM fields.

We have not yet analyzed the data to test hypotheses 2.

One hypothesis regarding nest activity is being tested:

Hypothesis 5. The duration of round leaf (LO) foraging trips remains the same when bees are exposed to ELF EM fields.

There were significant differences between years and between sites in the duration of LO collecting trips, however, there were no significant changes in LO durations at the experimental areas after the antenna became fully operational in 1989. Thus, ELF EM fields, even at full power, have not had any effect on LO trip durations.

One hypothesis concerning emergence and mortality data has been tested:

Hypothesis 6. Overwintering survival of megachilid bees is unchanged by exposure to ELF fields.

Overwintering mortality takes place when the bee is in the prepupal stage. Because of the effects of microhabitat and year on pre-overwintering (larval) mortality, it was decided to eliminate cells with this mortality from our analysis. Thus our hypothesis has been restated as: Given that a bee survives

to the prepupal stage, the probability that it will not survive past the prepupal stage does not change in the presence of ELF EM fields. We calculate proportion of mortality in the prepupal stage as the number of cells with a dead prepupa divided by the sum of cells with prepupae, pupae, dead adult, or emerging adult bees. Mortality of the parasitic cuckoo bee, Coelioxys, is included in the analysis, since we cannot distinguish the two bee species until the pupal stage.

One possible effect of ELF EM fields was detected in the 1989 analysis. M. inermis prepupal (overwintering) mortality in nests oriented along a NS axis was lower in experimental than in control areas for 1988 nests. 1988 was the first year with significant testing of the antenna during the winter, and the first year that the nests were overwintered in the direction that they were constructed. This year, three out of ten analyses of prepupal mortality had a significant effect that suggests greater mortality at experimental sites in full power years, and/or reduced mortality for nests oriented NS relative to nests oriented EW at experimental sites in full power years. These significant effects were very weak compared to other effects on prepupal mortality such as weather, and the effects may represent random yearly fluctuations that have nothing to do with ELF EM fields. We will collect emergence/mortality data for two more seasons (nests constructed in 1991 and 1992) to see whether such effects persist.



VIII REFERENCES

- Alcock, J. 1979. The relation between female body size and provisioning behavior in the bee Centris palida Fox (Hymenoptera: Anthophoridae). J. Kansas Ent. Soc. 52:623-632.
- Baird, C. R. and R. M. Bitner. 1991. Loose cell management of leafcutting bees. Western Regional Extension Publication 12. 7pp.
- Berman, E. 1990. The developmental effects of pulsed magnetic fields on animal embryos. Reproductive Toxicology 4:45-49.
- Bindokas, V. P., J. R. Gauger, and B. Greenberg. 1988. Mechanism of biological effects observed in honeybees (Apis mellifera L.) hived under extra-high-voltage transmission lines: implications derived from bee exposure to simulated intense electric fields and shocks. Bioelectromagnetics 9:285-301.
- Bindokas, V. P., J. R. Gauger, and B. Greenberg. 1989. Laboratory investigations of the electrical characteristics of honeybees and their exposure to intense electric fields. Bioelectromagnetics 10:1-12.
- Bohart, G. E. 1972. Managing wild bees for crop pollination. Ann. Rev. Entomol.
- Bohart, G. E. and G. F. Knowlton. 1964. Managing the leaf-cutting bee for higher alfalfa seed yields. Utah Ag. Expt. Sta. Circ. 144.
- Brodeur, P. 1989. Annals of radiation; the hazards of electromagnetic fields. III. Video-display terminals. The New Yorker, June 26, 1989. p.39-68.
- Cane, J. H. 1987. Estimation of bee size using intertegular span (Apoidea). J. Kansas Entomol. Soc. 60:145-147.
- Cowan, D. P. 1981. Parental investment in two solitary wasps, Ancistrocerus adiabatus, and Euodynerus foraminatus (Eumenidae: Hymenoptera). Behav. Ecol. and Sociobio. 9:95-102.
- Danforth, B. N. 1990. Provisioning behavior and the estimation of investment ratios in a solitary bee, Calliopsis (Hypomacrotera) persimilis (Cockerell) (Hymenoptera: Andrenidae). Behav. Ecol. and Sociobio. 27:159-168.

Erickson, E. H. 1975. Surface electric potentials on worker honeybees leaving and entering the hive. J. Apicultural Res. 14:141-147.

Frolich, D. R. and V. J. Tepedino. 1986. Sex Ratio, parental investment, and interparent variability in nesting success in a solitary bee. Evolution 40:142-151.

Gerber, H. S. and E. C. Klostermeyer. 1972. Factors affecting the sex ratio and nesting behavior of the alfalfa leafcutter bee. Wash. Ag. Expt. Sta. Tech. Bull. 73. 11pp.

Gould, J. L. 1980. The case for magnetic sensitivity in birds and bees (such as it is). Am. Sci. 68:256-67.

Gould, J. L., L. Kirschvink, and K. S. Deffeyes. 1978. Bees have magnetic remanence. Science 102:1026-28.

Gould, J. L., L. Kirschvink, K. S. Deffeyes, and M. L. Brines. 1980. Orientation of demagnetized bees. J. exp. biol. 86:1-8.

Greenberg, B., V. P. Bindokas, M. J. Frazier, and J. R. Gauger. 1981a. Response of Honey Bees, Apis mellifera L., to high-voltage transmission lines. Environ. Entomol. 10: 600-610.

Greenberg, B., V. P. Bindokas, M. J. Frazier, and J. R. Gauger. 1981b. Response of Honey Bees, Apis mellifera, to high-voltage transmission lines. Environ. Entomol. 10:600-610.

Hobbs, G. A. 1972 Beekeeping with alfalfa leafcutter bees in Canada. Bee World 53:167-173.

Johansen, C. A., E. C. Klostermeyer, J. D. Eves, and H. S. Gerber. 1969. Suggestions on alfalfa leafcutter bee management. Wash. Coop. Ext. Serv. EM 2775.

Johnson, M. D. 1988. The relationship of provision weight to adult weight and sex ratio in the solitary bee, Ceratina calcarata. Ecol. Entomol. 13:165-170.

Klostermeyer, E. C., S. J. Mech Jr., and W. B. Rasmussen. 1973. Sex and weight of Megachile rotundata progeny associated with provision weights. J. Kansas Entomol. Soc. 46:536-48.

Klostermeyer, E. C., and H. S. Gerber. 1970. Sex control by bees: A voluntary act of egg fertilization during oviposition. Science 167:82-84.

Kirschvink, J. L., and A. K. Kirschvink. 1991. Is Geomagnetic sensitivity real? Replication of the Walker-Bitterman magnetic conditioning experiment in honey bees. Amer. Zool. 31:169-185.

Krombein, K. V. 1967. Trap-nesting wasps and bees: life histories, nests, and associates. Smithsonian Press, Washington, D. C. 570p.

Leal, J., M. A. Trillo, A. Ubeda, V. Abraira, K. Shamsaifar and L. Chacon. 1986. Magnetic environment and embryonic development: a role of the earth's field. IRCS Med. Sci. 14:1145-1146.

Leucht, T. H. and H. Martin. 1990. Interactions between e-vector orientation and weak, steady magnetic fields in the honeybee, Apis mellifica. Naturwissenschaften. 77:130-133.

Longair, R. W. 1981. Sex ratio variations in xylophilous aculeate Hymenoptera. Evolution. 35:597-600.

Medler, J. T. 1958. A note on Megachile inermis Prov. in trap-nests in Wisconsin (Hymenoptera: Megachilidae) Canad. Entomol. 90:325-327.

Medler, J. T. and T. W. Koerber. 1958. Biology of Megachile relativa Cresson (Hymenoptera: Megachilidae) in trap-nests in Wisconsin. Ann. Entomol. Soc. Am. 51:337-344.

Mitchell, T. B. 1962. Bees of the Eastern United States Vol. II. North Carolina Agric. Exp. Sta. Tech. Bull. No. 152. pp. 108-191.

Rao, C. R. 1965. Linear Statistical Inference and its Applications. Wiley, New York.

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

Stephen, W. P. 1955. Alfalfa pollination in Manitoba. J. Econ. Entomol. 48:543-548.

Stephen, W. P. 1956. Notes on the biologies of Megachile frigida Smith and M. inermis Provancher (Hymenoptera: Megachilidae). Pan Pacific Entomol. 32:95-101.

Stephen, W. P. 1962. Propagation of the leaf-cutter bee for alfalfa seed production. Oregon Ag. Expt. Sta. Bull. 586.

Stephen, W. P. 1981. The design and function of field domiciles and incubators for leafcutting bee management (Megachile rotundata (Fabricius)). Oregon State University Agricultural Experiment Station Bulletin 654. 13pp.

Stephen, W. P. and C. E. Osgood. 1965. Influence of tunnel size and nesting medium on sex ratios in a leaf-cutter bee, Megachile rotundata. J. Econ. Entomol. 58:965-968.

Strickler, K. 1979. Specialization and foraging efficiency of solitary bees. Ecology 60:998-1009.

Strickler, K. 1982. Parental investment per offspring by a specialist bee: does it change seasonally? Evolution 36:1098-1100.

Sugiura, N. and Y. Maeta. 1989. Parental investment and offspring sex ratio in a solitary Mason Bee, Osmia cornifrons (Radoszkowski) (Hymenoptera, Megachilidae). Jpn. J. Entomol. 57:861-875.

Tepedino, V. J. and P. F. Torchio. 1982. Phenotypic variability in nesting success among Osmia lignaria propinqua females in a glasshouse environment (Hymenoptera: Megachilidae). Ecol. Entomol. 7:453-462.

Tepedino, V. J. and P. F. Torchio. 1989. Influence of nest hole selection on sex ratio and progeny size in Osmia lignaria propinqua (Hymenoptera: Megachilidae). Ann. Entomol. Soc. Am. 82:355-360.

Tomlinson, J., S. McGinty, and J. Kish. 1981. Magnets curtail Honey Bee dancing. Animal Behaviour 29:307-8.

Torchio, P. F. 1981a. Field experiments with Osmia lignaria propinqua Cresson as a pollinator in almond orchards: I. 1975 studies. J. Kansas Entomol. Soc. 54:815-823.

Torchio, P. F. 1981b. Field experiments with Osmia lignaria propinqua Cresson as a pollinator in almond orchards: II. 1976 studies. J. Kansas Entomol. Soc. 54:824-836.

Torchio, P. F. 1982a. Field experiments with Osmia lignaria propinqua Cresson as a pollinator in almond orchards: III. 1977 studies. J. Kansas Entomol. Soc. 55:101-116.

Torchio, P. F. 1982b. Field experiments with a pollinator species, Osmia lignaria propinqua Cresson, in apple orchards: I. 1975 studies. J. Kansas Entomol. Soc. 55:136-144.

Torchio, P. F. 1982c. Field experiments with a pollinator species, Osmia lignaria propinqua Cresson, in apple orchards: II. 1976 studies. J. Kansas Entomol. Soc. 55:759-778.

Torchio, P. F. 1984a. Field experiments with a pollinator species, Osmia lignaria propinqua Cresson, in apple orchards: III. 1977 studies. J. Kansas Entomol. Soc. 57:517-521.

Torchio, P. F. 1984b. Field experiments with a pollinator species, Osmia lignaria propinqua Cresson, in apple orchards: IV. 1978 studies. J. Kansas Entomol. Soc. 57:689-694.

Torchio, P. F. 1985. Field experiments with a pollinator species, Osmia lignaria propinqua Cresson, in apple orchards: V. (1979-1980), methods of introducing bees, nesting success, seed counts, fruit yields (Hymenoptera: Megachilidae). J. Kansas Entomol. Soc. 58:448-464.

Torchio, P. F. and V. J. Tepedino. 1980. Sex ratio, body size, and seasonality in a solitary bee, Osmia lignaria propinqua Cresson (Hymenoptera: Megachilidae). Evolution 34: 993-1003.

Trivers, R. L. and H. Hare. 1976. Haplodiploidy and the evolution of the social insects. Science 191:249-263.

Walker, M. M. and M. E. Bitterman. 1989. Conditioning analysis of magnetoreception in honeybees. Bioelectromagnetics 10:261-275.

Wellenstein, G. 1973. Der einfluss von hochspannungs-leitungen auf bienenvolker (Apis mellifica L.). Z. ang. Ent. 74:86-94.

Zar, J. H. 1984. Biostatistical Analysis 2nd Ed. Prentice-Hall, N.J. 718pp.



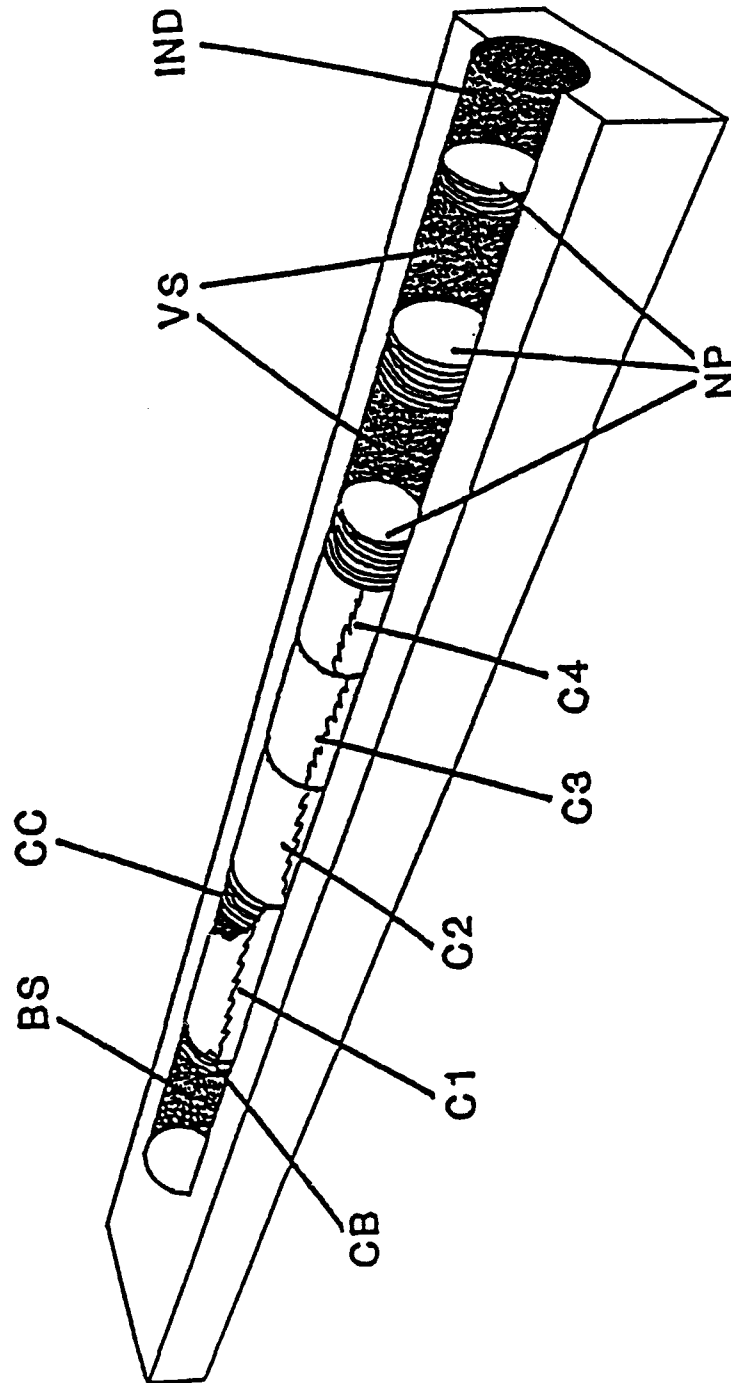


FIGURE 1. Cut away view of a completed Megachille nest.

BS - Basal Space; CB - Cell Base; C1, C2, C3, C4 - Reproductive Cells 1 through 4; CC - Cell Cap; NP - Nest Plug; VS -Vestibular Spaces; IND - Indentation.

TABLE 1: Diameter of drill bits used to create trap nests.

Diameter, mm	Used by <u>M. relativa</u>	Used by <u>M. inermis</u>
4.4*		
5.2*	xx	
5.5	xxx	
6.0	xxx	
7.2*	xx	x
9.4*		xx
11.0		xxx

* Drill bit diameters used before 1987 only.

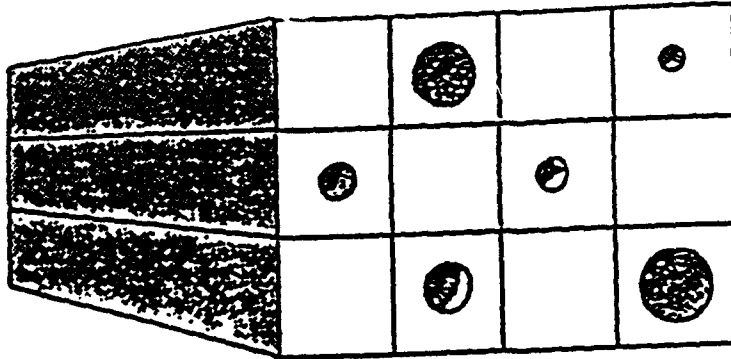


FIGURE 2. Example of arrangement of nests in block, 1983-1986.

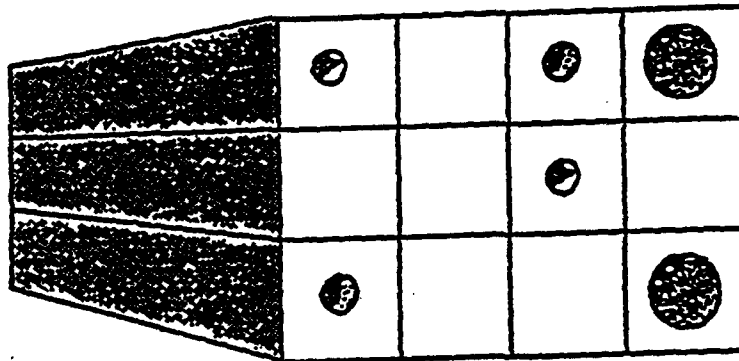


FIGURE 3. Example of arrangement of nests in block, 1987-1991.

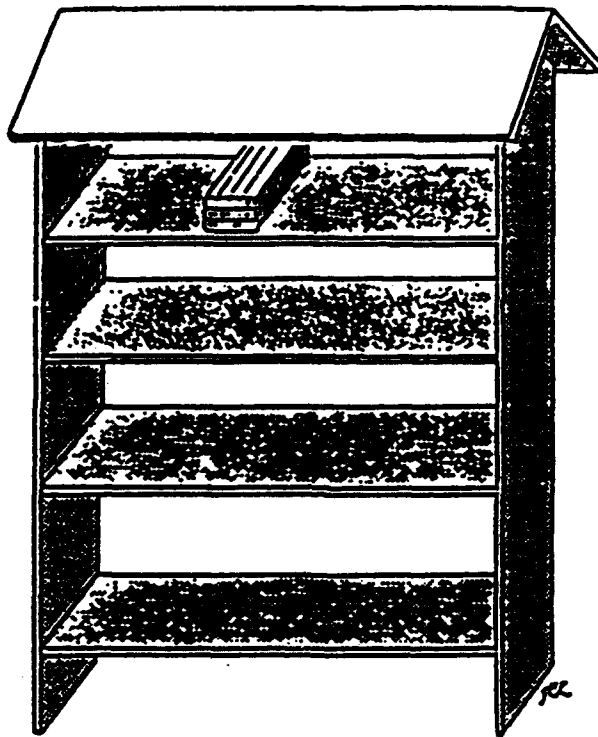
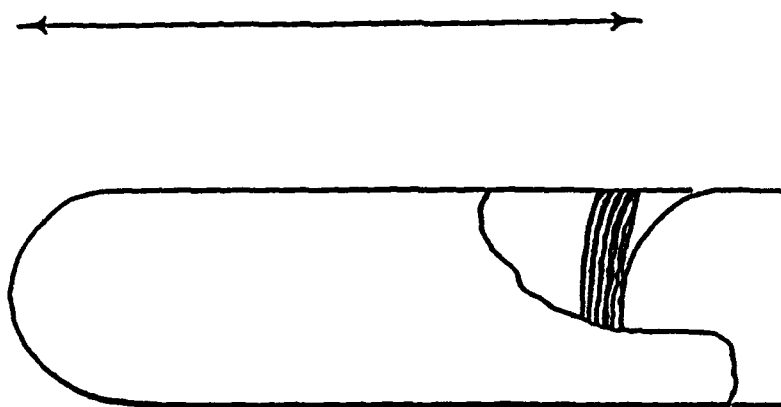
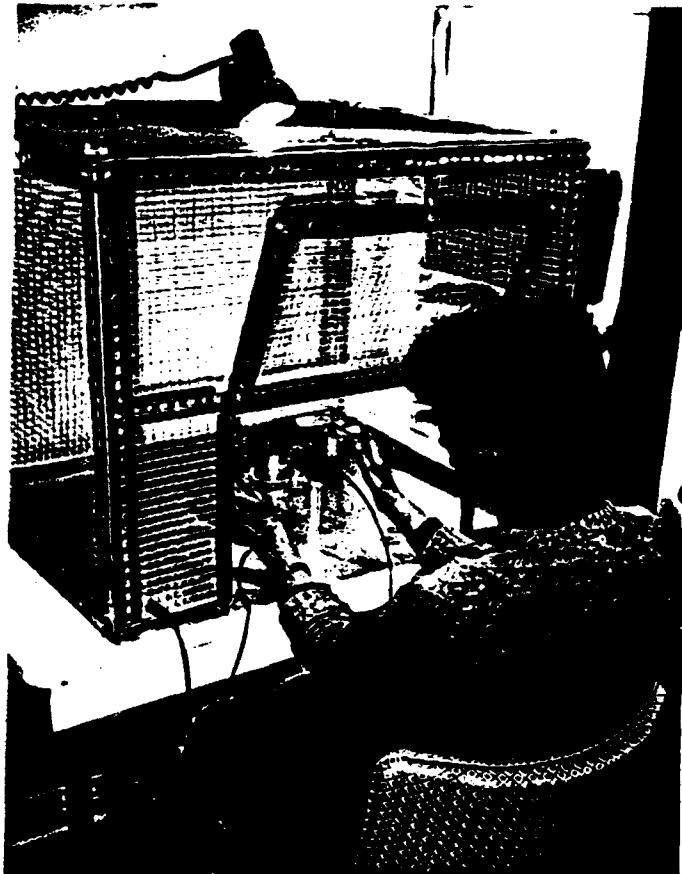


FIGURE 4. Hutch, with one block of nests.



↔ Cell Length Including Cap Length

FIGURE 5. A single reproductive cell, indicating how cell lengths are measured.



a



b

FIGURE 6a, b. Wire mesh Faraday cages, used to reduce exposure of nests to 60hz EM fields while nest architecture measurements are made in Crystal Falls.

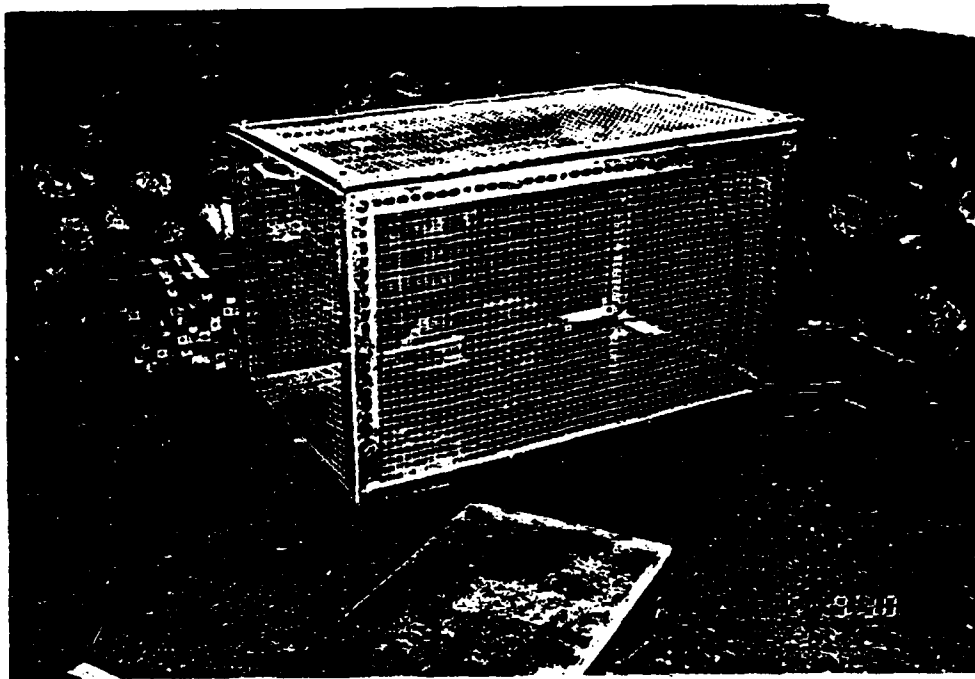


FIGURE 7. Wire mesh Faraday cage on front porch in Crystal Falls, used to store nests and cells just before and after nest measurements are made.

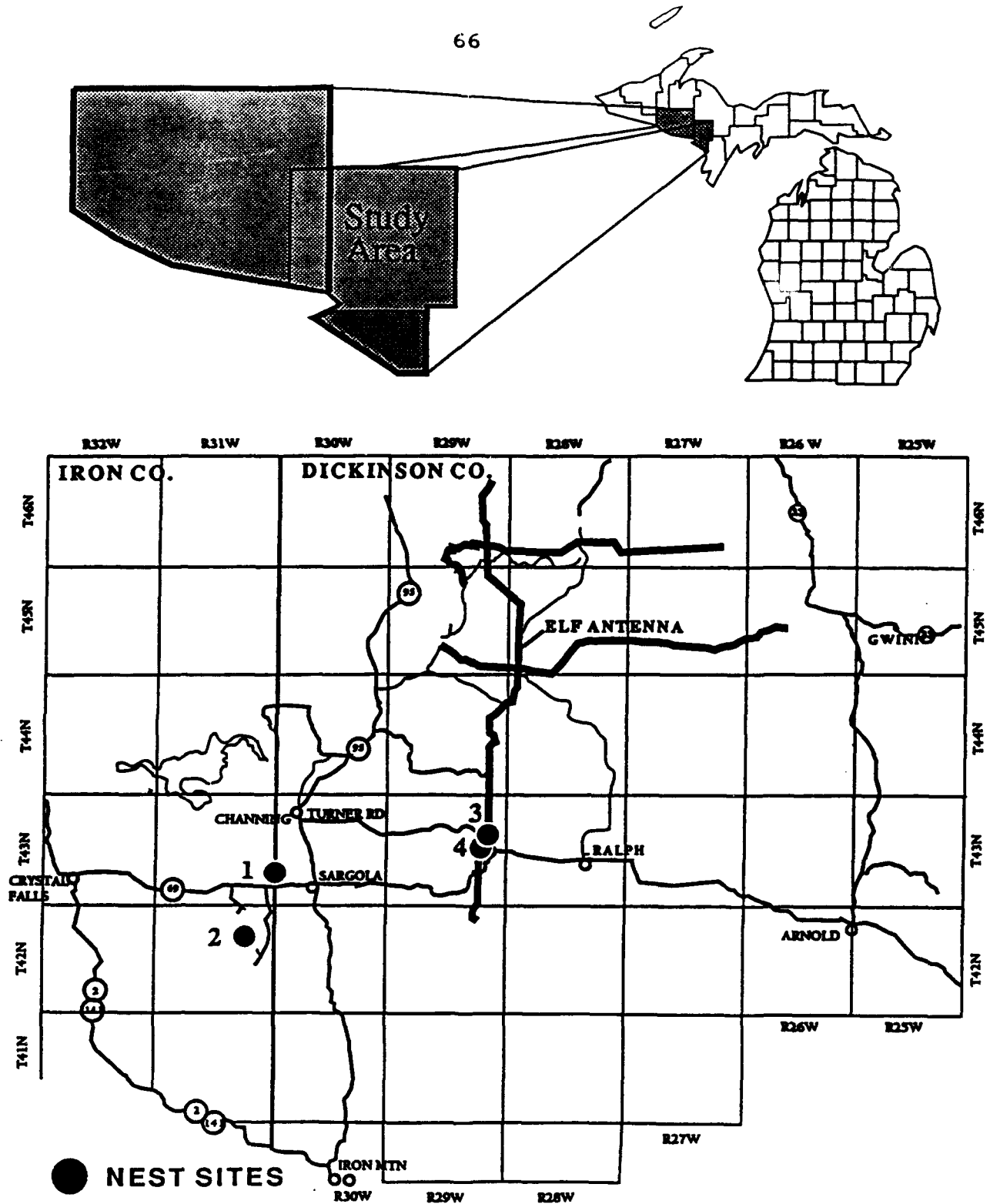


FIGURE 8. Map of the study areas in Iron and Dickinson Co. in Michigan's Upper Peninsula. Control sites: Site 1 = CL, Site 2 = C5. Experimental sites: Site 3 = F1, Site 4 = F2.

Table 2: Time line of ELF antenna operations, nest construction and overwintering, and data analysis. Nests constructed during the summer of the year listed at the top of the table yield activity data that are analyzed the same year, and architecture data that are analyzed the following year. Nests that overwinter during the year listed at the top of the table yield emergence data the following summer.

Year and Season of Nest Construction or Overwintering:

ELF EM Field	1985			1986			1987			1988			1989			1990			1991			1992			1993		
	Su	W	0	Su	W	0	Su	W	0	Su	W	50%	Su	W	100%**	Su	W	100%	Su	W	100%	Su	W	100%	Su	W	100%
	0	0	10%	10%	0	10%	10%	10%	10%	50%	50%	Testing*	100%**	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Antenna Pre-operational												Antenna Operational														

Year of Data Analysis:

Activity Data	---	---	1987	1988	1989	1990	1991	---
Architecture Data	1987	1987	1988	1989	1990	1991	1992 →	---
Overwintering (Emergence Data)	1987	1987	1988	1989	1990	1991	1992	1993 →

* Treated variously as pre-operational or operational.

**Not continuous operation in SU 1989.

MAGNETIC FIELD EXPOSURES OF FORAGING BEES

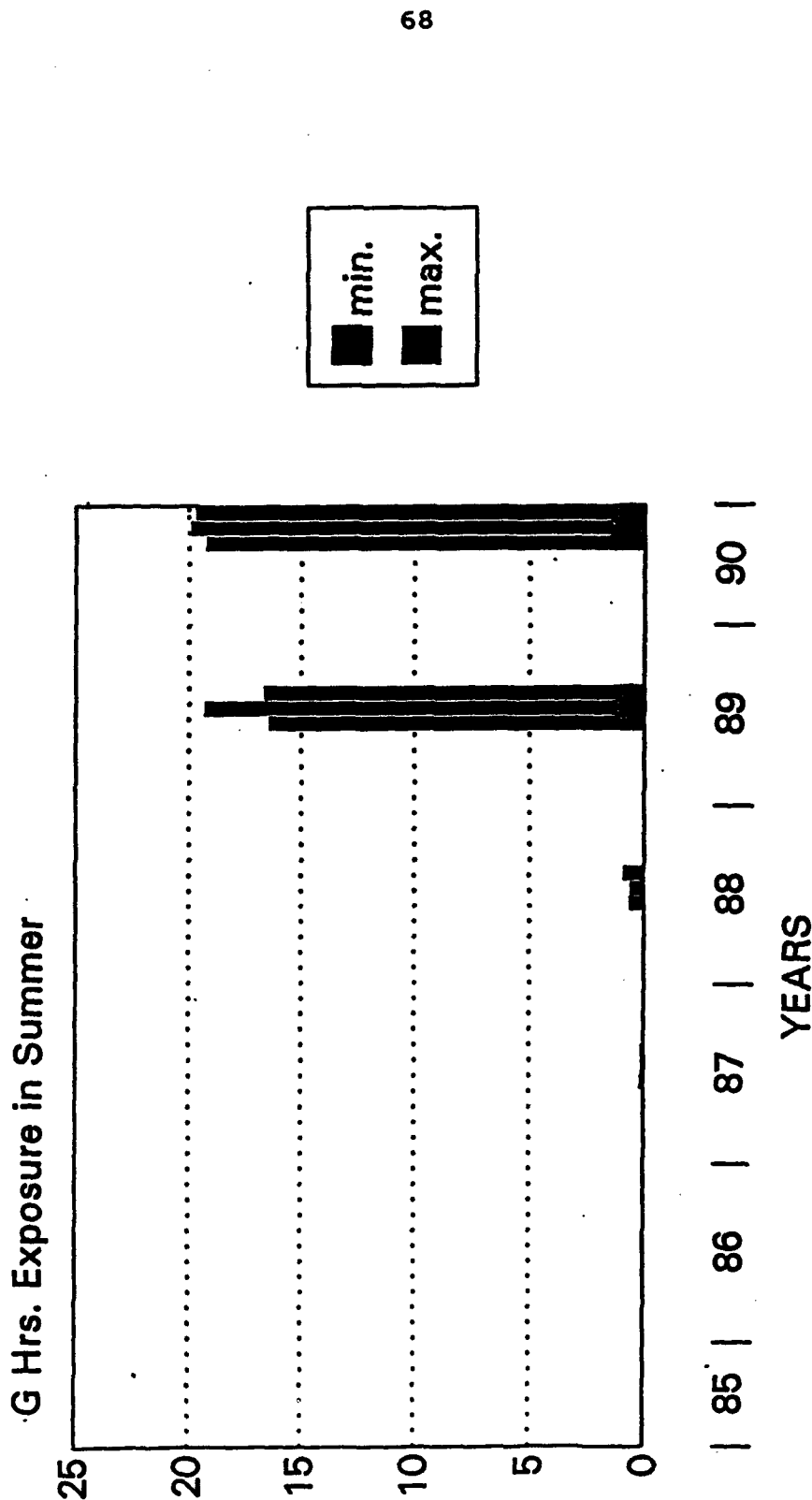


FIGURE 9. Cumulative magnetic field exposures (in Gauss- Hours) of foraging bees during the nesting season (June, July, August). A bee sitting directly under the antenna for the entire month would experience the maximum exposure plotted. A bee sitting on the hutch farthest from the antenna at the F2 site would experience the minimum exposure plotted. Most bees at the experimental sites would experience intermediate magnetic field exposures.

MAGNETIC FIELD EXPOSURES OF OVERWINTERING BEES

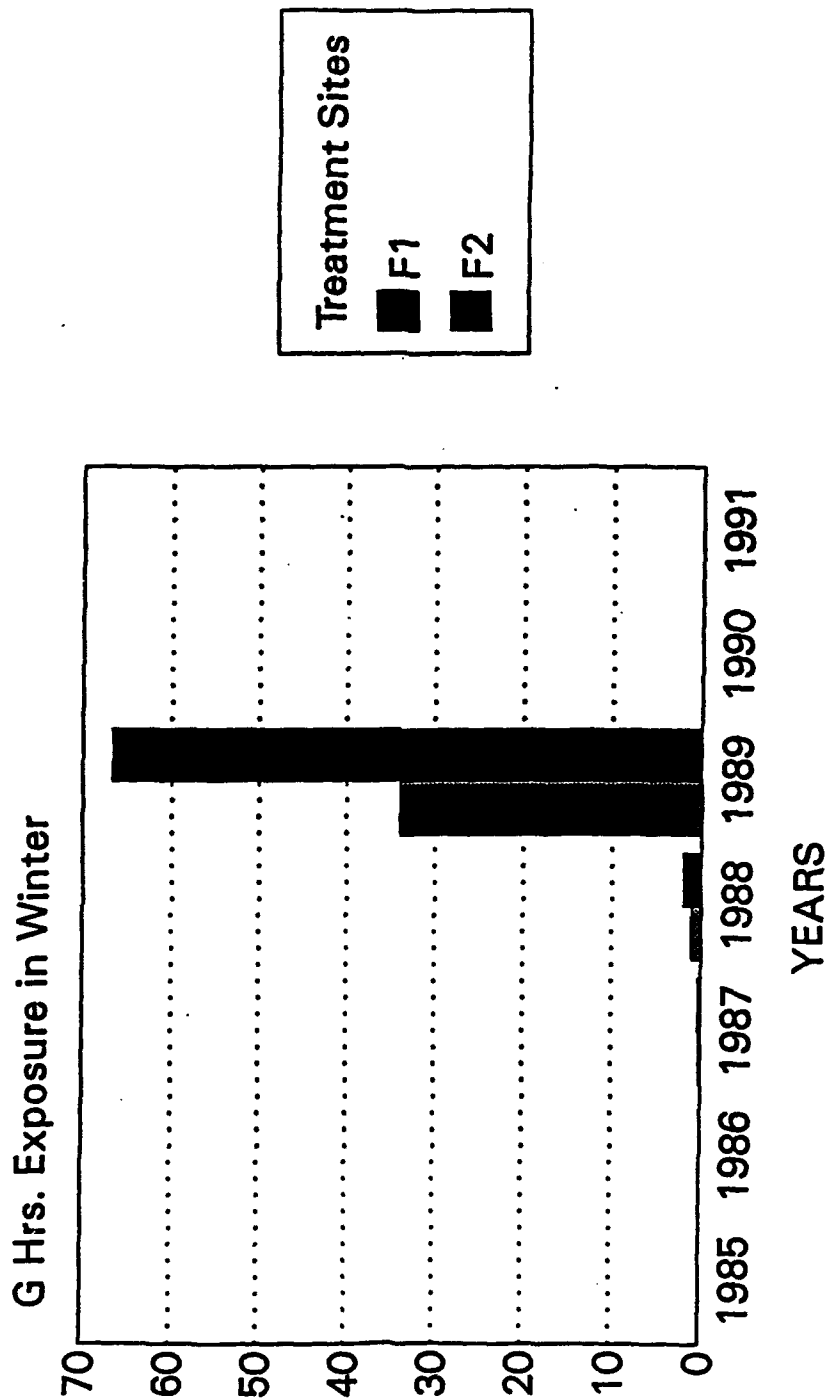


FIGURE 10. Cumulative magnetic field exposures (in Gauss-Hours) of overwintering prepupae between September and April.

Table 3a: Number of nests of M. relativa for which we have data on complete cell lengths, by site.

Site Year	Control Sites		Test Sites	
	Camp 5	County Line	Ford 1 (North)	Ford 2 (South)
		<u>M. relativa</u>		
1983	—	27 (2)	128 (4)	17 (2)
1985	51 (5)	78 (6)	84 (5)	92 (6)
1986	49 (6)	51 (5)	42 (5)	80 (5)
1987	78 (5)	47 (5)	76 (4)	47 (5)
1988	85 (6)	59 (5)	83 (5)	51 (6)
1989	75 (6)	60 (5)	38 (3)	73 (6)
1990	70 (6)	82 (6)	54 (5)	123 (6)
1991*	58 (6)	32 (2)	36 (3)	79 (6)

* Approximate numbers: Complete nests only; not yet measured.

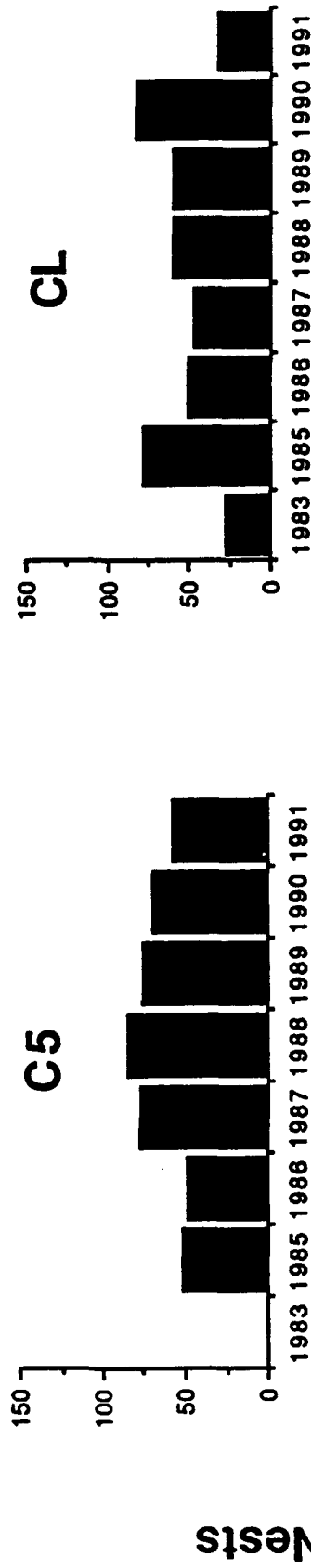
Table 3b: Number of nests of M. inermis for which we have data on complete cell lengths, by site.

Site Year	Control Sites		Test Sites	
	Camp 5	County Line	Ford 1 (North)	Ford 2 (South)
		<u>M. inermis</u>		
1985 nests measured	23 (3)	17 (2)	160 (6)	88 (6)
nests constructed**	26	18	212	121
1986	15 (1)	2 (0)	40 (3)	65 (4)
1987	56 (3)	25 (3)	122 (5)	108 (6)
1988	30 (4)	7 (0)	54 (2)	127 (5)
1989	106 (6)	23 (3)	172 (6)	262 (6)
1990	163 (6)	51 (3)	237 (6)	382 (6)
1991*	134 (5)	50 (4)	171 (6)	346 (6)

* Approximate numbers: Complete nests only; not yet measured.

** Some 1985 nests were not measured because they were used in a study of diapause. I do not have these nests, nor do I have the data from the diapause study.

Control Sites



Experimental Sites

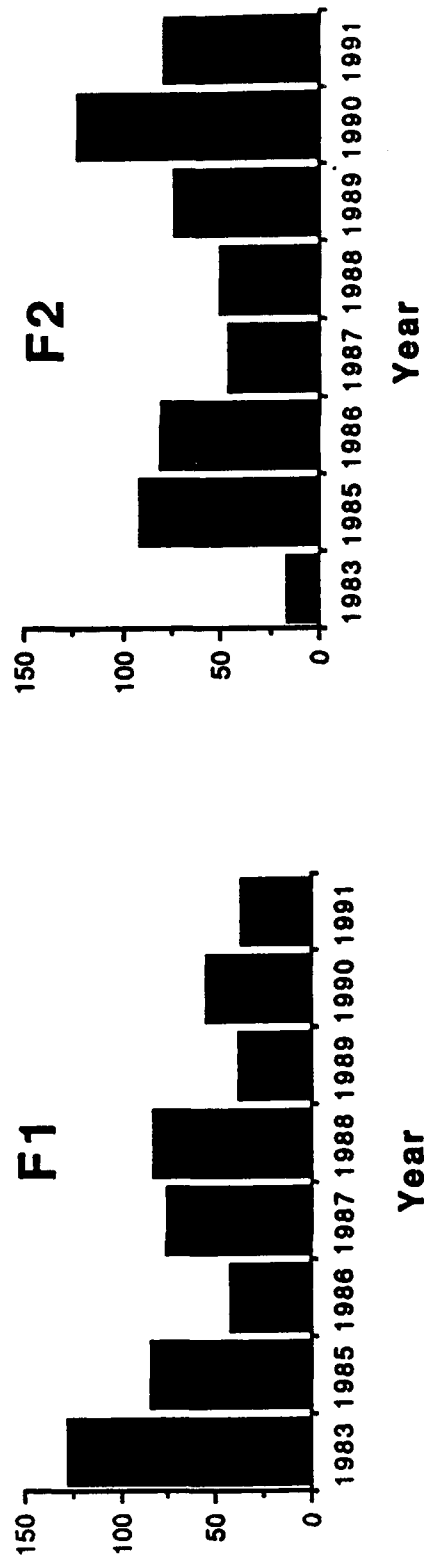
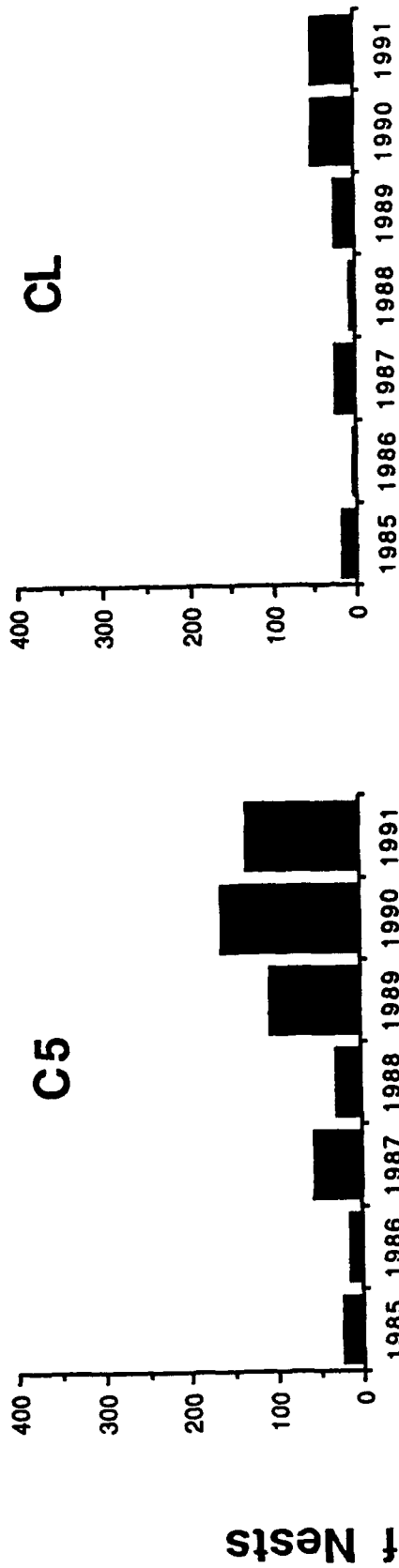
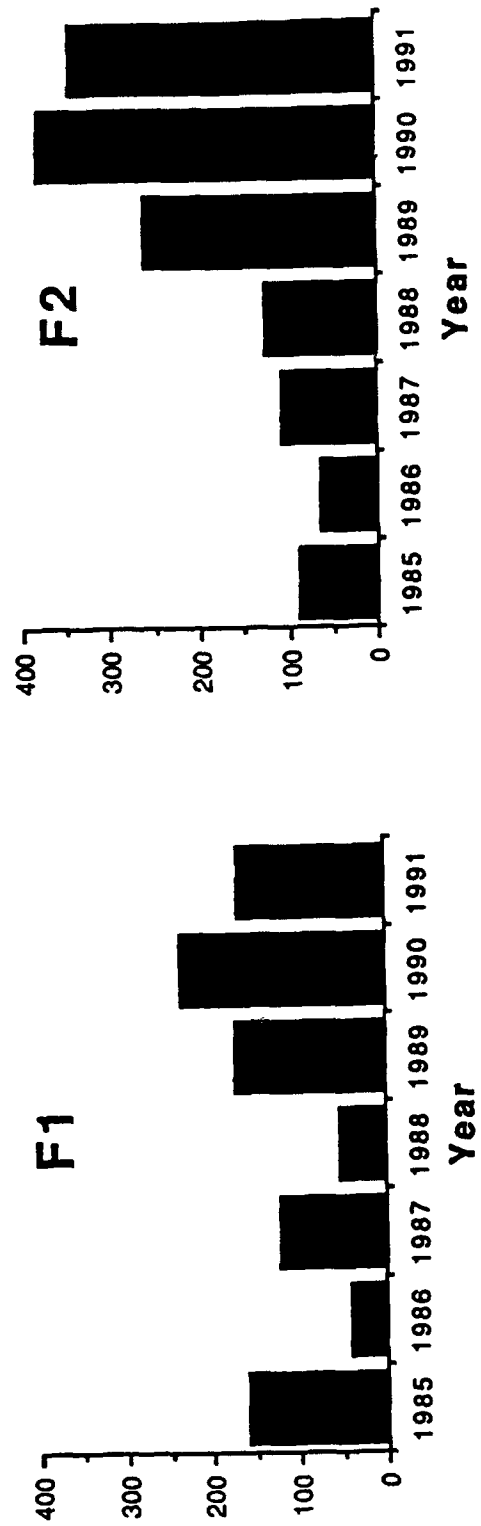


FIGURE 11. Number of nests of *M. relativa* constructed at four sites, 1983-1991.

Control Sites



Experimental Sites

FIGURE 12 Number of nests of *M. inermis* constructed at four sites, 1985-1991.

CUMULATIVE PRECIPITATION

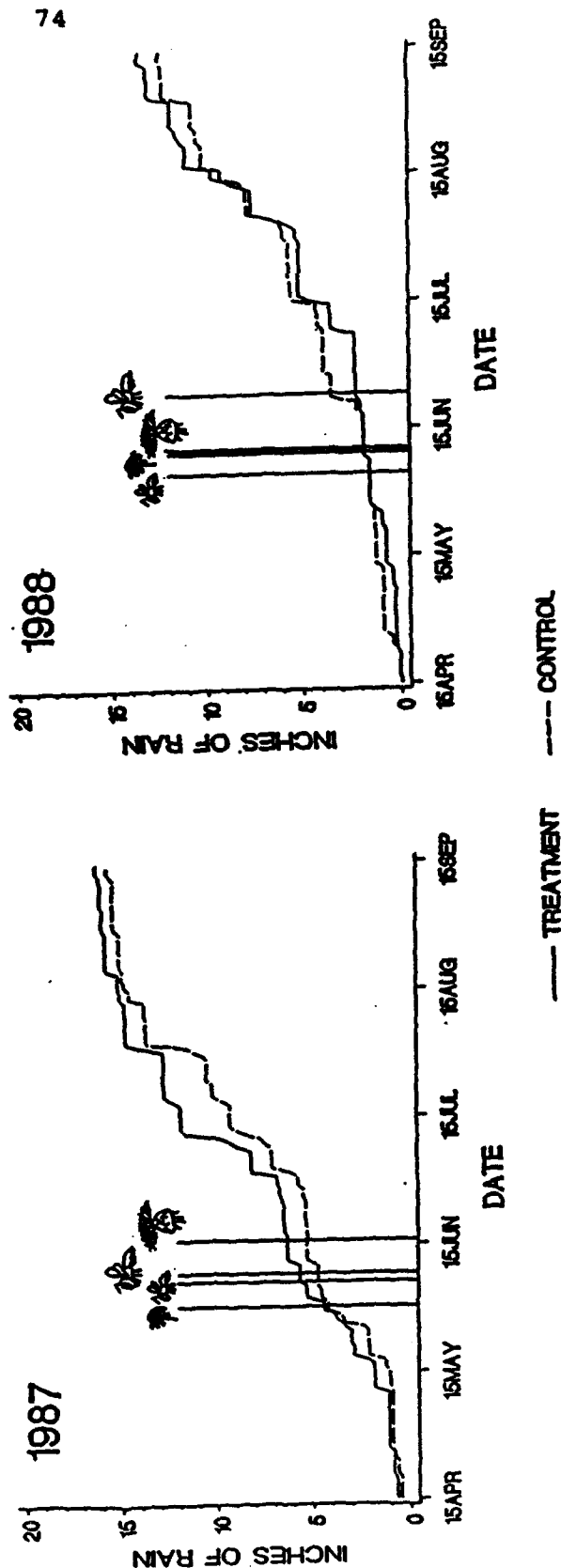
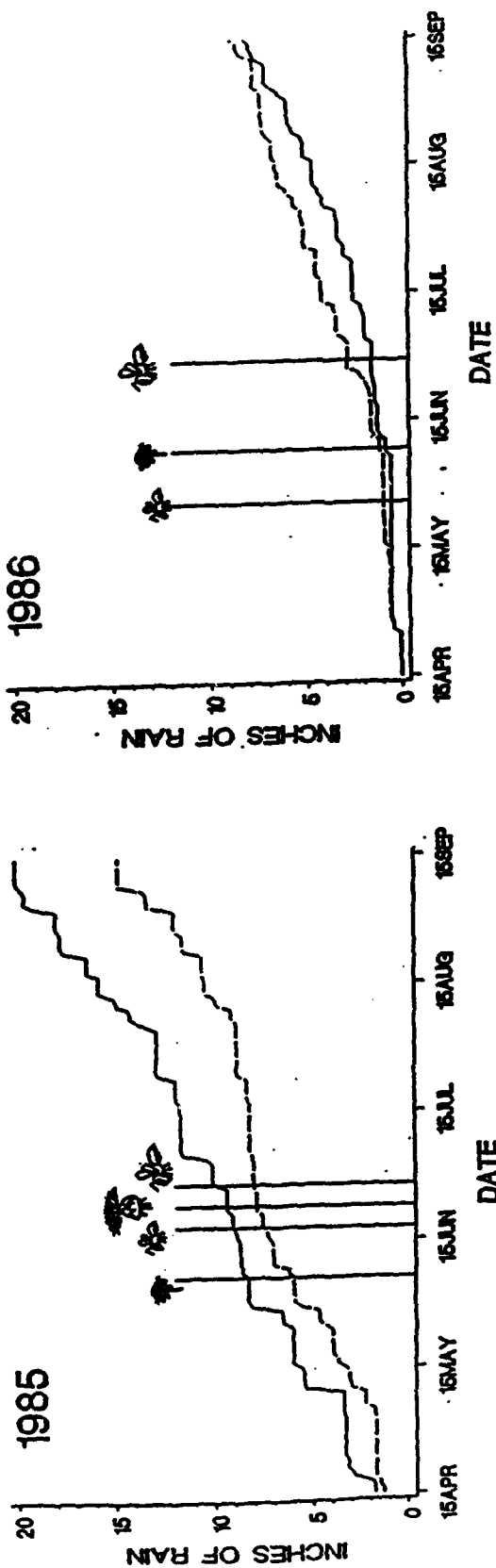
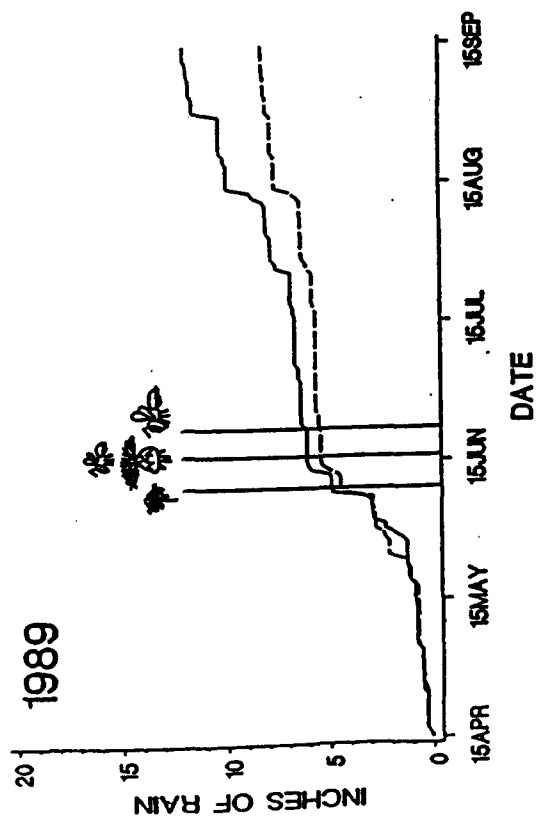
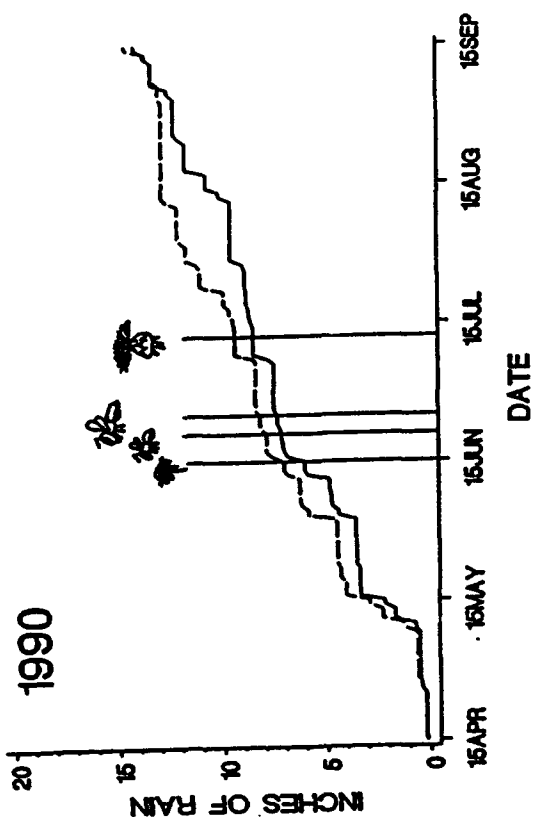


FIGURE 13. Cumulative precipitation at MTU pine plantations. Vertical lines indicate date of first nest of *M. relativa* (small bee) and *M. inermis* (large bee), and first bloom of orange hawkweed (*Hieracium aurantiacum*) and thistle (*Cirsium palustre*).

CUMULATIVE PRECIPITATION



75

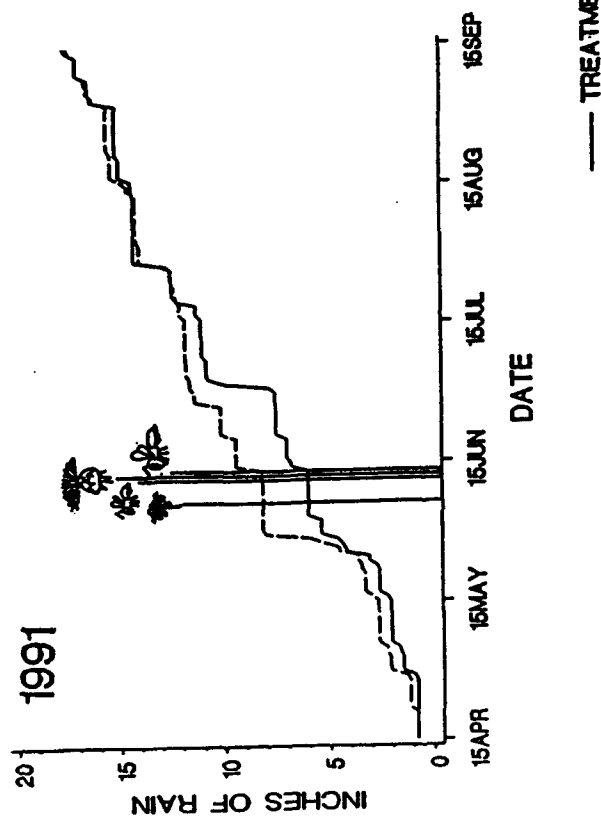


FIGURE 13 (cont.). Cumulative precipitation at MTU pine plantations.

Summary of Thistle Patches

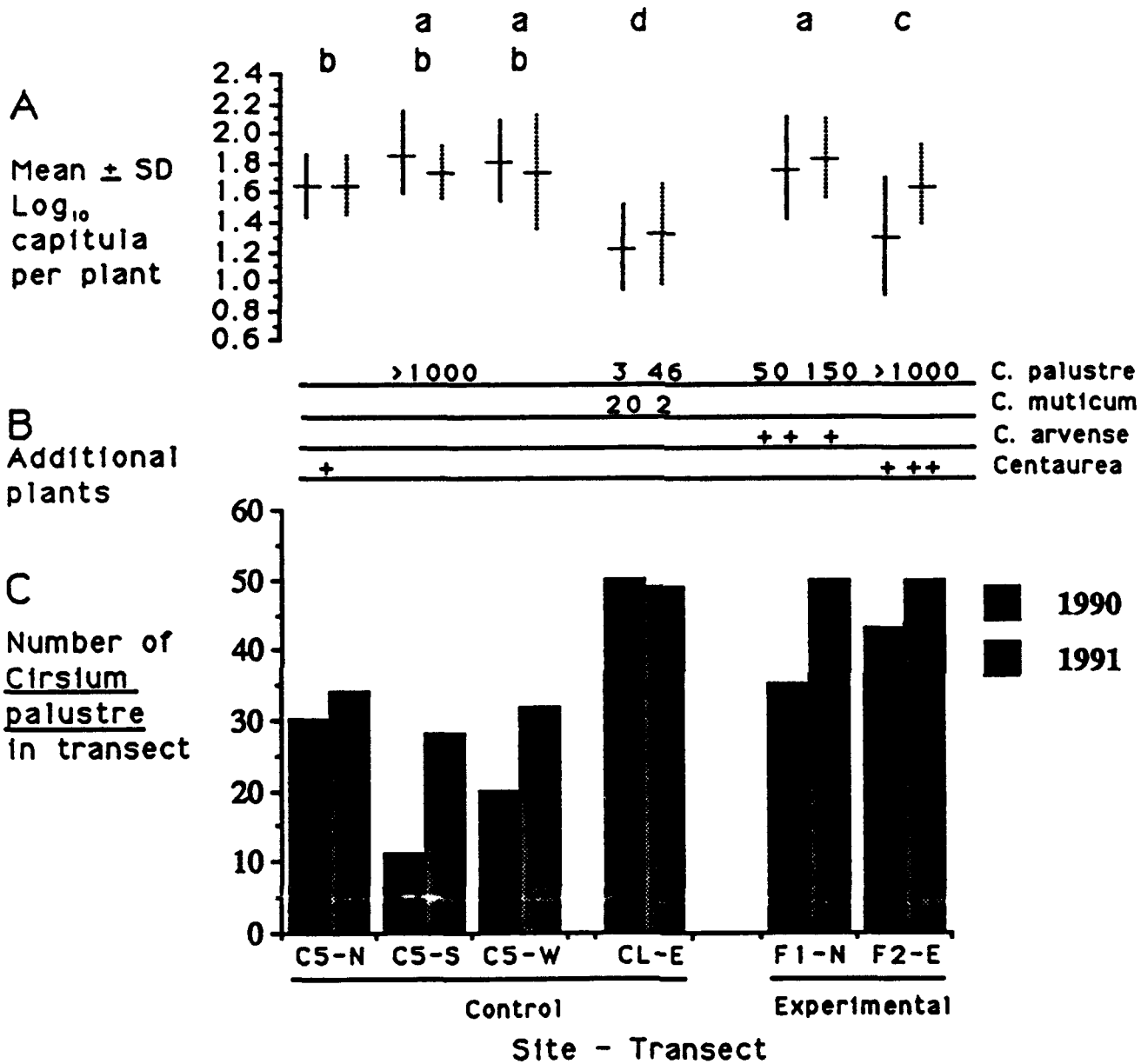


FIGURE 14. Summary of information about Cirsium palustre plants in bloom in 5 patches and along one transect in 1990 and 1991.

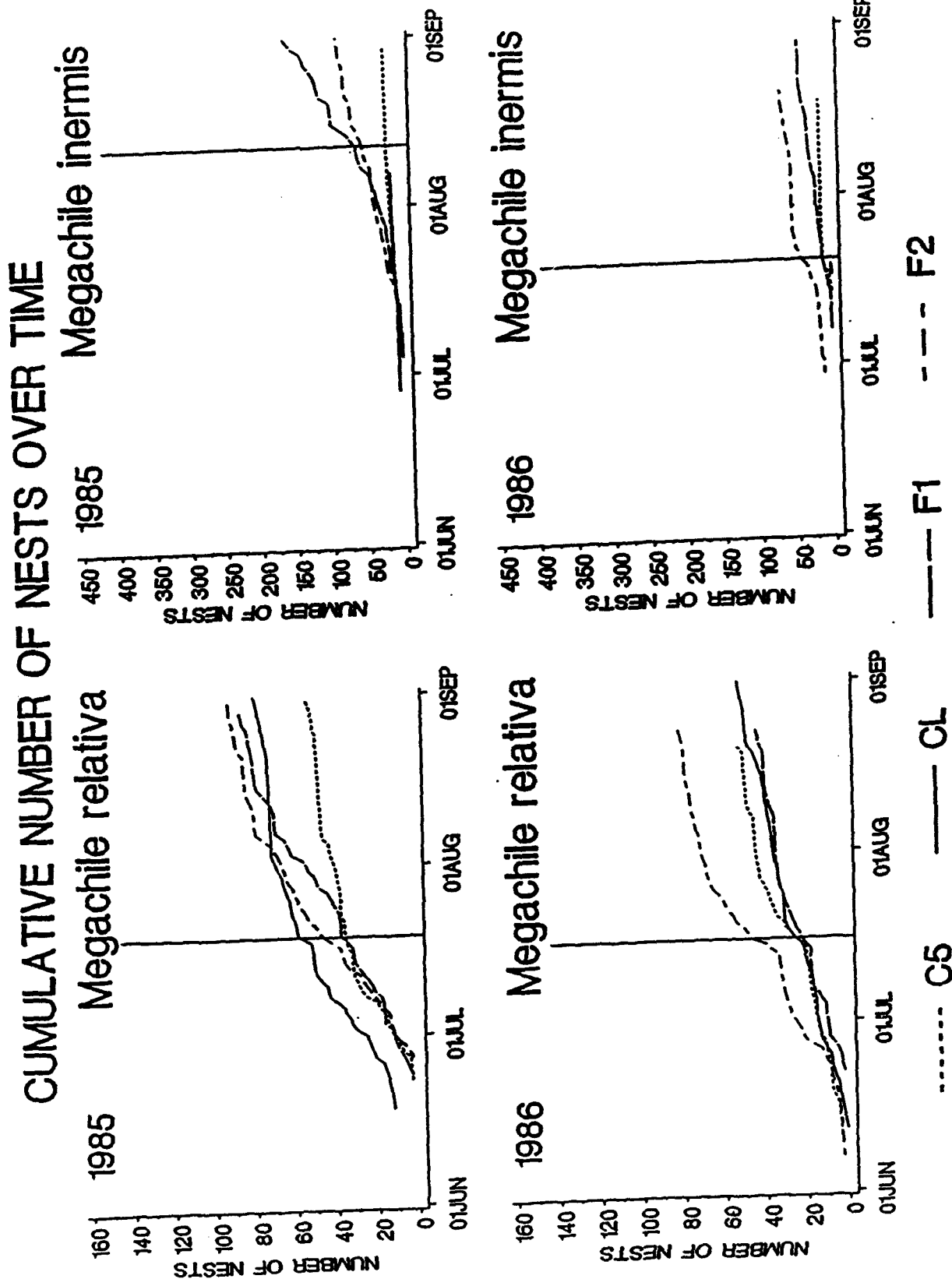


FIGURE 15a. Cumulative number of nests of *M. relativa* and *M. inermis* at each site, 1985-1986. Note different scales for each species. Vertical lines indicate date on which the last early season nests were begun for each site.

CUMULATIVE NUMBER OF NESTS OVER TIME

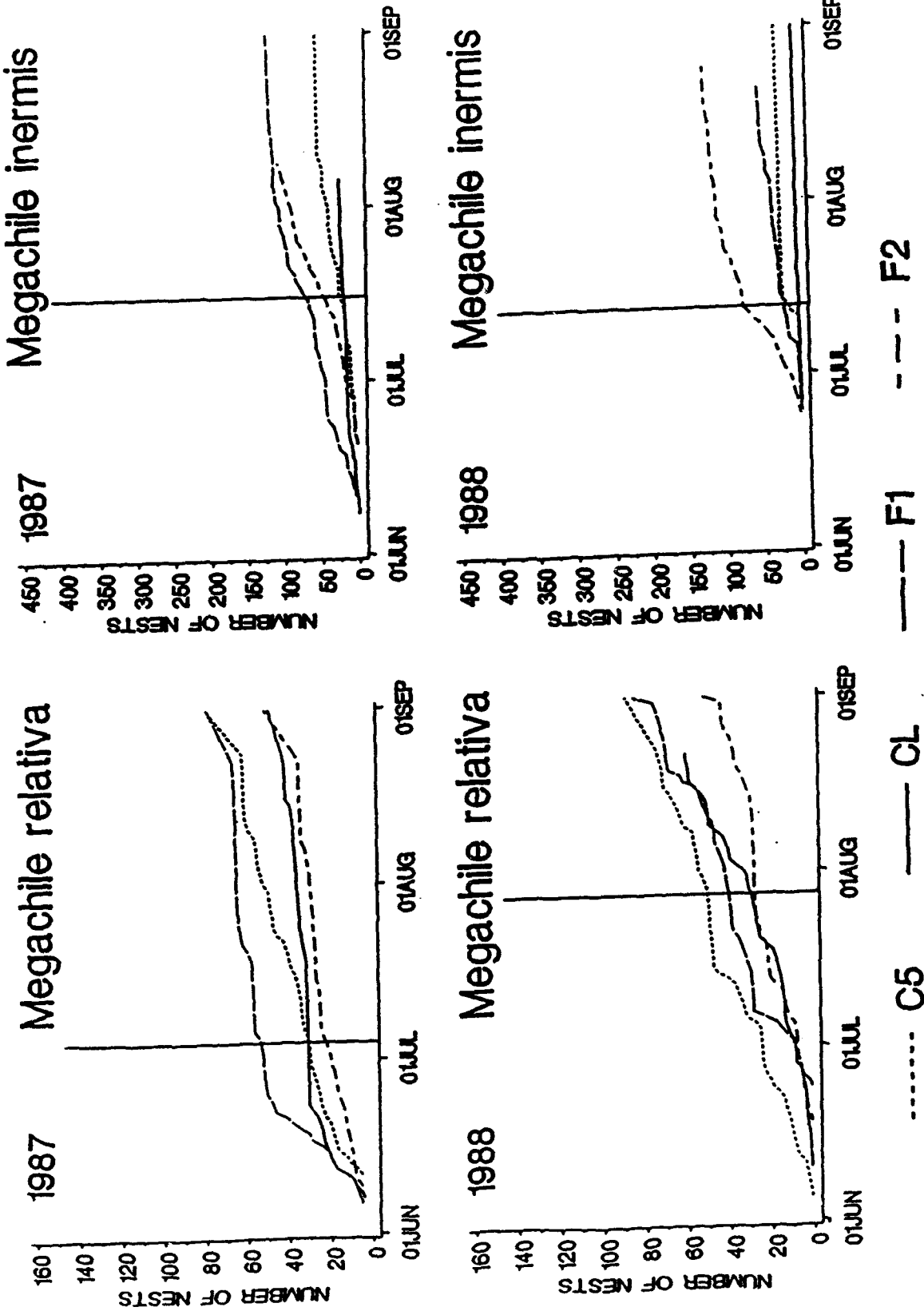


FIGURE 15b. Cumulative number of nests of *M. relativa* and *M. inermis* at each site, 1987-1988. Note different scales for each species. Vertical lines indicate date on which the last early season nests were begun for each site.

CUMULATIVE NUMBER OF NESTS OVER TIME

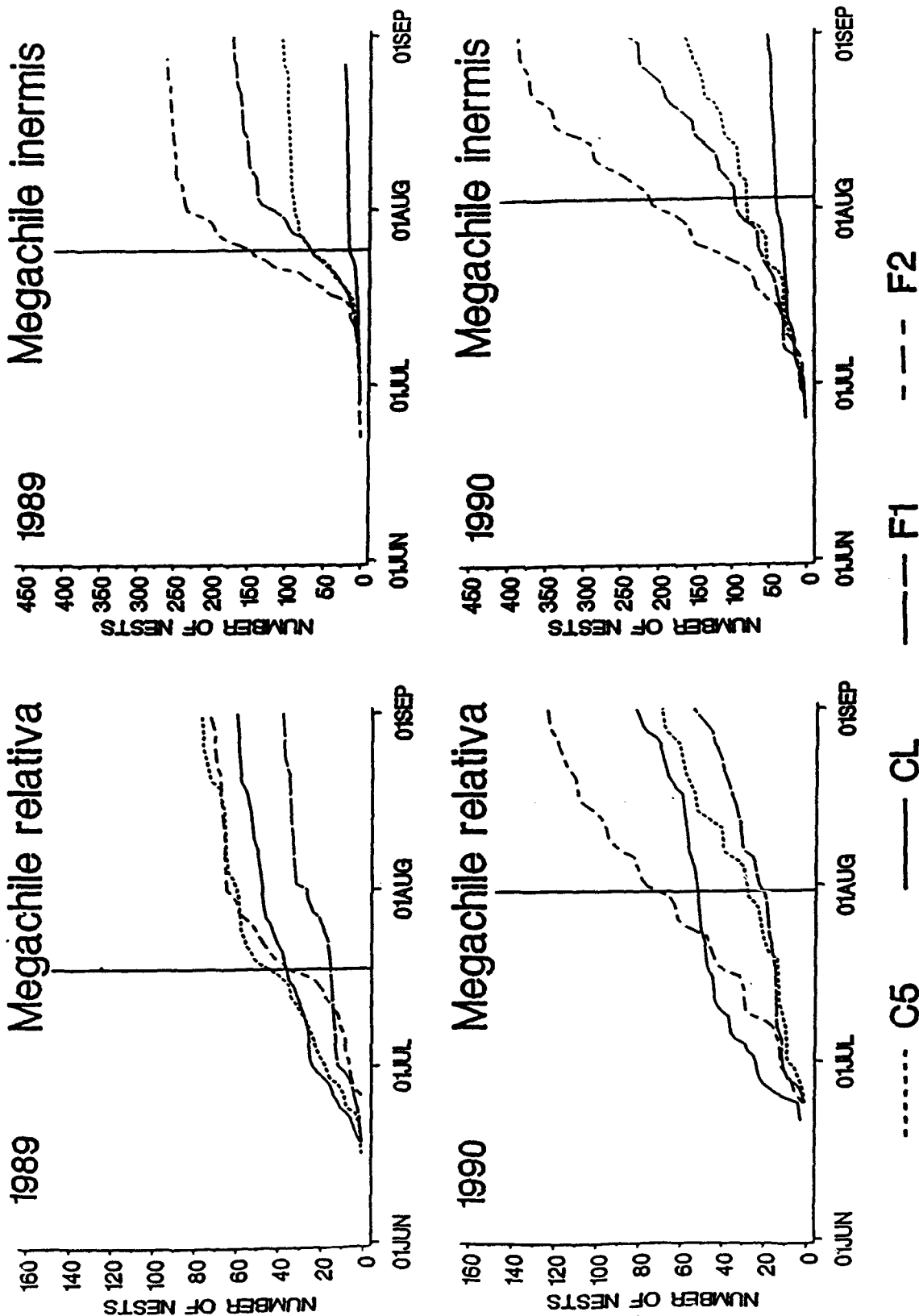


FIGURE 15c. Cumulative number of nests of *M. relativa* and *M. inermis* at each site, 1989-1990. Note different scales for each species. Vertical lines indicate date on which the last early season nests were begun for each site.

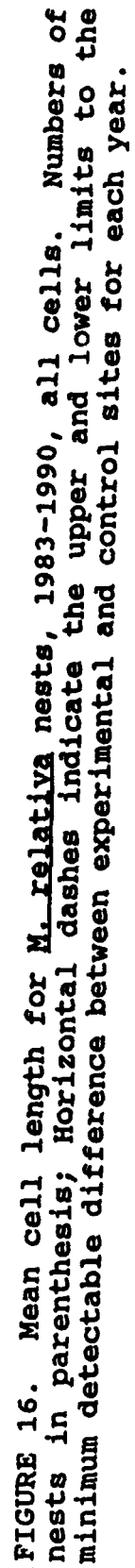


Table 4. GLM of mean cell length for all cells from 1983-1990 *M. relativa* nests.

CELL LENGTHS

Source of variation	df	SS	F	P>F
Year	6	37.03	2.72	0.0541
Diameter	1	17.24	23.86	0.0001***
Exp	1	1.71	0.22	0.6835
Site[Exp]	2	15.32	10.60	0.0001***
Exp*Year	6	19.41	0.42	0.8254
Complete vs. incomplete	1	4.39	6.08	0.0138*
Measurer[Yr]	15	34.00	3.14	0.0001***
Cells per nest	1	48.50	67.11	0.0001***
Early vs. Late				
Season	1	46.26	64.01	0.0001***
Model	34	232.61	9.47	0.0 ***
Error	1687	1219.09		
$\bar{X} = 11.1$ mm	CV = 7.6	$r^2 = 0.16$		

Table 4 (continued)

Parameter	Estimates:	T for H ₀ : Parameter = 0	PR > T
Yr: 1983	0.3300	0.38	0.7059
1985	-0.3331	-2.65	0.0081*
1986	-0.1458	-0.80	0.4243
1987	0.1595	1.25	0.2109
1988	-0.1461	-1.17	0.2441
1989	0.0516	0.38	0.7045
1990	0.0	—	—
Diameter	-0.1826	-4.88	0.0001***
Site C5	0.0	—	—
CL	0.2757	4.26	0.0001***
F1	0.0969	1.58	0.1141
F2	0.0	—	—
Complete vs. Incomplete	0.1222 0.0	2.47 —	0.0138* —
Cells per nest	-0.0796	-8.19	0.0001***
Early Season vs. Late Season	0.3516 0.0	8.00 —	0.0001*** —
Measurer[YR]- significant measurers only			
KS 1985	0.3196	2.50	0.0124*
KS 1988	0.2458	2.03	0.0425*
KS 1989	0.2653	2.01	0.0447*
JR 1990	0.3206	2.94	0.0034*

Table 5: GLM of mean cell length for 1983 - 1990 *M. relativa* nests; cells expected to have female offspring.

CELL LENGTHS

Source of variation	df	SS	F	P>F
Year	6	12.06	1.86	0.1632
Diameter	1	5.84	8.23	0.0044*
Exp	1	0.47	0.37	0.6054
Site[Exp]	2	2.56	1.81	0.1659
Exp*Year	6	7.86	1.02	0.5712
Complete vs. incomplete	1	0.69	0.97	0.3252
Measurer[Yr]	13	14.02	1.52	0.1082
Cells per nest	1	5.67	7.99	0.0050*
Early vs. Late Season	1	11.73	16.53	0.0001***
Model	32	74.50	3.37	0.0001***
Error	331	234.87		
$\bar{X} = 11.6\text{mm}$	CV = 7.3	$r^2 = 0.25$		

Parameter	Estimate	T for H ₀ : Parameter = 0	PR > T
Diameter	-0.23	-2.87	0.0044*
Cells per nest:	-0.06	-2.83	0.0050*
Early Season vs. Late Season	0.44 0.0	4.07 —	0.0001*** —

TABLE 6: GLM of mean cell lengths for 1983 - 1990 *M. relativa* nests; cells expected to have male offspring.

CELL LENGTHS

Source of variation	df	SS	F	P>F
Year	6	28.48	1.82	0.1720
Diameter	1	16.26	26.25	0.0001***
Exp	1	3.42	0.41	0.5872
Site[Exp]	2	16.67	13.45	0.0001***
Exp*Year	6	9.75	0.41	0.5872
Complete vs. incomplete	1	2.18	3.52	0.0608
Measurer[Yr]	13	33.91	4.21	0.0001***
Cells per nest	1	29.10	46.97	0.0001***
Early vs. Late Season	1	22.20	35.83	0.0001***
Model	32	166.26	8.39	0.0001***
Error	1025	635.00		
$\bar{Y} = 10.9\text{mm}$	CV = 7.2	$r^2 = 0.21$		

Table 6 continued

Parameter	Estimate	T for H_0 : Parameter = 0	PR > T
Diameter	-0.2200	-5.12	.0001***
Site [Exp]:			
C5	0.0	—	—
CL	0.4011	4.85	0.0001***
F1	0.1200	1.63	0.1030
F2	0.0	—	—
Cells per nest	-0.0773	-6.85	0.0001***
Early Season vs. Late Season	0.3115 0.0	5.99 —	0.0001*** —
Measurer[YR] - significant measurers only			
ER 1985	0.2977	2.11	0.0353*
KS 1985	0.3992	2.80	0.0052*
KS 1988	0.4311	2.55	0.0109*
JR 1990	0.4736	3.70	0.0002***

Table 7: M. relativa secondary sex ratio by site and year.

Site	1985			1986		
	Males	Females	Ratio	Males	Females	Ratio
C5	98	9	10.9	69	23	3.0
CL	129	49	2.6	75	9	8.3
F1	262	42	6.2	94	18	5.2
F2	129	30	4.3	204	32	6.4
Total	618	130	4.8	442	82	5.4

Site	1987			1988		
	Males	Females	Ratio	Males	Females	Ratio
C5	207	67	3.1	70	25	2.8
CL	55	24	2.3	23	7	3.3
F1	186	60	3.1	111	12	9.3
F2	38	7	5.4	32	9	3.6
Total	486	158	3.1	236	53	4.5

Site	1989			1990		
	Males	Females	Ratio	Males	Females	Ratio
C5	148	70	2.1	125	26	4.8
CL	54	35	1.5	78	16	4.9
F1	95	18	5.3	92	26	3.5
F2	101	21	4.8	221	44	5.0
Total	398	144	2.8	516	112	4.6

TABLE 8: *M. relativa* primary sex ratio by site and year.

Site	1985			1986		
	Males	Females	Ratio	Males	Females	Ratio
C5	173.0	25.0	6.9	143.5	44.5	3.2
CL	216.8	90.2	2.4	157.9	22.1	7.1
F1	373.9	79.1	4.7	160.0	27.0	5.9
F2	215.9	68.1	3.2	305.7	45.3	6.8
Total	979.6	262.4	3.7	767.1	138.9	5.5

Site	1987			1988		
	Males	Females	Ratio	Males	Females	Ratio
C5	316.5	98.5	3.2	194.2	55.8	3.5
CL	132.4	47.6	2.8	97.1	30.9	3.1
F1	302.1	83.9	3.6	260.9	25.1	10.4
F2	108.1	23.9	4.5	106.5	23.5	4.5
Total	859.1	253.9	3.4	658.7	135.3	4.9

Site	1989		
	Males	Females	Ratio
C5	251.2	107.8	2.3
CL	123.3	66.7	1.9
F1	145.3	23.7	6.1
F2	189.9	53.1	3.6
Total	709.7	251.3	2.8

TABLE 9: Differences between measurers in mean cell lengths for M. relativa.

Measurer	Mean Cell Lengths m m	No. Cells Measured
JH (1983)	11.1	1
MA (1983)	11.3	162
VS (1983)	11.7	1
ER (1985)	10.8	85
ND (1985)	10.6	99
KS (1985)	10.9	81
JZ (1986)	11.3	64
KS (1986)	11.2	58
LS (1986)	10.7	49
MS (1986)	11.1	36
KS (1987)	11.3	99
LS (1987)	11.2	28
VS (1987)	11.3	108
BZ (1988)	11.0	68
KS (1988)	11.4	80
VS (1988)	11.2	130
BZ (1989)	11.0	79
KS (1989)	11.4	83
VS (1989)	11.1	84
JR (1990)	11.4	102
KS (1990)	10.9	72
VS (1990)	11.0	153

TABLE 10: Two-Way, Model II ANOVA partitioning the variance in cell length within and between measurer.

CELL LENGTHS				
Source of Variance	DF	MS	F	P>F
Between Measurers	3	9.587	65.39	0.0001***
Between Cells	38	7.540	51.42	0.0000***
Within Measurer (Error)	355	0.147		
$\bar{X} = 10.5\text{mm}$	CV = 3.6	$r^2 = 0.86$		
Between Measurers	$s^2 + 2.55s_{mc}^2 + 39(2.55)s_m^2$		0.095	9.8%
Between Cells	$s^2 + 2.55s_{mc}^2 + 4(2.55)s_c^2$		0.725	75.0%
Within Measurer Error)	$s^2 + 2.55s_{mc}^2$		0.147	15.2%

Mean Cell Length Megachile inermis

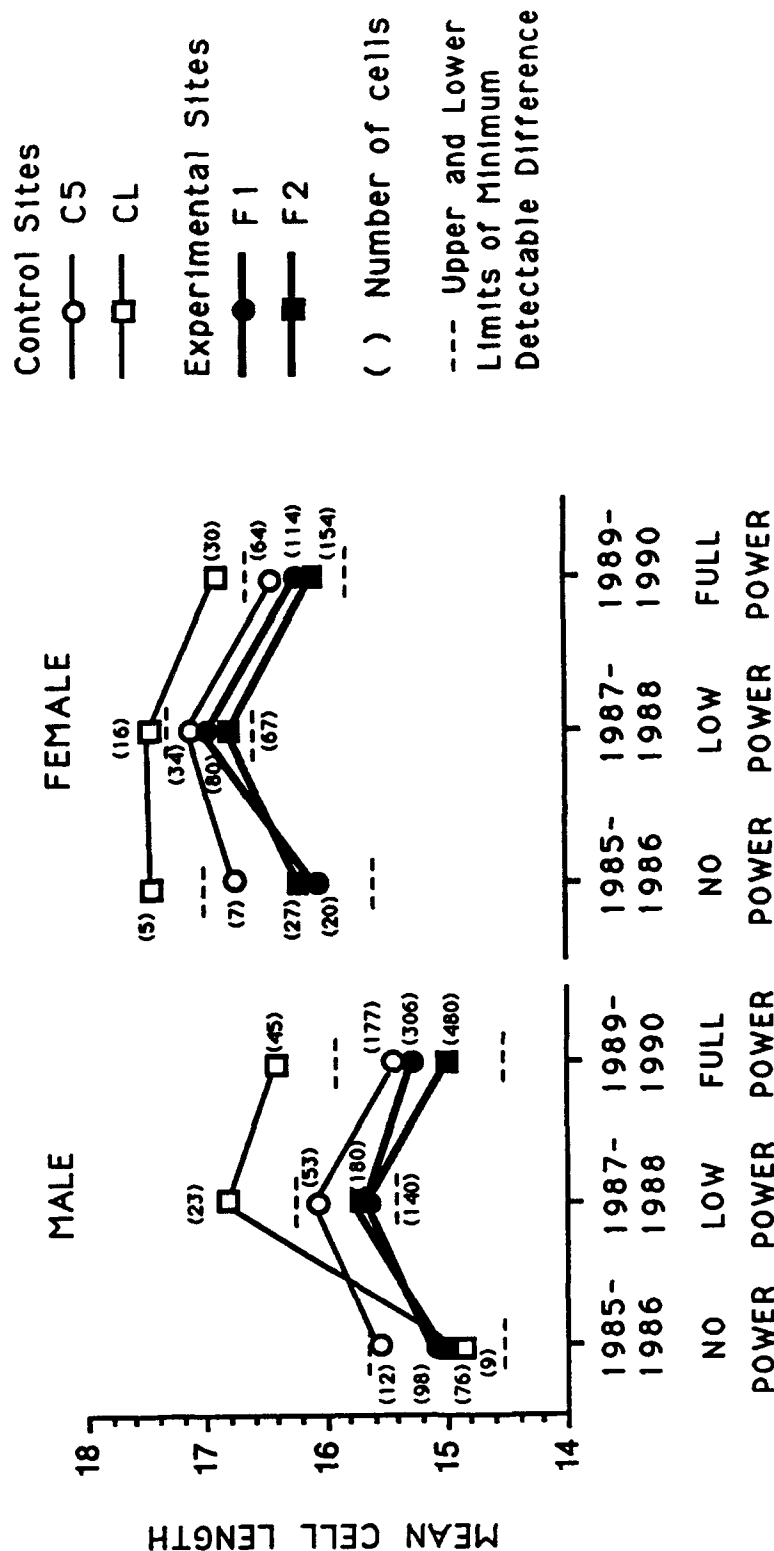


FIGURE 17. Mean cell length for *M. inermis* nests by sex, diameters >9.5mm. Pooled pre-operational (1985-1986), low power (1987-1988) and full power (1989-1990) years. Numbers of nests in parenthesis. Horizontal dashes indicate upper and lower limits to the minimum detectable difference between experimental and control sites for each year.

Table 11: GLM of mean cell lengths for M. inermis nests; cells expected to have female offspring, pooled pre-operational, low power, and full operational years; diameters > 9.5mm.

CELL LENGTHS

Source of variation	df	SS	F	P>F
Year (85-86; 87-88; 89-90)	2	8.37	0.36	0.7095
Diameter	1	1.53	1.49	0.2230
Exp	1	9.34	1.64	0.3288
Site[Exp]	2	11.39	5.53	0.0042*
Exp*Year	2	1.27	0.11	0.8996
Complete vs. incomplete	1	13.01	12.63	0.0004***
Measurer[Yr]	9	105.62	11.40	0.0001***
Cells per nest	1	54.08	52.52	0.0001***
Early vs. Late Season	1	0.63	0.61	0.4343
Bore Depth	1	1.73	1.68	0.1953
Bore Depth*Year	2	8.28	0.35	0.7121
Diameter*Bore depth	1	1.91	1.85	0.1743
Diameter*Year	2	7.84	0.33	0.7246
Diameter*Year* Bore Depth	2	7.76	0.33	0.7269
Model	28	291.04	10.09	0.0001***
Error	589	606.51		
$\bar{X} = 16.5\text{mm}$	CV = 6.2	$r^2 = 0.32$		

Table 11 continued

Parameter	Estimate	T for H_0 : Parameter = 0	PR > T
Site [Exp]:			
C5	0.0	—	—
CL	0.5225	2.94	0.0034*
F1	0.1487	1.49	0.1365
F2	0.0	—	—
Complete vs. Incomplete	0.5816 0.0	3.55 —	0.0004*** —
Cells per nest	-0.3062	-7.25	0.0001***
Measurer[YR] - significant measurers only			
JZ (85-86)	0.9812	2.05	0.0404*
KS (87-88)	1.3047	7.89	0.0001***
KS (89-90)	0.5239	4.01	0.0001***

Table 12: GLM of mean cell lengths for M. inermis nests; cells expected to have male offspring; pooled pre-operational, low power, and full operational years; diameters > 9.5mm.

CELL LENGTHS

Source of variation	df	SS	F	P>F
Year (85-86; 87-88; 89-90)	2	3.96	0.05	0.9511
Diameter	1	1.44	1.57	0.2108
Exp	1	19.18	0.88	0.4469
Site[Exp]	2	43.53	23.62	0.0001***
Exp*Year	2	6.47	0.15	0.8705
Complete vs. incomplete	1	30.41	33.00	0.0001***
Measurer[Yr]	9	353.62	42.63	0.0***
Cells per nest	1	214.27	232.50	0.0
Early vs. Late Season	1	0.97	1.05	0.3047
Bore Depth	1	1.59	1.73	0.1889
Bore Depth*Year	2	4.31	0.05	0.9469
Diameter*Bore depth	1	2.08	2.26	0.1331
Diameter*Year	2	4.22	0.05	0.9480
Diameter*Year* Bore Depth	2	4.55	0.06	0.9441
Model	28	858.54	33.27	0.0***
Error	1570	1446.95		
$\bar{X} = 15.3\text{mm}$	CV = 6.3	$r^2 = 0.37$		

Table 12 continued

Parameter	Estimate	T for H_0 : Parameter = 0	PR > T
Site [Exp]:			
C5	0.0	—	—
CL	0.6880	5.36	0.0001***
F1	0.2379	4.20	0.0001***
F2	0.0	—	—
Complete vs. Incomplete	0.4656 0.0	5.74 —	0.0001*** —
Cells per nest	-0.3288	-15.25	0.00 ***
Measurer[YR] - significant measurers only			
JZ (85-86)	0.5607	2.17	0.0298*
KS (85-86)	1.1781	4.24	0.0001***
LS (85-86)	-0.4582	-2.60	0.0094*
KS (87-88)	1.3197	12.42	0.0001***
BZ (89-90)	-0.5635	-5.23	0.0001***
JR (89-90)	0.3845	4.28	0.0001***
KS (89-90)	0.6770	9.10	0.0001***

TABLE 13: Differences between observers in mean male cell lengths for M. inermis, bore diameters > 9.5mm.

Measurer	Mean Cell Lengths m m	No. Nests Measured
LS (1985-86)	14.7	107
MS (1985-86)	15.0	49
JZ (1985-86)	15.7	21
KS (1985-86)	16.4	18
LS (1987-88)	15.1	36
VS (1987-88)	15.4	188
BZ (1987-88)	15.4	23
KS (1987-88)	16.6	149
VS (1989-90)	15.0	416
BZ (1989-90)	14.4	102
KS (1989-90)	15.7	284
JR (1989-90)	15.5	206

Table 14: *M. inermis* secondary sex ratio by site and year.

Site	1985			1986		
	Males	Females	Ratio	Males	Females	Ratio
C5	27	7	3.9	35	10	3.5
CL	25	12	2.1	6	2	3.0
F1	322	22	14.6	80	17	4.7
F2	140	37	3.8	180	29	6.2
Total	514	78	6.6	301	58	5.2

Site	1987			1988		
	Males	Females	Ratio	Males	Females	Ratio
C5	104	36	2.9	46	26	1.8
CL	46	29	1.6	8	1	8.0
F1	315	142	2.2	132	27	4.9
F2	295	79	3.7	262	65	4.0
Total	760	286	2.7	448	119	3.8

Site	1989			1990		
	Males	Females	Ratio	Males	Females	Ratio
C5	194	48	4.0	295	56	5.3
CL	35	15	2.3	57	34	1.7
F1	354	90	3.9	506	159	3.2
F2	556	93	6.0	890	213	4.2
Total	1139	246	4.6	1748	462	3.8

TABLE 15: *M. inermis* primary sex ratio by site and year.

Site	1985			1986		
	Males	Females	Ratio	Males	Females	Ratio
C5	56.6	17.4	3.3	49.8	16.2	3.1
CL	39.6	26.4	1.5	6	2	3.0
F1	503.9	56.1	9.0	127.2	42.8	3.0
F2	222.5	65.5	3.4	251.9	42.1	6.0
Total	822.6	165.4	5.0	434.9	103.1	4.2

Site	1987			1988		
	Males	Females	Ratio	Males	Females	Ratio
C5	185.7	66.3	2.8	73.4	42.6	1.7
CL	73.8	39.2	1.9	14	6	2.3
F1	431.4	189.6	2.3	191.6	44.2	4.3
F2	444.1	108.9	4.1	446.2	111.8	4.0
Total	1135.0	404.0	2.8	725.2	204.6	3.5

Site	1989		
	Males	Females	Ratio
C5	344.7	108.3	3.2
CL	66.0	30.1	2.2
F1	621.7	185.3	3.4
F2	1027.7	215.3	4.8
Total	2060.1	539.0	3.8

TABLE 16: *M. relativa* Weights by Sex, Site and Year.

$\overline{\text{mg}} \pm \text{S.D.}$ (N)					
Female					
YEAR	C5	CL	F1	F2	TOTAL
Dry Weights					
1986	14.6 ± 2.6 (8)	13.5 ± 1.5 (3)	14.9 ± 4.7 (11)	14.8 ± 3.5 (18)	14.7 ± 3.5 (40)
1987	15.2 ± 2.2 (26)	14.1 ± 2.3 (11)	15.7 ± 1.5 (36)	15.8 ± 1.5 (6)	15.4 ± 1.9 (79)
1988	12.4 ± 2.8 (6)	10.6 ± 0.8 (3)	10.8 ± 3.1 (7)	13.3 ± 3.6 (5)	11.8 ± 2.9 (21)
Live Weights					
1987	41.5 ± 5.8 (18)	44.6 ± 5.1 (6)	43.6 ± 5.3 (19)	45.4 ± 3.7 (4)	43.1 ± 5.4 (47)
1988	39.8 ± 6.3 (23)	33.8 ± 3.2 (7)	31.5 ± 10.6 (8)	38.9 ± 8.3 (9)	37.3 ± 7.8 (47)

TABLE 16 continued

 $\overline{\text{mg}} \pm \text{S.D.}$
(N)

Male

YEAR	C5	CL	F1	F2	TOTAL
Dry Weights					
1986	10.9 $\pm$ 2.5 (34)	10.2 $\pm$ 2.3 (28)	10.8 $\pm$ 3.2 (27)	11.9 $\pm$ 2.5 (86)	11.3 $\pm$ 2.6 (175)
1987	12.3 $\pm$ 2.3 (89)	11.4 $\pm$ 2.3 (35)	12.2 $\pm$ 2.0 (95)	11.5 $\pm$ 2.5 (26)	12.1 $\pm$ 2.2 (245)
1988	8.6 $\pm$ 1.7 (51)	9.2 $\pm$ 1.9 (12)	9.6 $\pm$ 1.9 (63)	8.5 $\pm$ 1.4 (20)	9.1 $\pm$ 1.8 (146)
Live Weights					
1987	35.5 $\pm$ 5.2 (73)	32.6 $\pm$ 5.7 (25)	35.5 $\pm$ 4.5 (112)	33.2 $\pm$ 6.4 (33)	34.9 $\pm$ 5.2 (243)
1988	27.7 $\pm$ 4.6 (63)	27.7 $\pm$ 4.8 (22)	31.0 $\pm$ 5.8 (106)	28.5 $\pm$ 4.4 (29)	29.4 $\pm$ 5.4 (220)

TABLE 17: M. inermis Weights by Sex, Site and Year.

$\overline{\text{mg}} \pm \text{S.D.}$ (N)					
Female					
YEAR	C5	CL	F1	F2	TOTAL
Dry Weights					
1986	46.0 ± 6.0 (4)	64.0 ± 18.8 (5)	58.5 (1)	—*	56.3 ± 15.8 (10)
1987	49.3 ± 19.3 (12)	50.1 ± 10.9 (6)	57.3 ± 9.9 (51)	54.2 ± 12.4 (21)	55.0 ± 12.3 (90)
1988	51.7 ± 3.8 (4)	—*	51.9 ± 5.0 (5)	44.8 ± 9.5 (18)	47.1 ± 8.7 (27)
Live Weights					
1987	—*	—*	181.7 ± 16.1 (9)	159.4 ± 38.8 (8)	171.2 ± 30.3 (17)
1988	149.4 ± 22.4 (24)	159.4 (1)	150.2 ± 22.1 (23)	146.8 ± 27.0 (63)	148.2 ± 24.8 (111)

* No bees weighed.

TABLE 17 continued.

$\overline{\text{mg}} \pm \text{S.D.}$ (N)					
Male					
YEAR	C5	CL	F1	F2	TOTAL
Dry Weights					
1986	29.0 ± 5.4 (4)	—*	37.2 ± 10.2 (29)	39.6 ± 7.7 (47)	38.2 ± 8.8 (80)
1987	37.7 ± 7.4 (29)	37.5 ± 6.0 (15)	38.4 ± 6.9 (144)	37.6 ± 6.6 (79)	38.0 ± 6.8 (297)
1988	31.0 ± 5.6 (20)	31.0 ± 3.7 (6)	31.6 ± 6.7 (74)	32.6 ± 6.3 (143)	32.1 ± 6.3 (243)
Live Weights					
1987	100.6 ± 22.8 (7)	—*	111.7 ± 19.1 (39)	112.1 ± 22.6 (46)	111.1 ± 21.2 (92)
1988	97.1 ± 16.9 (43)	95.8 ± 11.7 (8)	98.5 ± 18.0 (118)	103.7 ± 20.3 (227)	101.3 ± 19.3 (396)

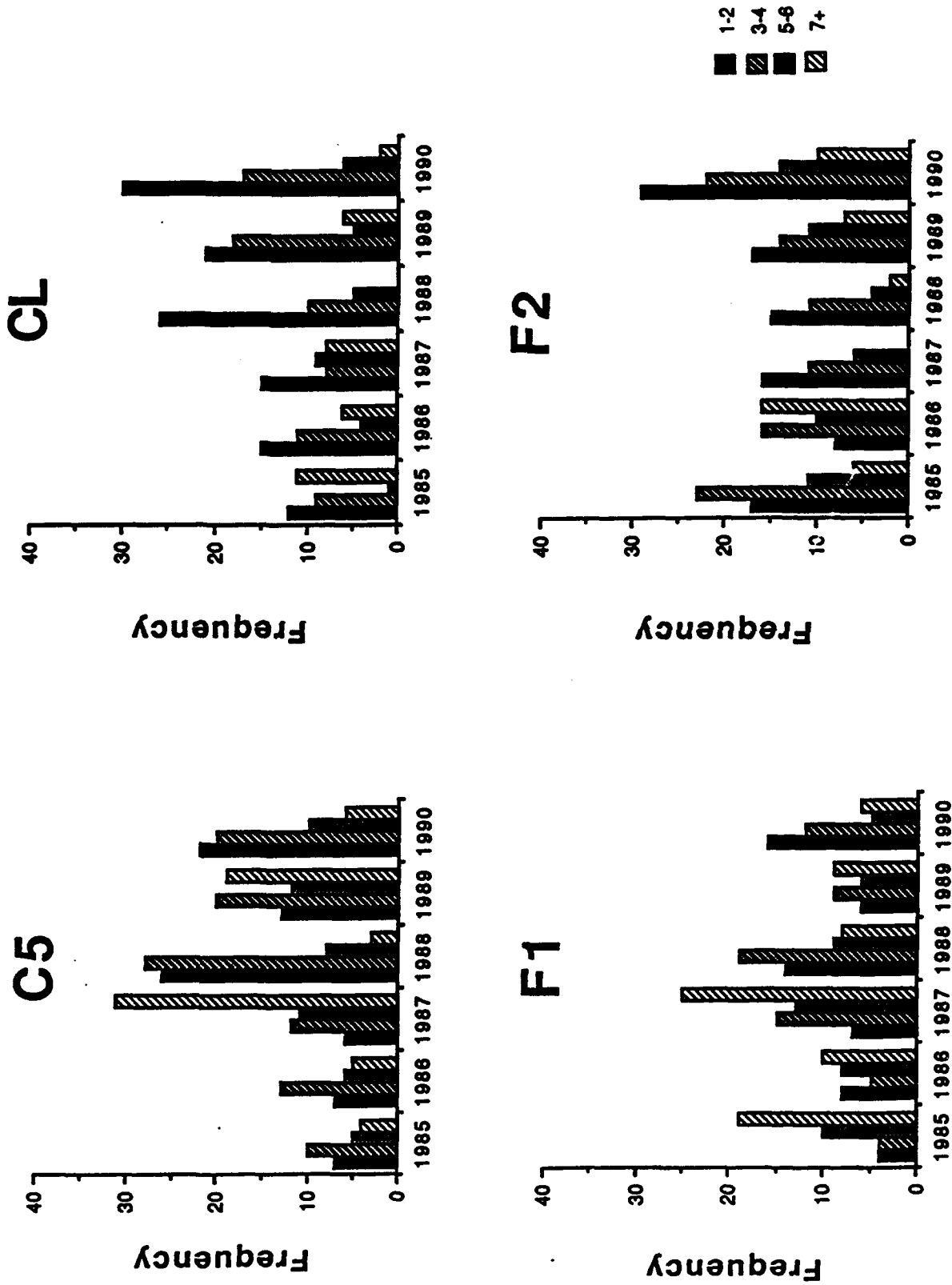


Figure 18. Number of complete nests of *M. relativus* with 1-2, 3-4, 5-6 or 7+ cells.

Table 18: Categorical modeling of number of cells per complete nest of Megachile relativa, 1985-1990.

NUMBER OF CELLS PER COMPLETE NEST

Source of variation	df	Chi.Square	Prob.
Intercept	3	72.58	0.0001***
Exp	3	15.08	0.0018*
Site[Exp]	6	57.65	0.0001***
Year	15	66.91	0.0001***
Exp*Year	15	23.12	0.0815
Likelihood Ratio	30	59.85	0.0010**
Contrast	df	Chi.Square	Prob.
1987 vs. 1988	1	34.37	0.0001***
1985-87 vs. 1988-90	1	45.71	0.0001***
Exp 85-87 vs. Exp 88-90	1	2.42	0.1198
Exp 85-88 vs. Exp 89-90	1	0.03	0.8559

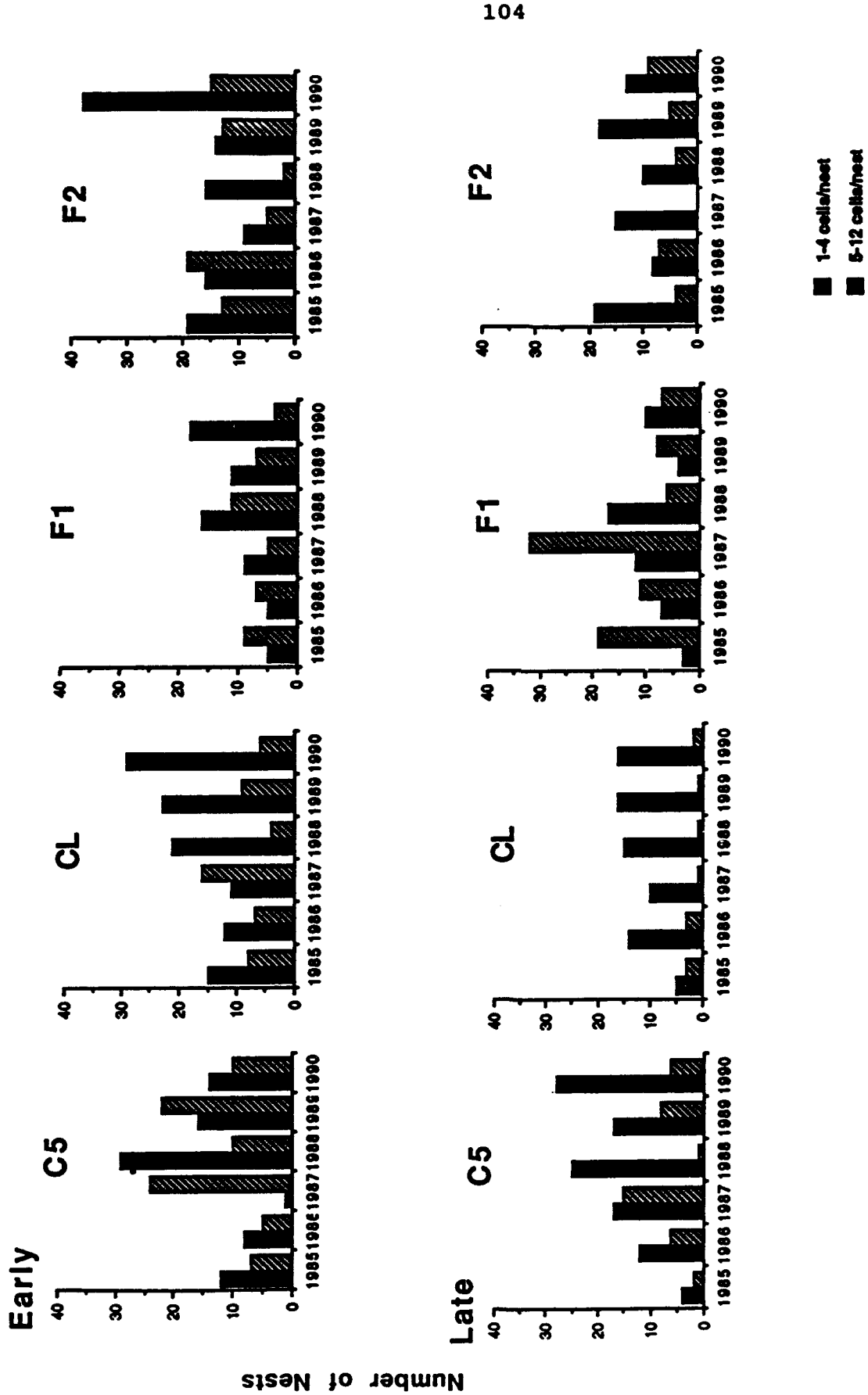


Figure 19. Number of complete nests of *M. relativa* with few (1-4) or many (5-12) cells, separated by season.

Table 19: Categorical modeling of number of cells per complete nest of Megachile relativa by season, 1985-1990.

NUMBER OF CELLS PER COMPLETE NEST			
Source of variation	df	Chi.Square	Prob.
Intercept	1	76.49	0.0001***
Exp	1	11.68	0.0006**
Site[Exp]	2	40.71	0.0001***
Year	5	4.80	0.0001***
Early vs. Late Season	1	32.06	0.0001***
Exp*Year	5	19.04	0.0019*
Exp*Season	1	1.98	0.1595
Year*Season	5	13.59	0.0184*
Exp*Year*Season	5	9.16	0.1028
Likelihood Ratio	22	36.72	0.0254*
Contrast	df	Chi.Square	Prob.
1987 vs. 1988	1	26.08	0.0001***
1985-87 vs. 1988-90	1	31.82	0.0001***
Exp 85-87 vs. Exp 88-90	1	0.31	0.5756
Exp 85-88 vs. Exp 89-90	1	0.31	0.5756
Early 87 vs. Early 85+86+89	1	9.68	0.0019*
Early 87 vs. Early 85+86+89+90	1	10.23	0.0014*

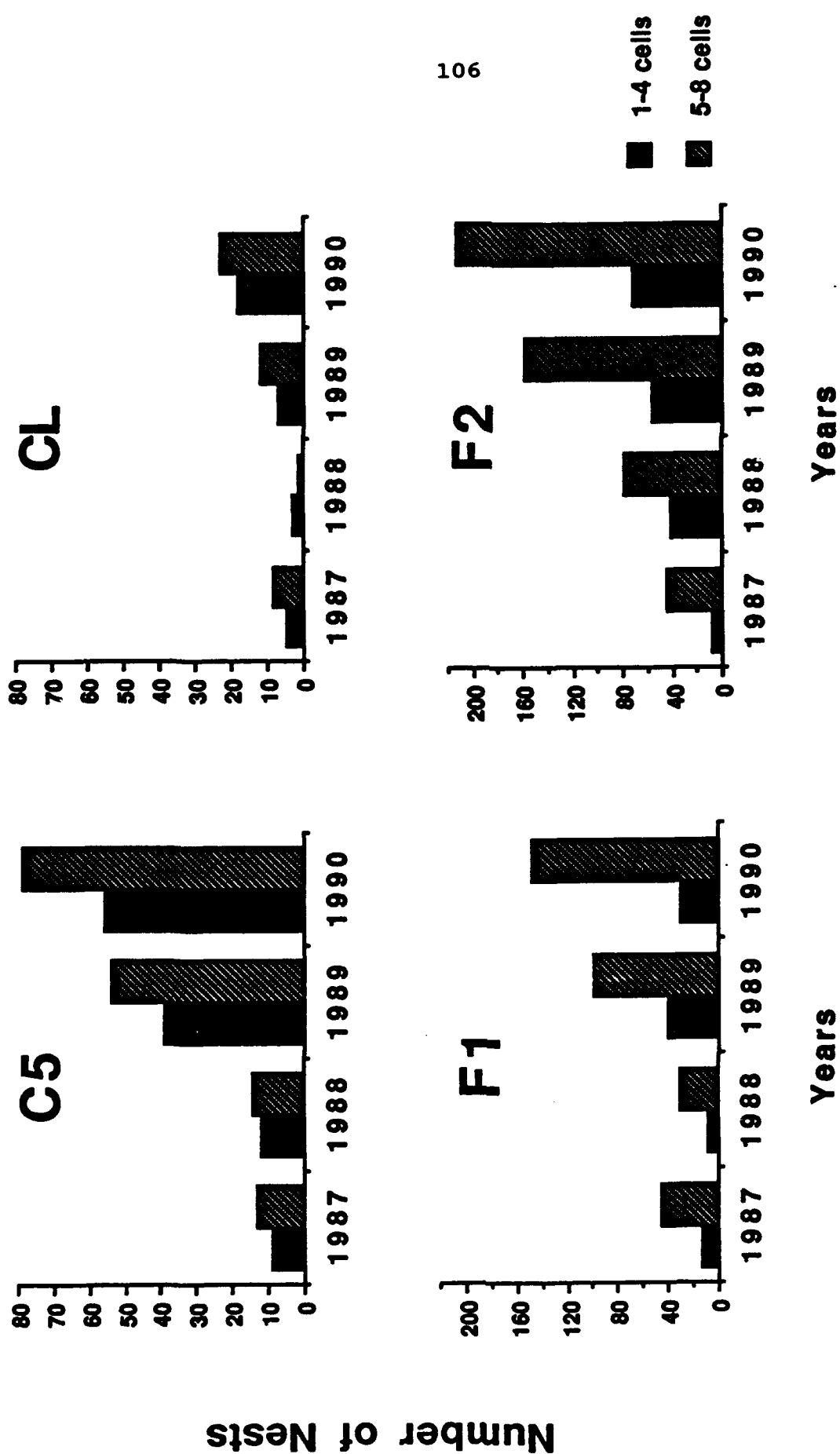


Figure 20. Number of complete nests of *M. inermis* with few (1-4) or many (5-8) cells, separated by season; diameters >9.5 mm, bore depths >135 mm.

TABLE 20: Categorical modeling of number of cells per complete nest of Megachile inermis, 1987-1990: (diameters > 9.5mm, bore depths > 135mm).

NUMBER OF CELLS PER COMPLETE NEST

Source of variation	df	Chi.Square	Prob.
Intercept	1	60.53	0.0001***
Exp	1	24.15	0.0001***
Site[Exp]	2	1.35	0.5098
Year	3	4.15	0.2461
Exp*Year	3	1.50	0.6814
Likelihood Ratio	6	7.48	0.2790

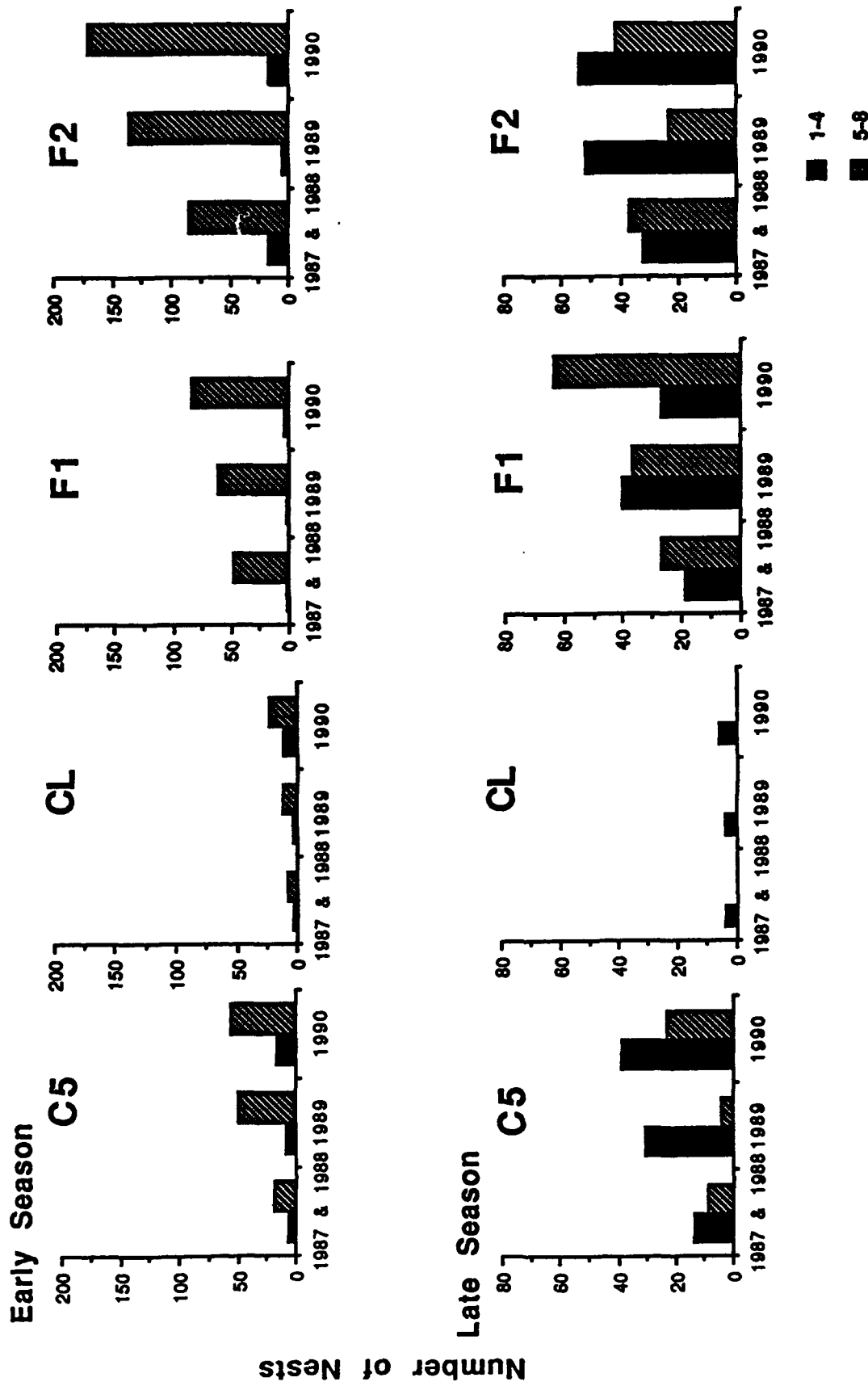


Figure 21. Number of complete nests of *M. inermis* with few (1-4) or many (5-8) cells, separated by season; diameters >9.5 mm, bore depths >135 mm.

Table 21: Categorical modeling of number of cells per complete nest of Megachile inermis, by season, 1987 + 1988 vs. 1989 vs. 1990; diameters > 9.5mm, bore depths > 135mm.

NUMBER OF CELLS PER COMPLETE NEST

Source of variation	df	Chi.Square	Prob.
Intercept	1	36.16	0.0001***
Exp	1	64.34	0.0000***
Site[Exp]	2	26.69	0.0001***
Year (87+88 vs 89 vs 90)	2	0.67	0.7157
Early vs. Late Season	1	204.42	0.0001***
Exp*Year	2	2.88	0.2364
Exp*Season	1	0.29	0.5883
Year*Season	2	23.70	0.0001***
Exp.*Year*Season	2	0.66	0.7182
Likelihood Ratio	10	10.56	0.3927

Mean Leaves per Cell Megachile inermis

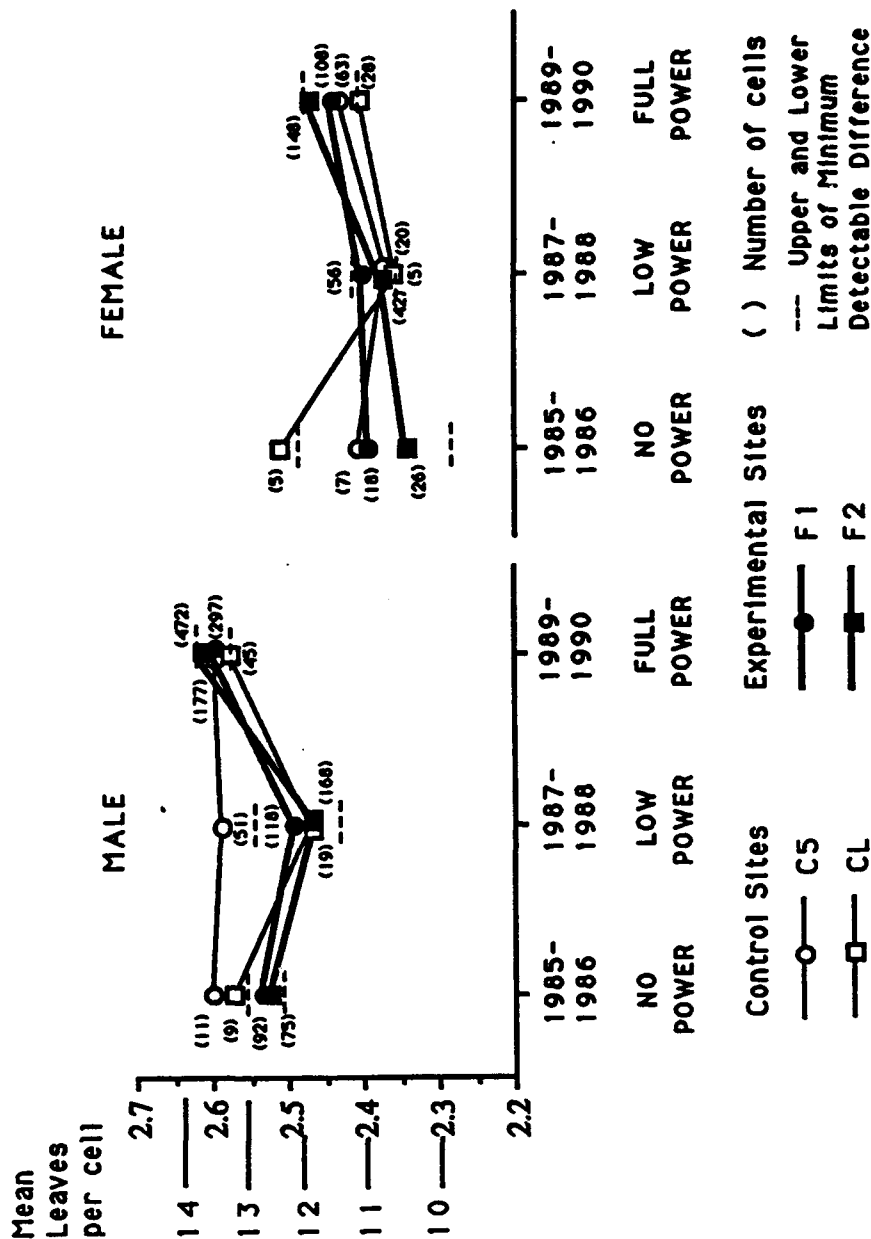


FIGURE 22. Mean leaves per cell for *M. inermis* nests by sex, diameters >9.5mm. Pooled pre-operational (1985-1986), low power (1987-1988), and full power (1989-1990) years. Numbers of nests in parenthesis; horizontal dashes indicate the minimum detectable difference between experimental and control sites for each year.

Table 22: GLM of mean of ln transformed leaves per cell in M. inermis nests. Cells expected to have female offspring; pooled pre-operational, low power and full operational years; diameters >9.5mm.

LEAVES PER CELL

Source of variation	df	SS	F	P>F
Year (85-86; 87-88; 89-90)	2	0.01	0.11	0.8926
Diameter	1	0.09	3.29	0.0701
Exp	1	0.03	9.97	0.0874
Site[Exp]	2	0.01	0.12	0.8900
Exp*Year	2	0.19	30.17	0.0321*
Complete vs. incomplete	1	0.00	0.05	0.8306
Cells per nest	1	0.03	1.02	0.3126
Early vs. Late Season	1	0.43	16.04	0.0001***
Diameter*Year	2	0.02	0.73	0.3939
Bore depth	1	0.07	2.54	0.1118
Bore depth*Year	2	0.01	0.10	0.9064
Diameter*Bore depth	1	0.07	2.42	0.1208
Diameter*Year* Bore depth	2	0.00	0.06	0.9375
Model	19	6.37	12.40	0.0001***
Error	506	13.69		
$\bar{X} = 2.44$ (11.4 leaves) $CV = 6.8$ $r^2 = 0.32$				

Table 22 continued

Parameter	Estimate	T for H_0 : Parameter = 0	PR > T
Early Season vs Late Season	-0.07 0.0	-4.01 —	0.0001*** —
EXP*YR control 1986	0.15	2.64	0.0086*

Table 23: GLM of mean of $\ln$ transformed leaves per cell in M. inermis nests. Cells expected to have male offspring; pooled pre-operational, low power and full operational years; diameters >9.5mm.

LEAVES PER CELL

Source of variation	df	SS	F	P>F
Year (85-86; 87-88; 89-90)	2	0.15	2.27	0.1040
Diameter	1	0.14	4.33	0.0375*
Exp	1	0.45	15.83	0.0578
Site[Exp]	2	0.06	0.89	0.4112
Exp*Year	2	0.48	8.36	0.1068
Complete vs. incomplete	1	0.62	19.22	0.0001***
Cells per nest	1	0.04	1.12	0.2892
Early vs. Late Season	1	3.31	103.14	0.0001***
Diameter*Year	2	0.14	2.22	0.1086
Bore depth	1	0.08	2.44	0.1184
Bore depth*Year	2	0.18	2.74	0.0648
Diameter*Bore depth	1	0.09	2.91	0.0885
Diameter*Year* Bore depth	2	0.17	2.72	0.0661
Model	19	28.26	46.36	0.0 ***
Error	1514	48.58		
$\bar{X} = 2.57$ (13.0 leaves) CV = 7.0 $r^2 = 0.37$				

Table 23 continued:

Parameter	Estimate	T for H_0 : Parameter = 0	PR > T
Diameter	-0.37	-0.53	0.5932
Complete vs. Incomplete	-0.07 0.0	-4.38 —	0.0001*** —
Early Season vs. Late Season	-0.1079 0.0	-10.16 —	0.0001*** —

Table 24: Log-likelihood ratio contingency tables for *M. relativa* nest entrance orientation by hutch set and year.

H_0 : Nest orientations at each hutch set are homogeneous between years (i.e., have the same directional preference).

	EW	NS	R		EW	NS	R	
C5-S					CL-E			
1983	—	—	—		14	9	23	
1985	6	5	11		15	9	24	
1986	4	6	10	G=6.847	8	3	11	G=4.899
1987	6	16	22	df = 5	12	6	18	df=6
1988	4	19	23	n.s.	13	2	15	n.s.
1989	9	12	21		12	7	19	
1990	12	18	30		13	10	23	
C	41	76	117		87	46	133	
C5-N					CL-N			
1983	—	—	—		—	—	—	
1985	4	2	6		12	7	19	
1986	5	6	11	G=6.623	10	7	17	G=7.917
1987	4	3	7	df=5	10	3	13	df=5
1988	12	3	15	n.s.	17	4	21	n.s.
1989	9	13	22		11	1	12	
1990	10	8	18		10	1	11	
C	44	35	79		70	23	93	
C5-W					CL-W			
1983	—	—	—		—	—	—	
1985	8	14	22		7	4	11	
1986	11	7	18		6	8	14	
1987	18	18	36	G=5.936	5	6	11	G=2.041
1988	14	24	38	df=5	3	6	9	df=5
1989	14	10	24	n.s.	9	11	20	n.s.
1990	8	6	14		12	14	26	
C	73	79	152		42	49	91	
C5 - BY HUTCH SETS					CL - BY HUTCH SETS			
C5-S	41	76	117		CL-E	87	46	133
C5-N	44	35	79	G=8.950 ¹	CL-N	70	23	93
C5-W	73	79	152	df=2	CL-W	42	49	91
C	158	190	348	.01 < P < .025		199	118	317
								P < .001

1. Within hutch sets, data are homogeneous between years. However, hutch sets (data pooled across years) are heterogeneous. Thus, hutch set data cannot be pooled by year.

2. Within hutch sets data are heterogeneous; cannot be pooled.

* Hutches were moved in spring, 1987, so 1985 & 1986 were not included in analyses.

Table 24 (continued)

H₁: Nest orientations at each hutch set are heterogeneous between years and hutch sets at a site, so data cannot be pooled.

EW	NS	R		EW	NS	R	
F1-E				F2-E			
42	25	67		—	—	—	
15	6	21		9	5	14	
12	4	16	G=9.712 ²	10	16	26	G=10.042 ¹
18	21	39	df=6	6	9	15	df=5
7	9	16	n.s.	4	16	20	n.s.
5	6	11		10	12	22	
5	7	12		6	20	26	
104	78	182		45	78	123	
F1-N				F2-N			
—	—	—		—	—	—	
15	5	20		20	17	37*	
5	8	13		10	23	33*	
6	16	22	G=24.454 ²	7	10	17	G=12.42
4	22	26	df=5	5	8	13	df=3*
2	16	18	P<.001	19	8	27	.005<P<.01
6	9	15		28	12	40	
38	76	114		89	78	167	
F1-W				F2-W			
21	21	42		—	—	—	
2	12	14		8	10	18	
4	2	6	G=19.267 ²	5	1	6	G=6.469 ¹
2	2	4	df=6	2	4	6	df=5
10	5	15	.001<P<.005	3	3	6	n.s.
2	2	4		3	4	7	
1	12	13		14	6	20	
42	56	98		35	28	63	

DURATION OF LO COLLECTING TRIPS Based on analysis of the mean of Trip Numbers 1 to 3

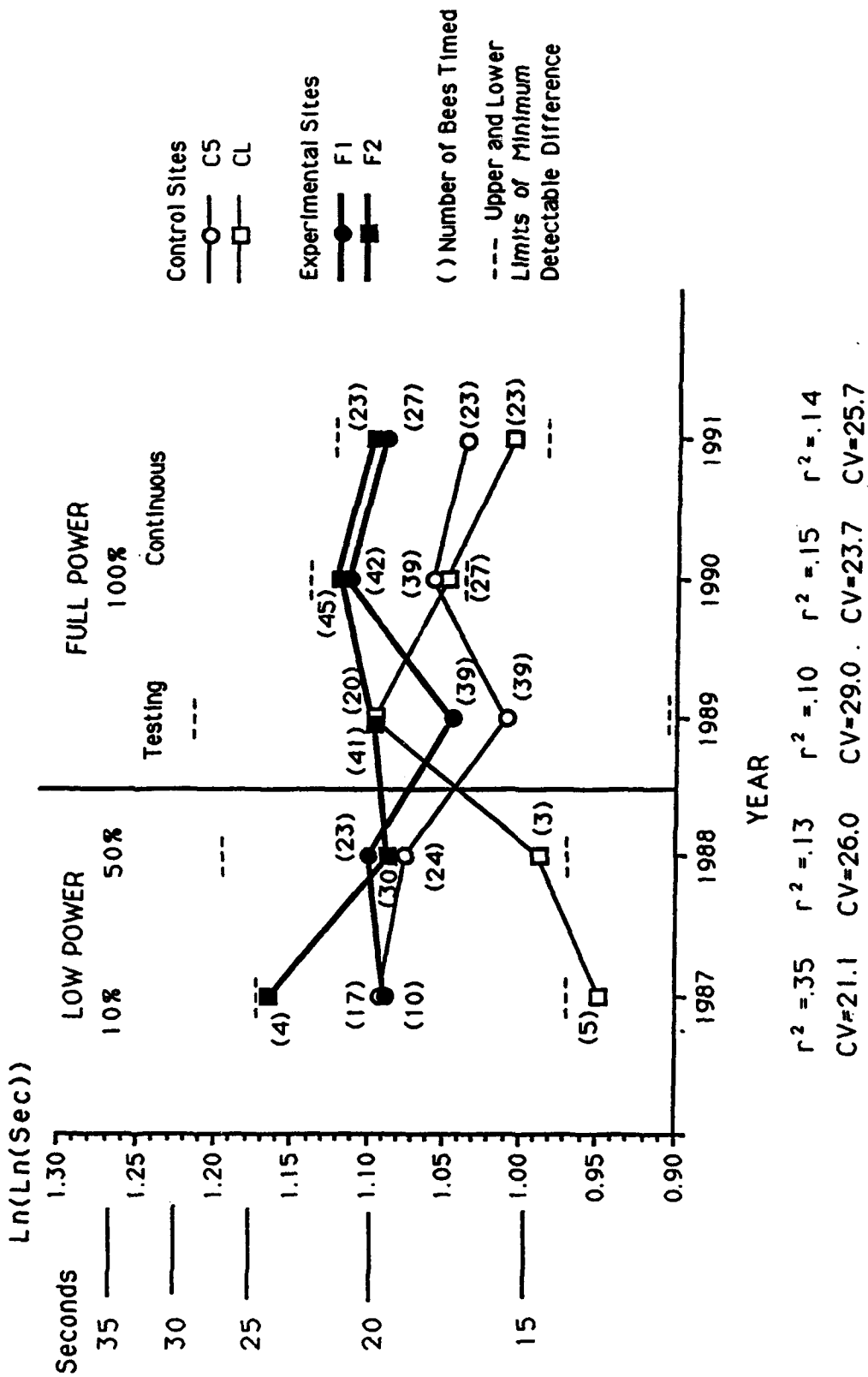


FIGURE 23. Mean duration of LO collecting trips for the first three leaf collecting trips in a cell cap. Numbers of bees timed in parenthesis; horizontal dashes indicate the minimum detectable difference between experimental and control sites for each year.

Table 25. GLM of mean of ln ln transformed LO trip durations; trips 1-3 for each timed M. inermis, 1987-91.

MEAN LO TRIP DURATIONS

Source of variation	df	SS	F	P>F
Year	4	0.16	0.87	0.5027
Exp	1	0.44	7.62	0.1100
Site[Exp]	2	0.12	0.75	0.4716
Exp*Year	4	0.06	0.28	0.8737
Observer[Year]	17	0.81	0.62	0.8772
Time of day[Year]	5	0.26	0.68	0.6411
Time*Time[Year]	5	0.27	0.71	0.6142
Date[Year]	5	1.28	3.34	0.0056*
Model	43	5.25	1.60	0.0116
Error	460	35.22		
$\bar{X} = 1.07$ (18.4 sec.)	CV = 25.9	$r^2 = 0.13$		

Parameter Estimates:

		T for H_0 : Parameter = 0	PR> T
Date[Year]			
1987	0.0020	0.79	0.4278
1988	0.0023	1.15	0.2504
1989	0.0021	1.56	0.1198
1990	0.0036	3.43	0.0007**
1991	0.0011	0.82	0.4147

Table 26. GLM of mean of $\ln \ln$ transformed LO trip durations; trips 1-3 for each timed M. inermis; Pre vs. Full antenna operation.

MEAN LO TRIP DURATIONS

Source of variation	df	SS	F	P>F
Pre vs. Full antenna operations	1	0.01	0.09	0.7585
Exp	1	0.65	11.94	0.0745
Site[Exp]	2	0.11	0.71	0.4939
Exp*Pre-vs. Full operations	3	0.10	1.82	0.3097
Date	1	1.11	14.45	0.0002***
Model	6	2.18	4.70	0.0001***
Error	497	38.30		
$\bar{X} = 1.07$ (18.4 sec.)	CV = 26.0	$r^2 = 0.05$		

Parameter Estimates:		T for H_0 : Parameter = 0	PR> T
Date	0.0020	3.80	0.0002***

Table 27: Late Summer Emergences (% bivoltinism) of M. relativa and Coelioxys moesta.

<u>M. relativa</u>						
Year	cells emerging late summer	total cells emerging ¹	(%)	nests emerging late summer	total nests emerging ¹	(%)
1987	33/629		(5.2%)	7/186		(3.8%)
1988	13/285		(4.6%)	7/144		(4.9%)
1989	112/515		(21.7%)	24/166		(14.5%)
1990	41/621		(6.6%)	13/232		(5.6%)
1991	29/430 ³		(6.7%)	9/205 ³		(4.4%)

<u>Coelioxys moesta</u>						
Year	cells emerging late summer	total cells emerging ²	(%)	nests emerging late summer	total nests emerging ²	(%)
1987	11/99		(11.1%)	10/77		(13.0%)
1988	10/87		(11.5%)	8/62		(12.9%)
1989	18/71		(25.4%)	11/50		(22.0%)
1990	7/116		(6.0%)	6/192		(6.5%)
1991	5/?			5/?		

¹Total cells or nests with adult M. relativa.

²Total cells or nests with adult Coelioxys in M. relativa nests.

³Estimate, since spring emergence has not yet taken place.

Table 28: Late Summer Emergences (% bivoltinism) of M. inermis and Coelioxys spp.

<u>M. inermis</u>						
Year	cells emerging late summer	total cells emerging ¹	(%)	nests emerging late summer	total nests emerging ¹	(%)
1987	2/1,011		(0.2%)	1/262		(0.4%)
1988	0/562		(0.0%)	0/168		(0.0%)
1989	4/1190		(0.3%)	1/400		(0.3%)
1990	5/1969		(0.3%)	1/628		(0.2%)
1991	3/2094 ³		(0.1%)	1/701 ³		(0.1%)

<u>Coelioxys</u> spp.						
Year	cells emerging late summer	total cells emerging ²	(%)	nests emerging late summer	total nests emerging ²	(%)
1987	0/62		(0.0%)	0/48		(0.0%)
1988	0/18		(0.0%)	0/16		(0.0%)
1989	0/86		(0.0%)	0/67		(0.0%)
1990	0/5		(0.0%)	0/70		(0.0%)
1991	0/?			0/?		

¹Total cells or nests with adult M. inermis.

²Total cells or nests with adult Coelioxys in M. inermis nests.

³Estimate, since spring emergence has not yet taken place.

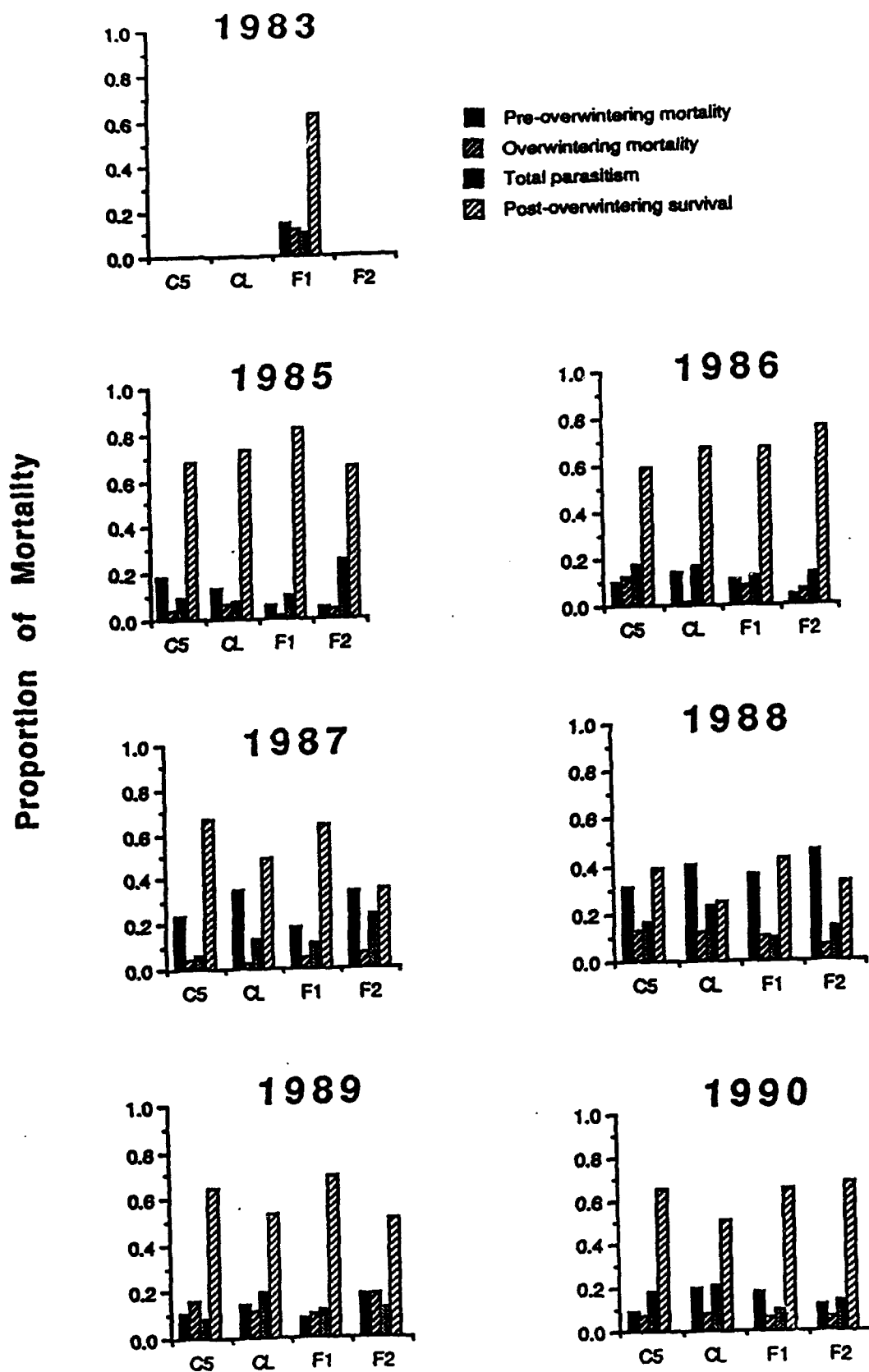


FIGURE 24. Proportion of mortality from various sources by site, *M. relativa*.

Table 29: Proportion of M. relativa mortality from various sources by site.

Stage or source of mortality	SITE			
	C5	CL	F1	F2
1983				
Pre-overwintering (egg & larvae)			0.149	
Overwintering (Prepupae)			0.117	
Total parasitism (<u>Coelioxys</u> only)			0.102 (0.063)	
Post-overwintering Survival*			0.632	
1985				
Pre-overwintering (egg & larvae)	0.185	0.131	0.059	0.053
Overwintering (Prepupae)	0.045	0.069	0.014	0.041
Total parasitism (<u>Coelioxys</u> only)	0.089 (0.076)	0.073 (0.053)	0.100 (0.089)	0.254 (0.234)
Post-overwintering Survival*	0.681	0.727	0.327	0.652
1986				
Pre-overwintering (egg & larvae)	0.104	0.138	0.109	0.041
Overwintering (Prepupae)	0.130	0.015	0.085	0.063
Total parasitism (<u>Coelioxys</u> only)	0.169 (0.130)	0.177 (0.138)	0.127 (0.127)	0.149 (0.114)
Post-overwintering Survival*	0.597	0.669	0.679	0.749
1987				
Pre-overwintering (egg & larvae)	0.235	0.354	0.186	0.344
Overwintering (Prepupae)	0.041	0.030	0.055	0.070
Total parasitism (<u>Coelioxys</u> only)	0.058 (0.041)	0.128 (0.122)	0.118 (0.110)	0.234 (0.195)
Post-overwintering Survival*	0.665	0.488	0.640	0.352

* Includes cells with dead pupae, dead adults, and successfully emerging adult M. relativa.

Table 29 (continued)

Stage or source of mortality	C5	CL	SITE F1	F2
1988				
Pre-overwintering (egg & larvae)	0.313	0.407	0.363	0.464
Overwintering (Prepupae)	0.134	0.122	0.106	0.064
Total parasitism (<u>Coelioxys</u> only)	0.167 (0.138)	0.228 (0.195)	0.099 (0.070)	0.144 (0.128)
Post-overwintering Survival*	0.386	0.244	0.433	0.328
1989				
Pre-overwintering (egg & larvae)	0.106	0.127	0.080	0.176
Overwintering (Prepupae)	0.165	0.127	0.105	0.188
Total parasitism (<u>Coelioxys</u> only)	0.083 (0.071)	0.206 (0.139)	0.117 (0.111)	0.130 (0.092)
Post-overwintering Survival*	0.646	0.539	0.698	0.506
1990				
Pre-overwintering (egg & larvae)	0.095	0.201	0.179	0.116
Overwintering (Prepupae)	0.069	0.082	0.067	0.067
Total parasitism (<u>Coelioxys</u> only)	0.182 (0.147)	0.207 (0.179)	0.101 (0.101)	0.136 (0.105)
Post-overwintering Survival*	0.654	0.511	0.654	0.681

* Includes cells with dead pupae, dead adults, and successfully emerging adult M. relativa.

Proportion of Mortality

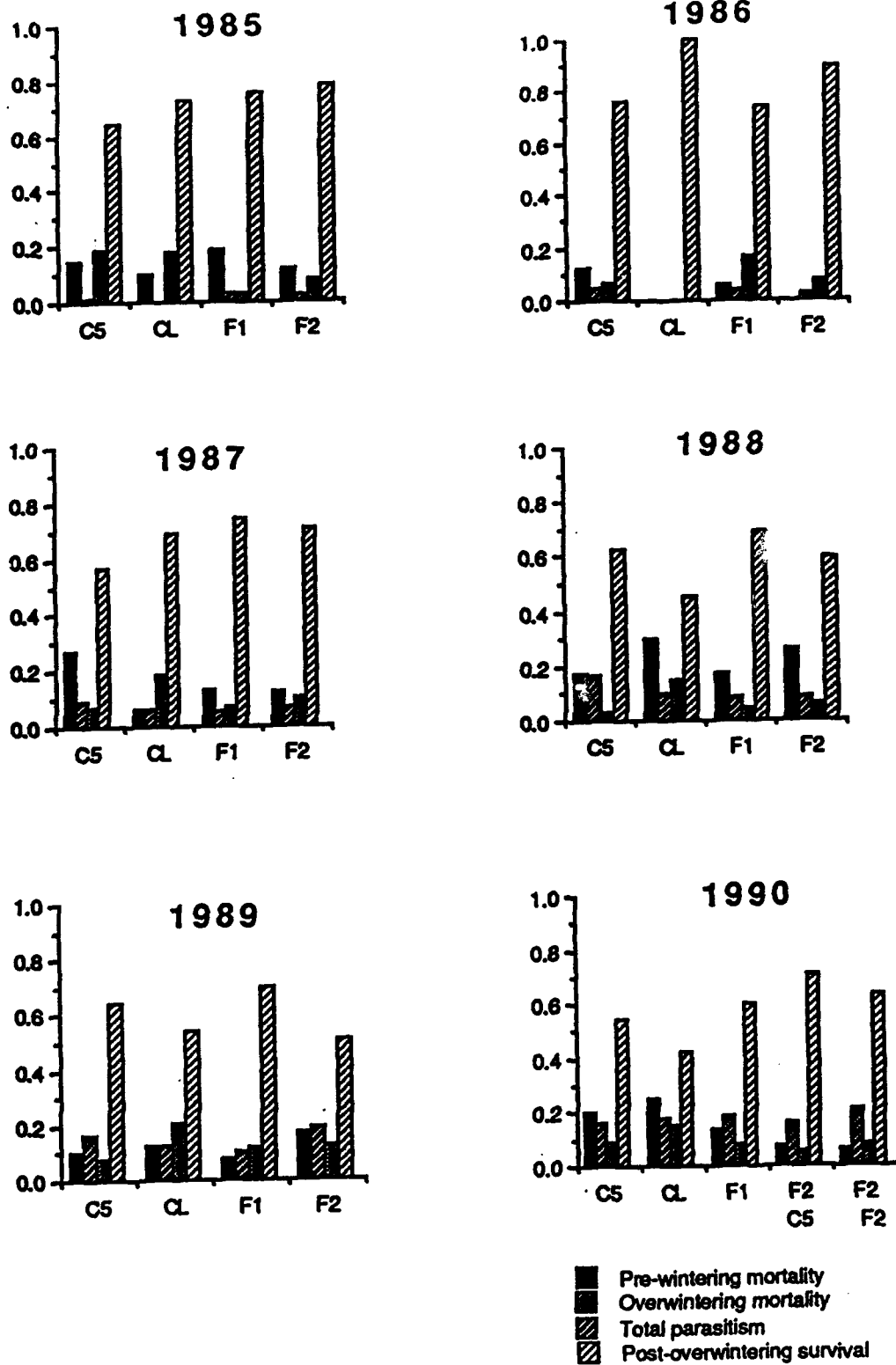


FIGURE 25. Proportion of mortality from various sources by site, *M. inermis*.

Table 30: Proportion of M. inermis mortality from various sources by site.

Stage or source of mortality	SITE			
	C5	CL	F1	F2
1985				
Pre-overwintering (egg & larvae)	0.151	0.098	0.184	0.114
Overwintering (Prepupae)	0.019	0.000	0.028	0.022
Total parasitism (<u>Coelioxys</u> only)	0.189 (0.170)	0.176 (0.059)	0.031 (0.011)	0.079 (0.035)
Post-overwintering Survival*	0.641	0.725	0.757	0.786
1986				
Pre-overwintering (egg & larvae)	0.119	0.000	0.061	0.004
Overwintering (Prepupae)	0.051	0.000	0.038	0.026
Total parasitism (<u>Coelioxys</u> only)	0.068 (0.034)	0.000 (0.000)	0.167 (0.038)	0.073 (0.009)
Post-overwintering Survival*	0.763	1.000	0.735	0.897
1987				
Pre-overwintering (egg & larvae)	0.272	0.062	0.131	0.124
Overwintering (Prepupae)	0.092	0.062	0.055	0.069
Total parasitism (<u>Coelioxys</u> only)	0.072 (0.048)	0.186 (0.088)	0.070 (0.032)	0.103 (0.041)
Post-overwintering Survival*	0.564	0.690	0.744	0.704
1988				
Pre-overwintering (egg & larvae)	0.174	0.300	0.175	0.260
Overwintering (Prepupae)	0.165	0.100	0.087	0.085
Total parasitism (<u>Coelioxys</u> only)	0.035 (0.009)	0.150 (0.150)	0.044 (0.000)	0.060 (0.025)
Post-overwintering Survival*	0.626	0.450	0.694	0.595

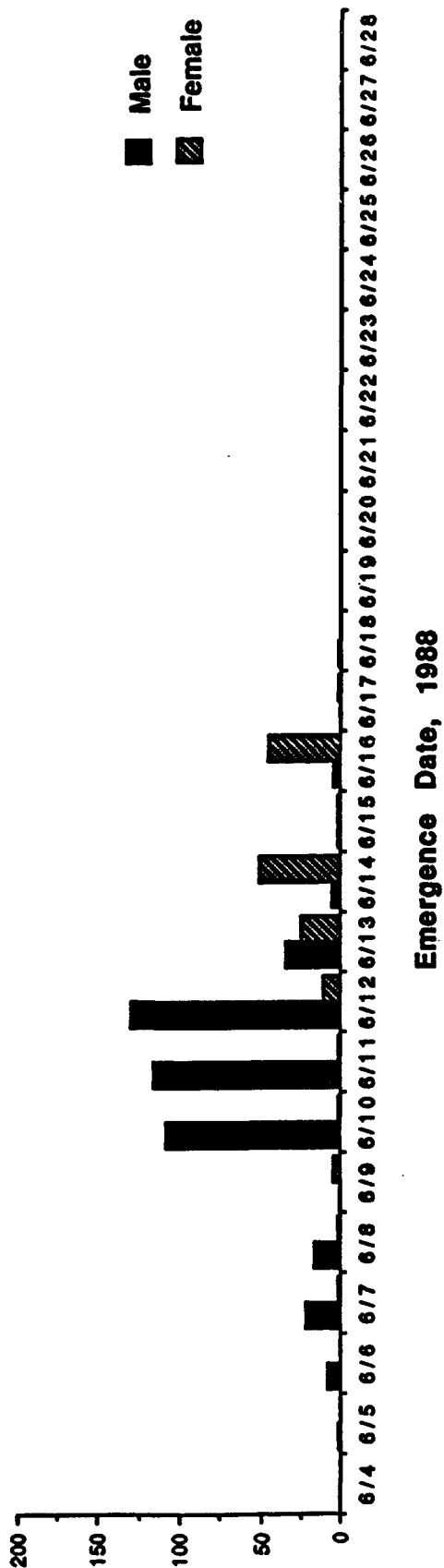
* Includes cells with dead pupae, dead adults, and successfully emerging adult M. inermis.

Table 30 continued

Stage or source of mortality	C5	CL	SITE		
			F1	F2	
				<u>overwintered</u> C5	F2
1989					
Pre-overwintering (egg & larvae)	0.183	0.156	0.130		0.171
Overwintering (Prepupae)	0.214	0.167	0.213		0.240
Total parasitism (<u>Coelioxys</u> only)	0.060 (0.036)	0.156 (0.115)	0.099 (0.042)		0.062 (0.032)
Post-overwintering Survival*	0.542	0.521	0.558		0.527
1990					
Pre-overwintering (egg & larvae)	0.206	0.249	0.137	0.074	0.069
Overwintering (Prepupae)	0.159	0.180	0.186	0.164	0.214
Total parasitism (<u>Coelioxys</u> only)	0.091 (0.042)	0.152 (0.106)	0.078 (0.013)	0.057 (0.021)	0.083 (0.028)
Post-overwintering Survival*	0.543	0.419	0.599	0.706	0.634

* Includes cells with dead pupae, dead adults, and successfully emerging adult *M. inermis*.

Megachile relativa emergence



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Megachile inermis emergence

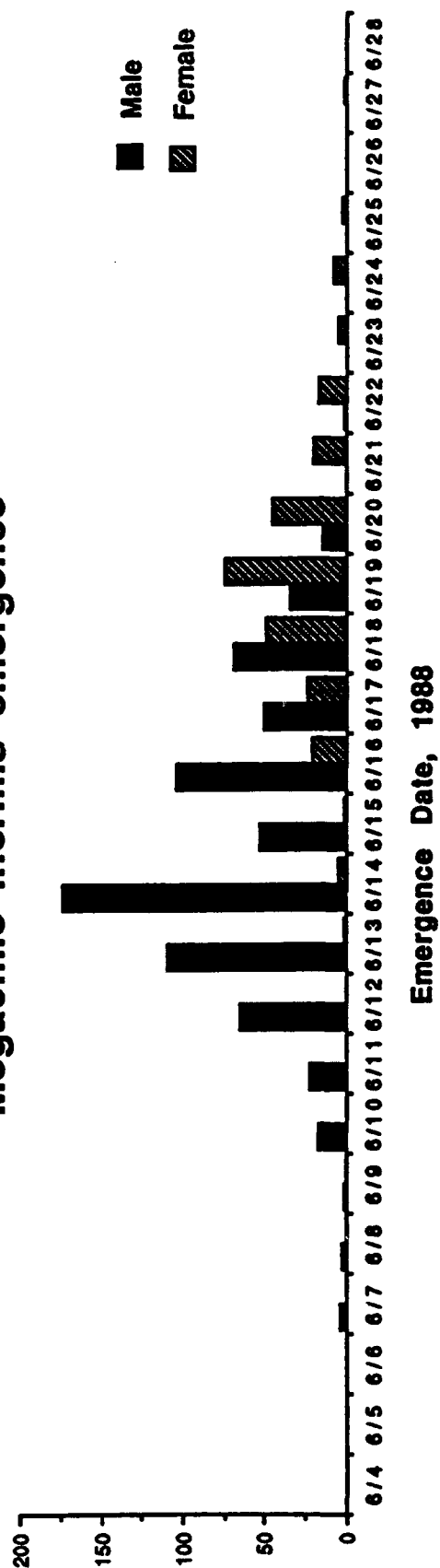
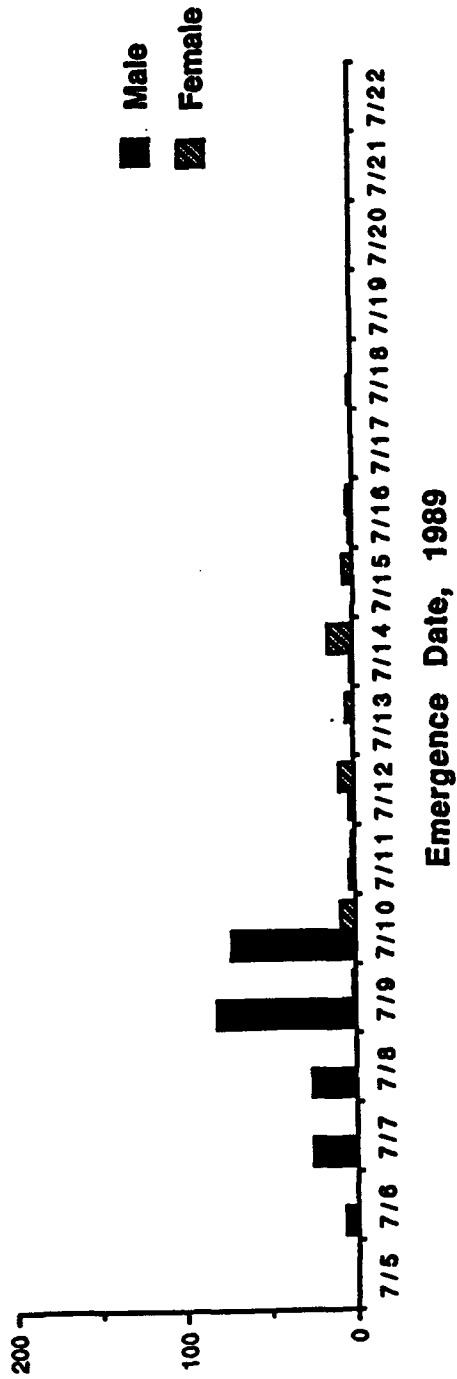


Figure 26. Phenology of emergence, 1987 nests emerging in 1988.

Megachille relativa emergence



Megachille inermis emergence

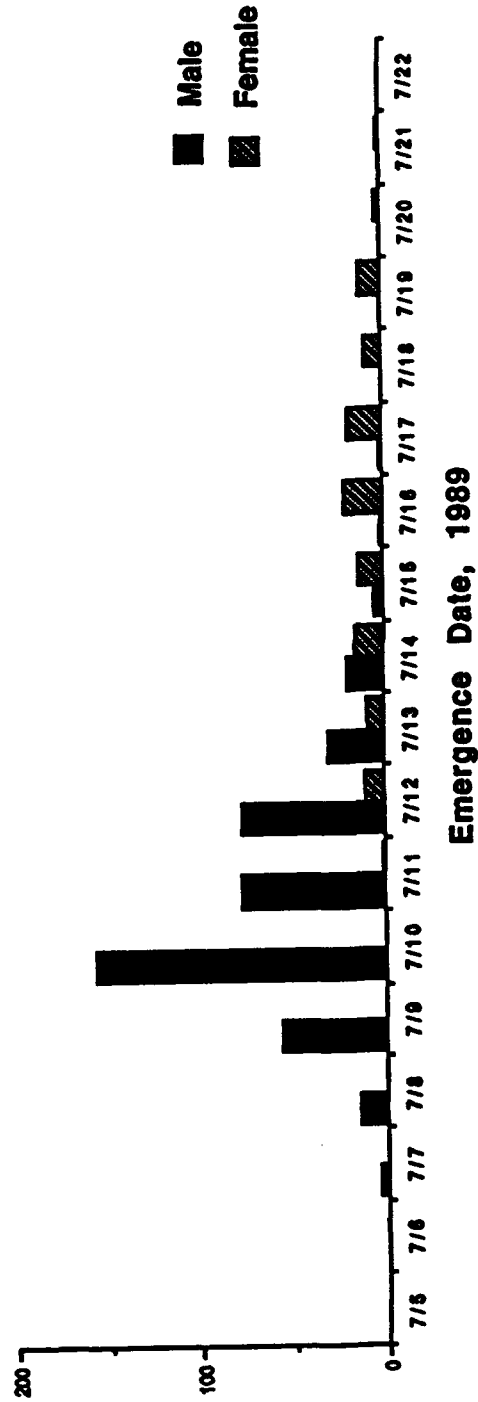


Figure 27. Phenology of emergence, 1988 nests emerging in 1989.

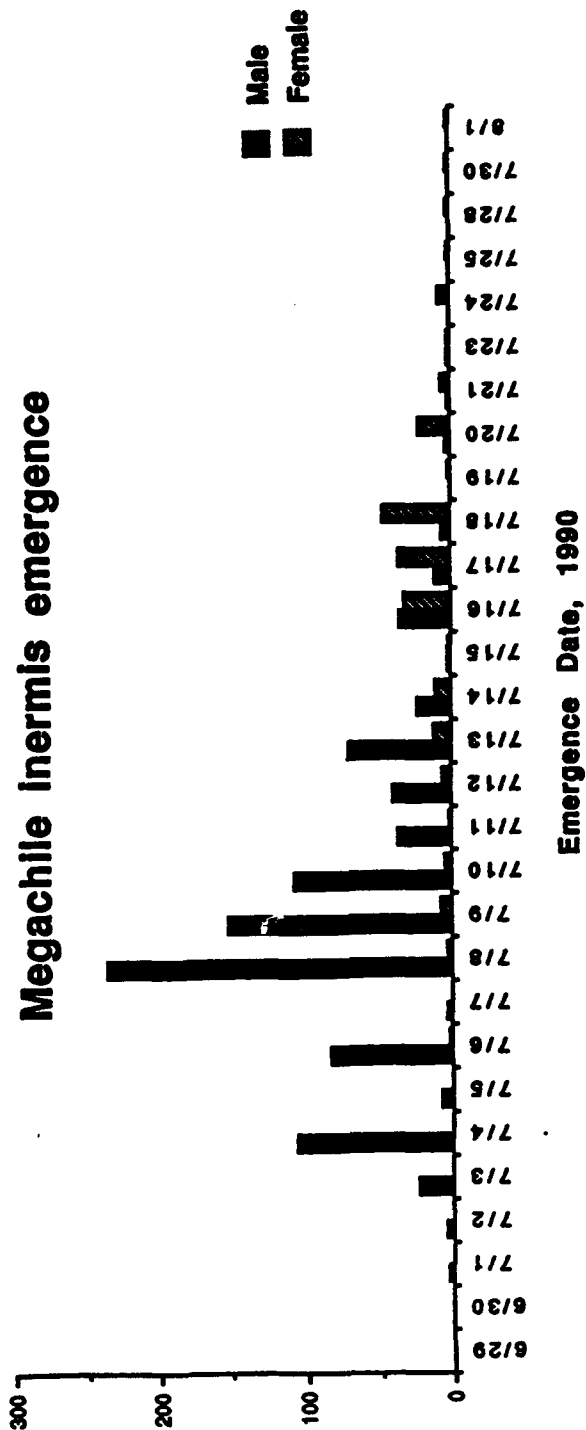
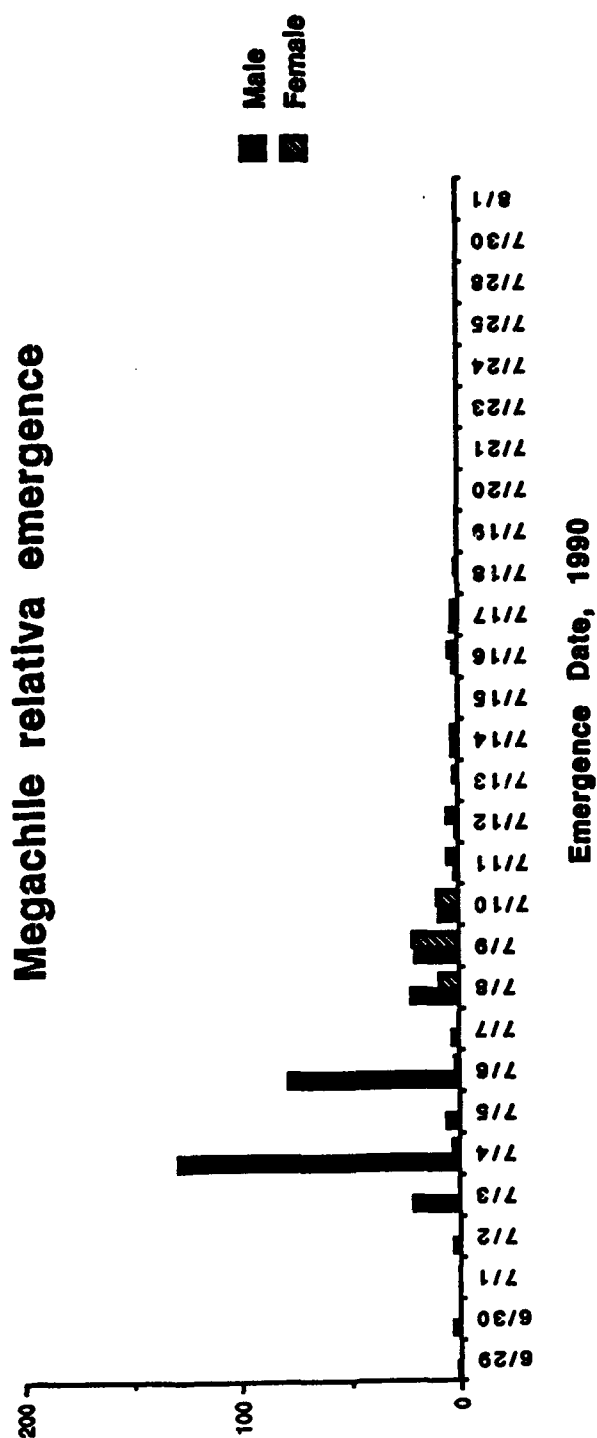


Figure 28. Phenology of emergence, 1989 nests emerging in 1990.

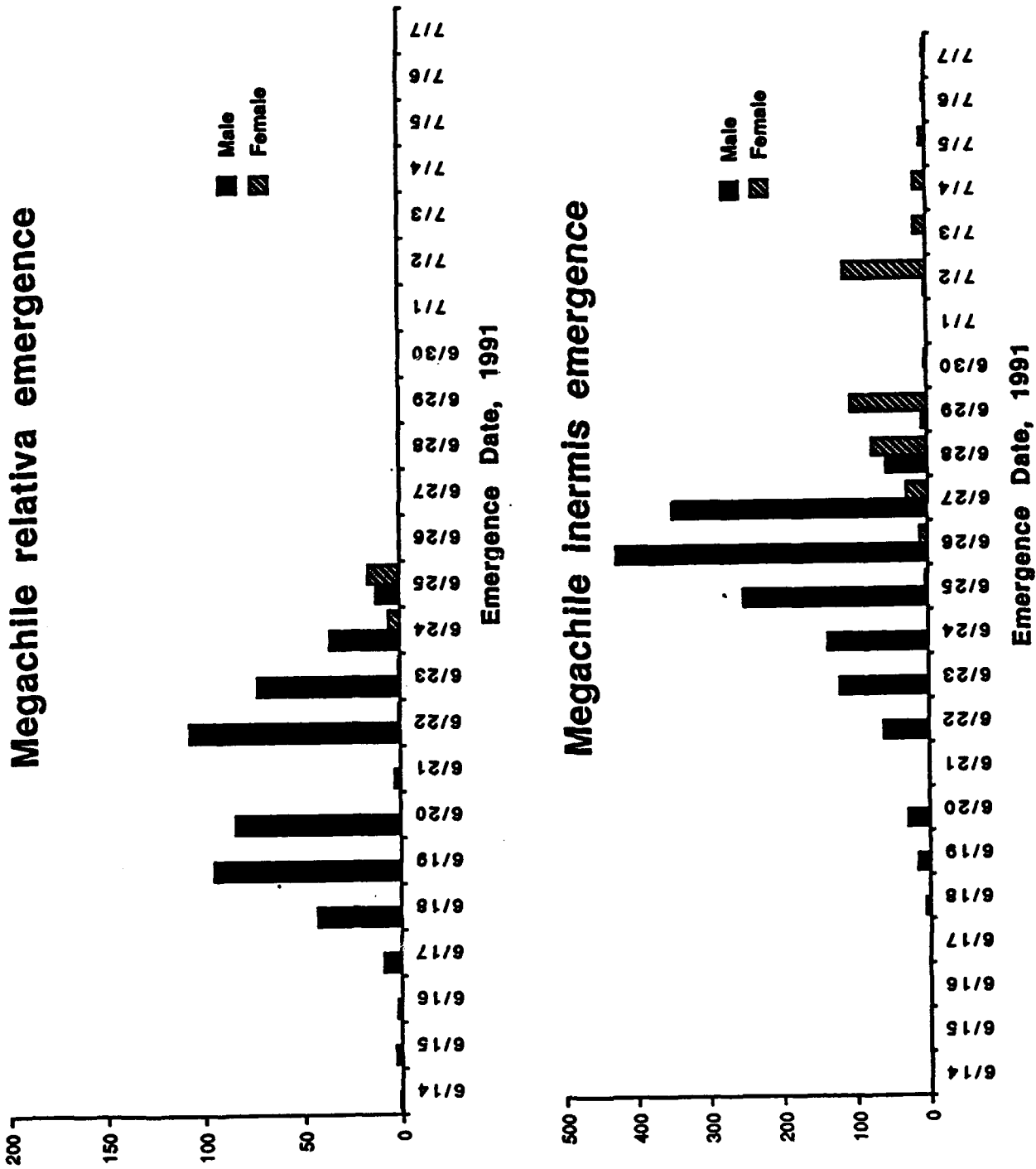


Figure 29. Phenology of emergence, 1990 nests emerging in 1991.

% cells with prepupal mortality

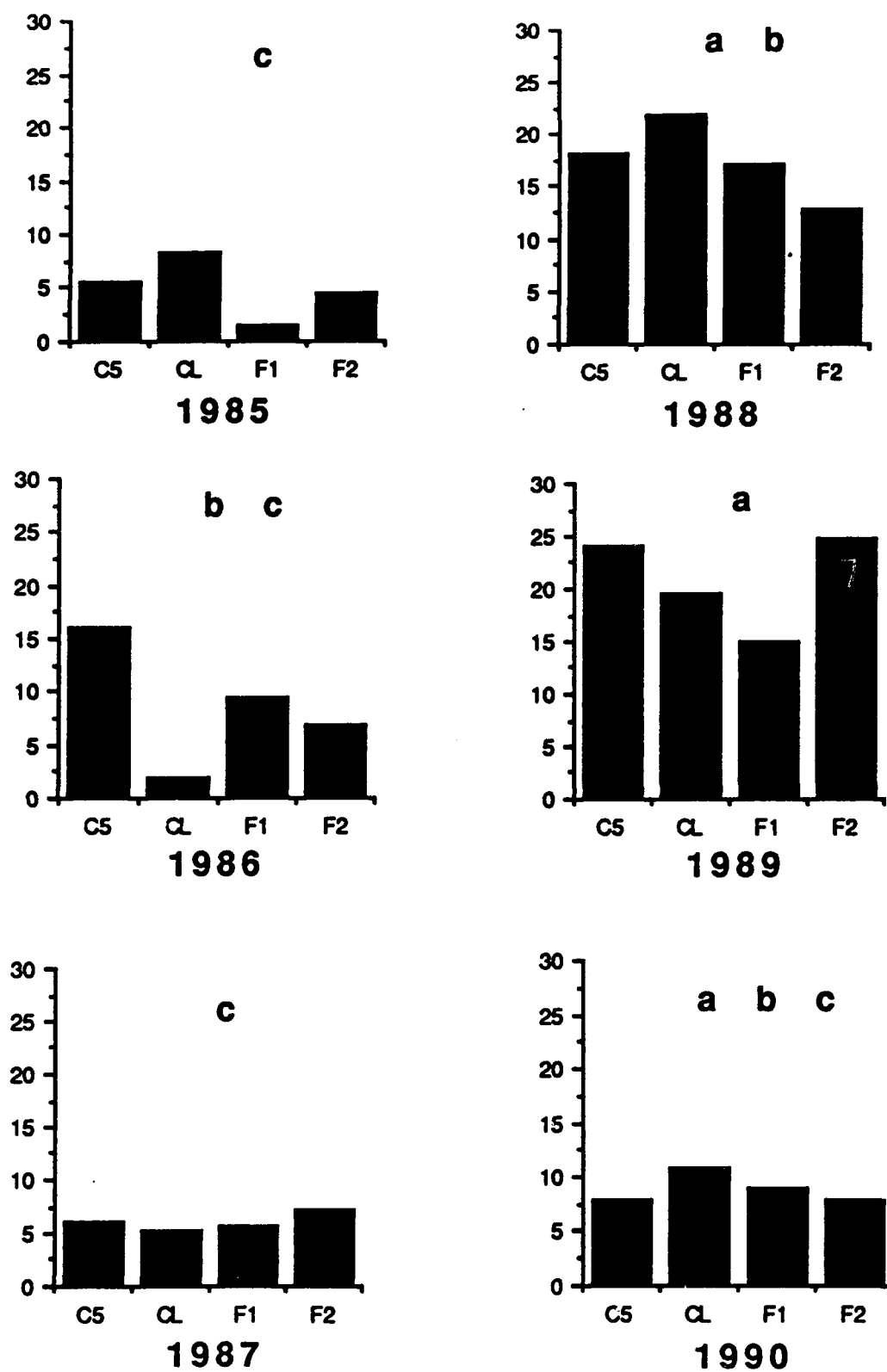


FIGURE 30. Percent of cells with prepupal mortality by year and site, *M. relativa*.

Table 31: ANOVA of arcsine transformed proportion of cells with prepupal mortality for M. relativa, 1985-1990.

PROPORTION OF CELLS WITH PREPUPAL MORTALITY

Source of variation	df	SS	F	P>F
Year	5	0.21	8.13	0.0027*
Exp	1	0.01	2.82	0.2351
Site[Exp]	2	0.00	0.38	0.6962
Exp*Year	5	0.01	1.01	0.5659
Model	13	0.23	3.40	0.029*
Error	10	0.05		
$\bar{X} = 0.33$ radians (0.10) CV = 21.7 $r^2 = 0.82$				

Multiple comparison tests for differences between years in the proportion of cells with prepupal mortality for M. relativa 1985-1990.

TUKEY GROUPING			MEAN proportion prepupal mortality	N	YEAR
A			0.21	4	1989
B	A		0.18	4	1988
B	A	C	0.09	4	1990
B	C		0.08	4	1986
	C		0.06	4	1987
	C		0.05	4	1985

Experimentwise error rate $\alpha = 0.05$ df=10

% cells with prepupal mortality

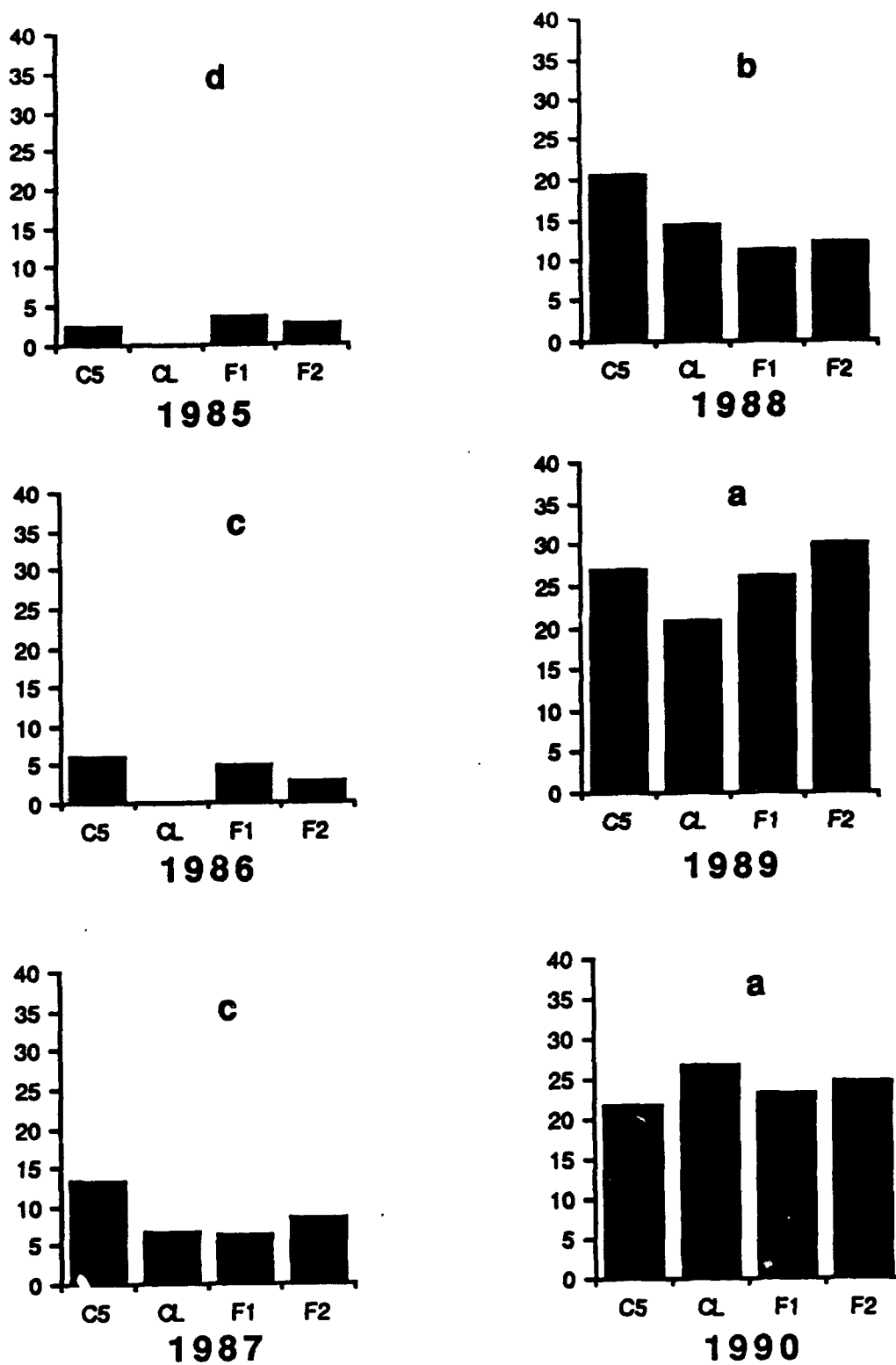


FIGURE 31. Percent of cells with prepupal mortality by year and site, *M. inermis*.

Table 32: ANOVA of arcsine transformed proportion of cells with prepupal mortality for M. inermis, 1985 - 1990.

PROPORTION OF CELLS WITH PREPUPAL MORTALITY

Source of variation	df	SS	F	P>F
Year	5	0.50	74.02	0.0001***
Exp	1	0.00	0.11	0.7737
Site[Exp]	2	0.01	4.26	0.0460*
Exp*Year	5	0.02	0.55	0.7471
Model	13	0.52	30.00	0.0001***
Error	10	0.01		
$\bar{X} = 0.35$ radians (0.12) CV = 10.4 $r^2 = 0.98$				

Multiple comparison tests for differences between years in the proportion of cells with prepupal mortality for M. inermis 1985-1990.

TUKEY GROUPING	MEAN Proportion prepupal mortality	N	YEAR
A	0.26	4	1989
A	0.24	4	1990
B	0.15	4	1988
C	0.09	4	1987
C	0.04	4	1986
D	0.02	4	1985

Experimentwise error rate $\alpha = 0.05$ df=10

% nests with prepupal mortality

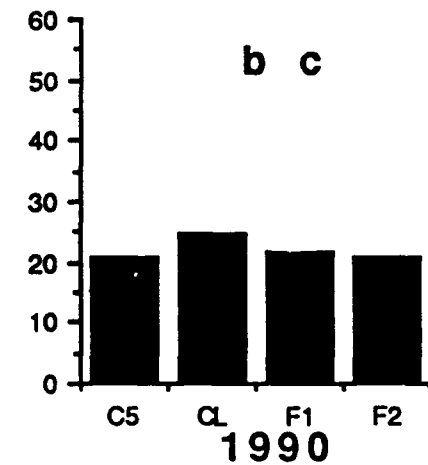
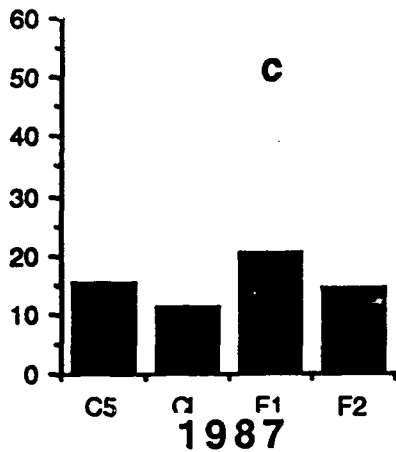
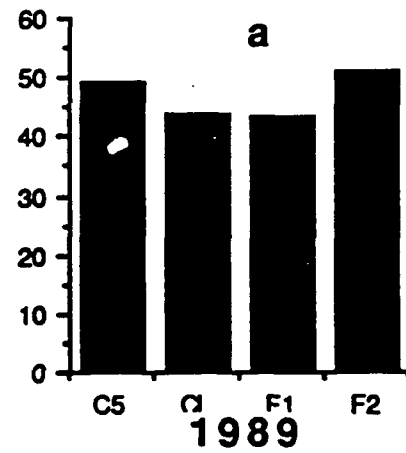
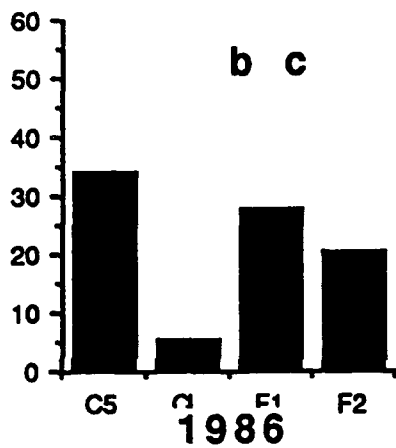
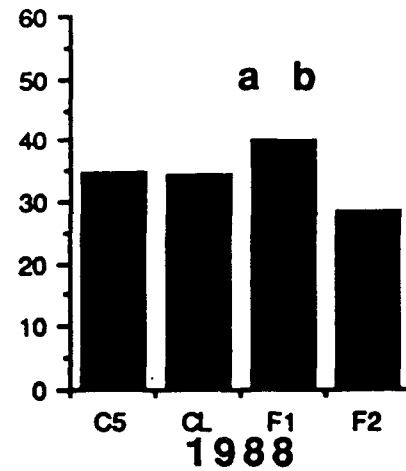
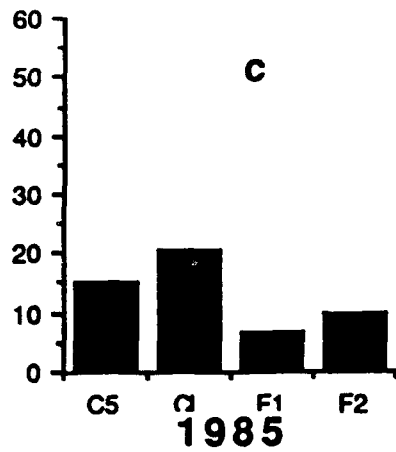


FIGURE 32. Percent of nests with prepupal mortality by year and site, M. relativa.

Table 33: ANOVA of arcsine transformed proportion of nests with prepupal mortality for M. relativa, 1985 - 1990.

PROPORTION OF NESTS WITH PREPUPAL MORTALITY

Source of variation	df	SS	F	P>F
Year	5	0.42	10.51	0.0010**
Exp	1	0.00	0.06	0.8272
Site[Exp]	2	0.01	0.82	0.4692
Exp*Year	5	0.03	0.91	0.5985
Model	13	0.46	4.40	0.011*
Error	8	0.08		
$\bar{X} = 0.52$ radians (0.25) CV = 17.1 $r^2 = 0.85$				

Multiple comparison tests for differences between years in the proportion of nests with prepupal mortality for M. relativa 1985-1990.

TUKEY GROUPING		MEAN Proportion prepupal mortality	N	YEAR
	A	0.47	4	1989
B	A	0.34	4	1988
B	C	0.22	4	1990
B	C	0.21	4	1986
	C	0.16	4	1987
	C	0.13	4	1985

Experimentwise error rate $\alpha = 0.05$ df=10

% nests with prepupal mortality

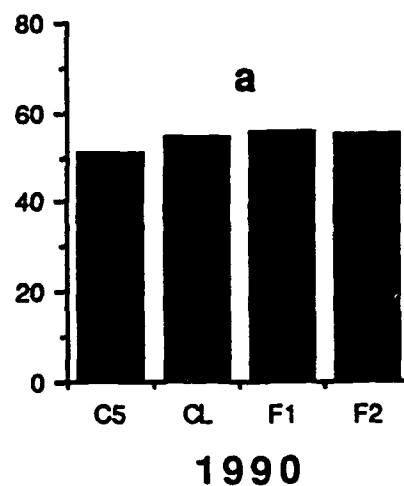
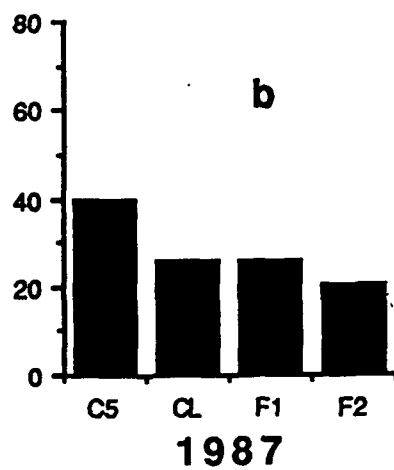
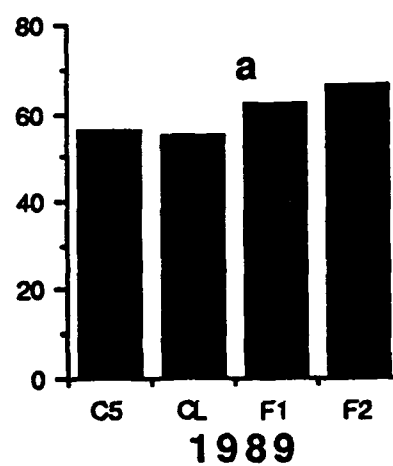
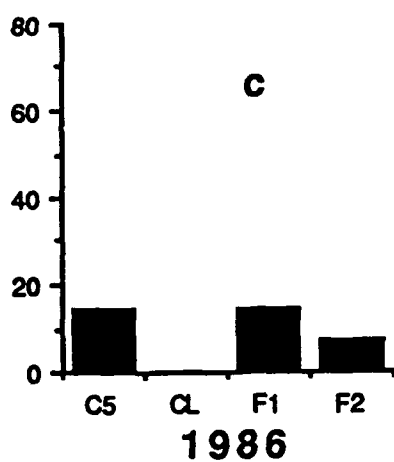
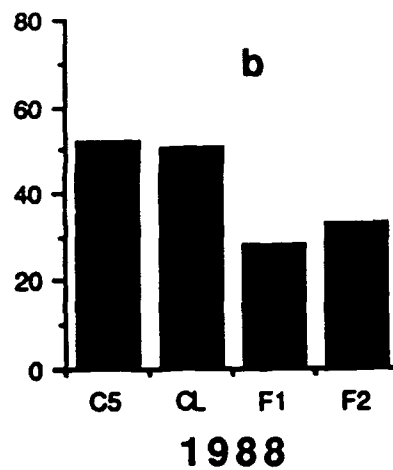
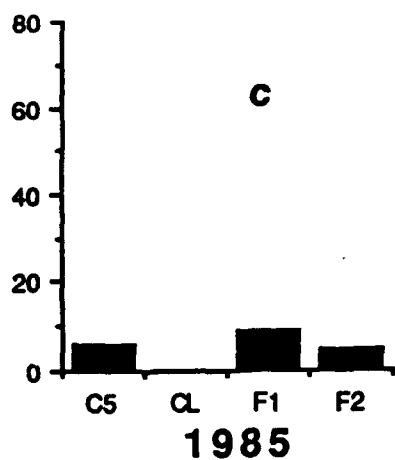


FIGURE 33. Percent of nests with prepupal mortality by year and site, M. inermis.

Table 34: ANOVA of arcsine transformed proportion of nests with prepupal mortality for M. inermis, 1985 - 1990.

PROPORTION OF NESTS WITH PREPUPAL MORTALITY

Source of variation	df	SS	F	P>F
Year	5	1.33	91.70	0.0001***
Exp	1	0.00	0.57	0.5298
Site[Exp]	2	0.02	2.87	0.1037
Exp*Year	5	0.06	1.54	0.4388
Model	13	1.42	37.55	0.0001***
Error	8	0.02		
$\bar{X} = 0.59$ radians (0.31) CV = 9.1 $r^2 = 0.98$				

Multiple comparison tests for differences between years in the proportion of nests with prepupal mortality for M. inermis 1985-1990.

TUKEY GROUPING	MEAN Proportion prepupal mortality	N	YEAR
A	0.60	4	1989
A	0.54	4	1990
B	0.41	4	1988
B	0.28	4	1987
C	0.12	4	1986
C	0.06	4	1985

Experimentwise error rate $\alpha = 0.05$ df=10

% cells with prepupal mortality

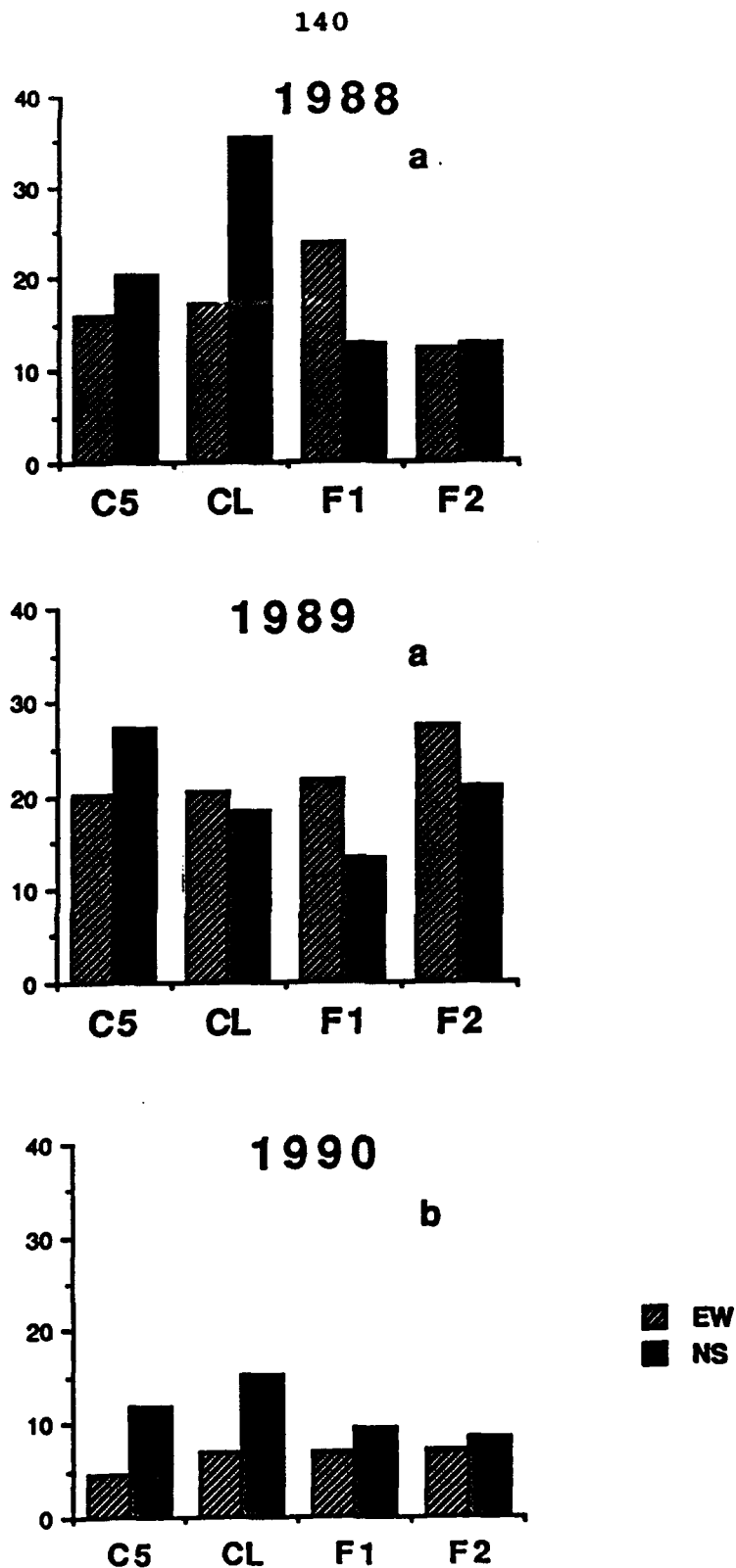


FIGURE 34. Percent of cells with prepupal mortality by year, site, and nest entrance orientation, M. relativa.

Table 35: ANOVA of arcsine transformed proportion of cells with prepupal mortality for M. relativa, 1988 - 1990, by nest entrance direction.

PROPORTION OF CELLS WITH PREPUPAL MORTALITY

Source of variation	df	SS	F	P>F
Year	2	0.14	21.09	0.0003***
Exp	1	0.01	4.63	0.1644
Site[Exp]	2	0.00	0.52	0.6101
Direction	1	0.00	1.02	0.3369
Direction*Exp	1	0.03	18.66	0.0496*
Year*Exp	2	0.01	1.59	0.3862
Year*Exp*Direction	2	0.00	0.91	0.5238
Model	13	0.21	4.80	0.008 *
Error	10	0.03		
$\bar{X} = 0.41$ radians (0.16) CV = 14.0 $r^2 = 0.86$				

Multiple comparison tests for differences between years in the proportion of cells with prepupal mortality for M. relativa 1988-1990.

TUKEY GROUPING	MEAN Proportion prepupal mortality	N	YEAR
A	0.22	8	1989
A	0.19	8	1988
B	0.09	8	1990

Experimentwise error rate $\alpha = 0.05$ df=10

% cells with prepupal mortality

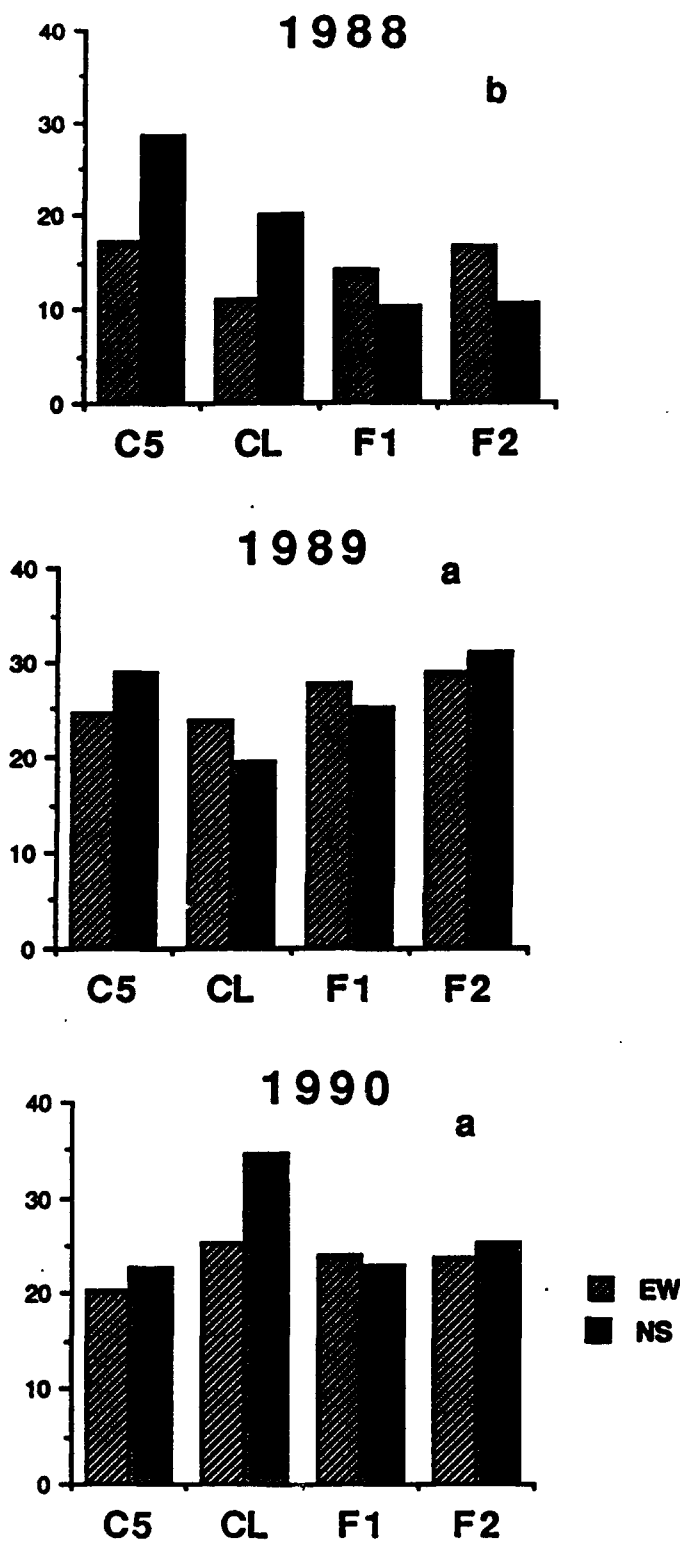


FIGURE 35. Percent of cells with prepupal mortality by year, site, and nest entrance orientation, *M. inermis*.

Table 36: ANOVA of arcsine transformed proportion of cells with prepupal mortality for M. inermis, 1988 - 1990, by nest entrance direction.

PROPORTION OF CELLS WITH PREPUPAL MORTALITY

Source of variation	df	SS	F	P>F
Year	2	0.06	15.23	0.0009**
Exp	1	0.00	6.61	0.1239
Site[Exp]	2	0.00	0.37	0.6998
Direction	1	0.00	1.06	0.3273
Direction*Exp	1	0.01	17.41	0.0529
Year*Exp	2	0.02	14.97	0.0626
Year*Exp*Direction	2	0.01	8.19	0.1088
Model	13	0.12	4.54	0.0109*
Error	10	0.02		
$\bar{X} = 0.45$ radians (0.23) CV = 9.0 $r^2 = 0.86$				

Multiple comparison tests for differences between years in the proportion of cells with prepupal mortality for M. relativa 1988-1990.

TUKEY GROUPING	MEAN Proportion prepupal mortality	N	YEAR
A	0.26	8	1989
A	0.25	8	1990
B	0.17	8	1988

Experimentwise error rate $\alpha = 0.05$ df=10

% nests with prepupal mortality

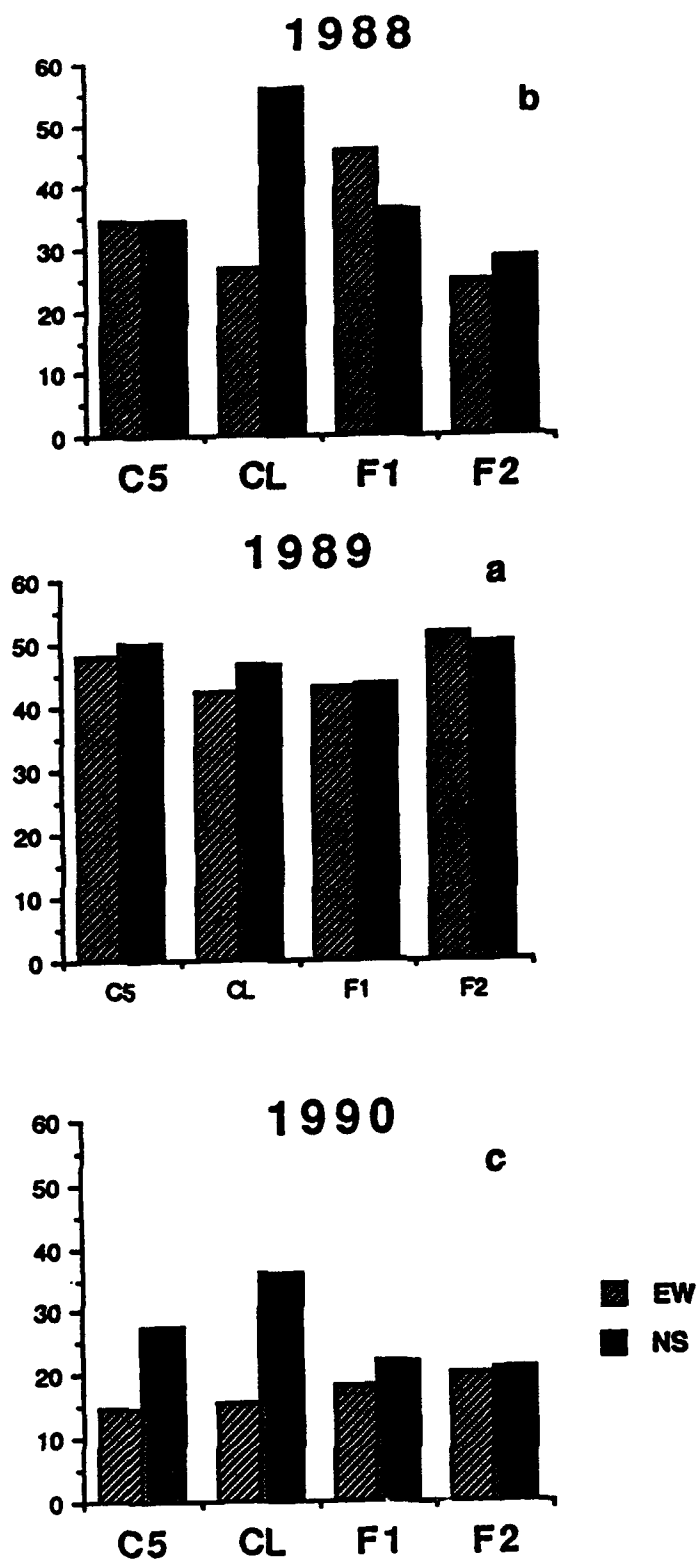


FIGURE 36. Percent of nests with prepupal mortality by year, site, and nest entrance orientation, M. relativa.

Table 37: ANOVA of arcsine transformed proportion of nests with prepupal mortality for M. relativa, 1988-1990, by nest entrance direction.

PROPORTION OF NESTS WITH PREPUPAL MORTALITY

Source of variation	df	SS	F	P>F
Year	2	0.28	26.43	0.0001***
Exp	1	0.00	1.54	0.3401
Site[Exp]	2	0.00	0.30	0.7440
Direction	1	0.02	3.61	0.0865
Direction*Exp	1	0.03	15.79	0.0579
Year*Exp	2	0.00	0.53	0.6525
Direction*Year	2	0.09	0.84	0.4618
Year*Exp*Direction	2	0.01	1.97	0.3371
Model	13	0.34	5.04	0.0074*
Error	10	0.05		
$\bar{X} = 0.63$ radians (0.35) CV = 11.4 $r^2 = 0.87$				

Multiple comparison tests for differences between years in the proportion of nests with prepupal mortality for M. relativa 1988-1990.

TUKEY GROUPING	MEAN Proportion prepupal mortality	N	YEAR
A	0.47	8	1989
B	0.36	8	1988
C	0.23	8	1990

Experimentwise error rate $\alpha = 0.05$ df=10

% nests with prepupal mortality

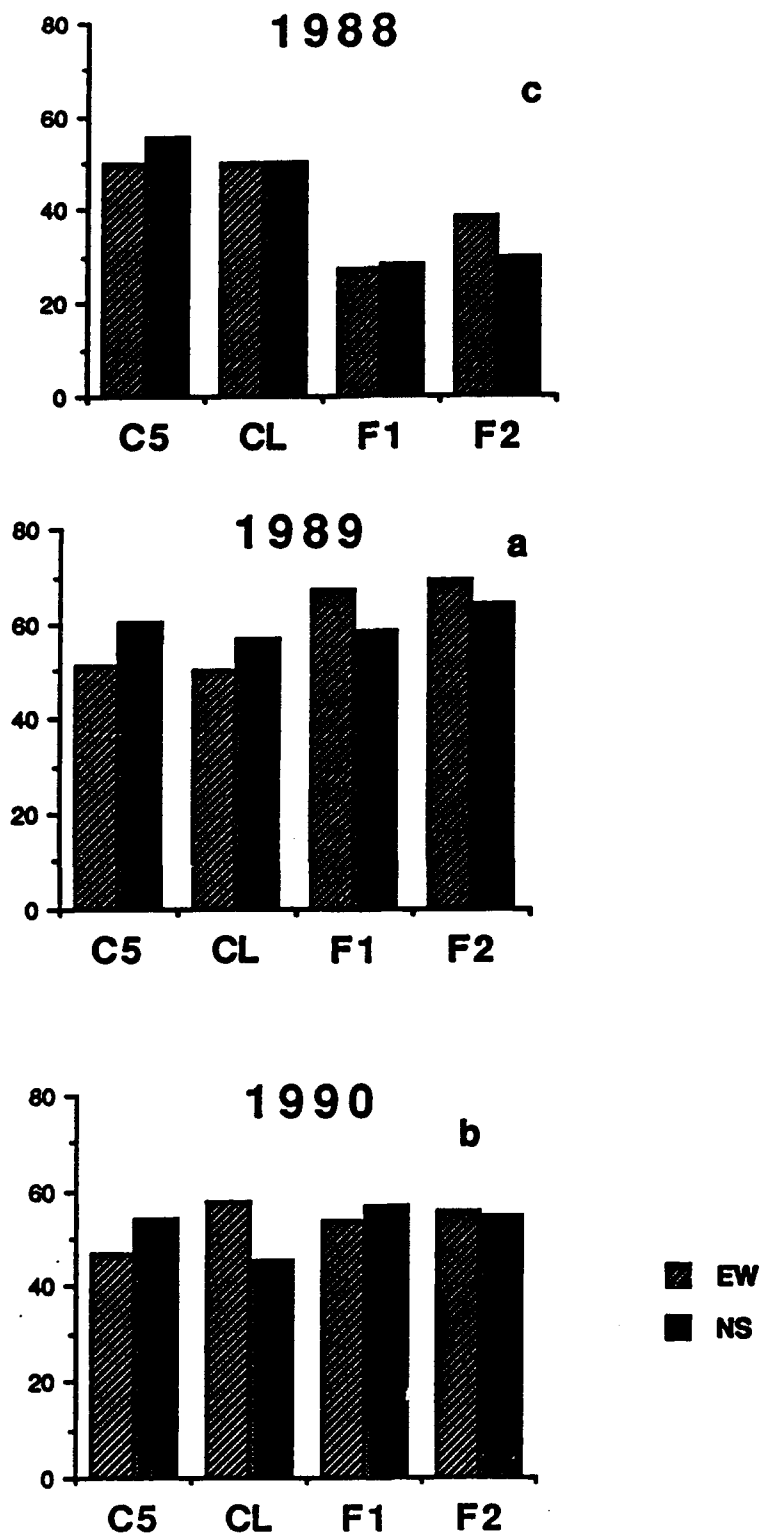


FIGURE 37. Percent of nests with prepupal mortality by year, site, and nest entrance orientation, *M. inermis*.

Table 38: ANOVA of arcsine transformed proportion of nests with prepupal mortality for M. inermis, 1988-1990, by nest entrance direction.

PROPORTION OF PREPUPAL MORTALITY

Source of variation	df	SS	F	P>F
Year	2	0.14	44.99	0.0001***
Exp	1	0.00	1.18	0.3907
Site[Exp]	2	0.00	1.19	0.3441
Direction	1	0.00	0.07	0.7932
Direction*Exp	1	0.01	3.33	0.2097
Year*Exp	2	0.10	27.69	0.0349*
Direction*Year	2	0.00	0.09	0.9145
Year*Exp*Direction	2	0.01	2.24	0.3087
Model	13	0.26	13.01	0.0001***
Error	10	0.02		
$\bar{X} = 0.80$ radians (0.51) $CV = 4.9$ $r^2 = 0.94$				

Multiple comparison tests for differences between years in the proportion of nests with prepupal mortality for M. inermis 1988-1990.

TUKEY GROUPING	MEAN Proportion prepupal mortality	N	YEAR
A	0.60	8	1989
B	0.53	8	1990
C	0.41	8	1988

Experimentwise error rate $\alpha = 0.05$ $df=10$

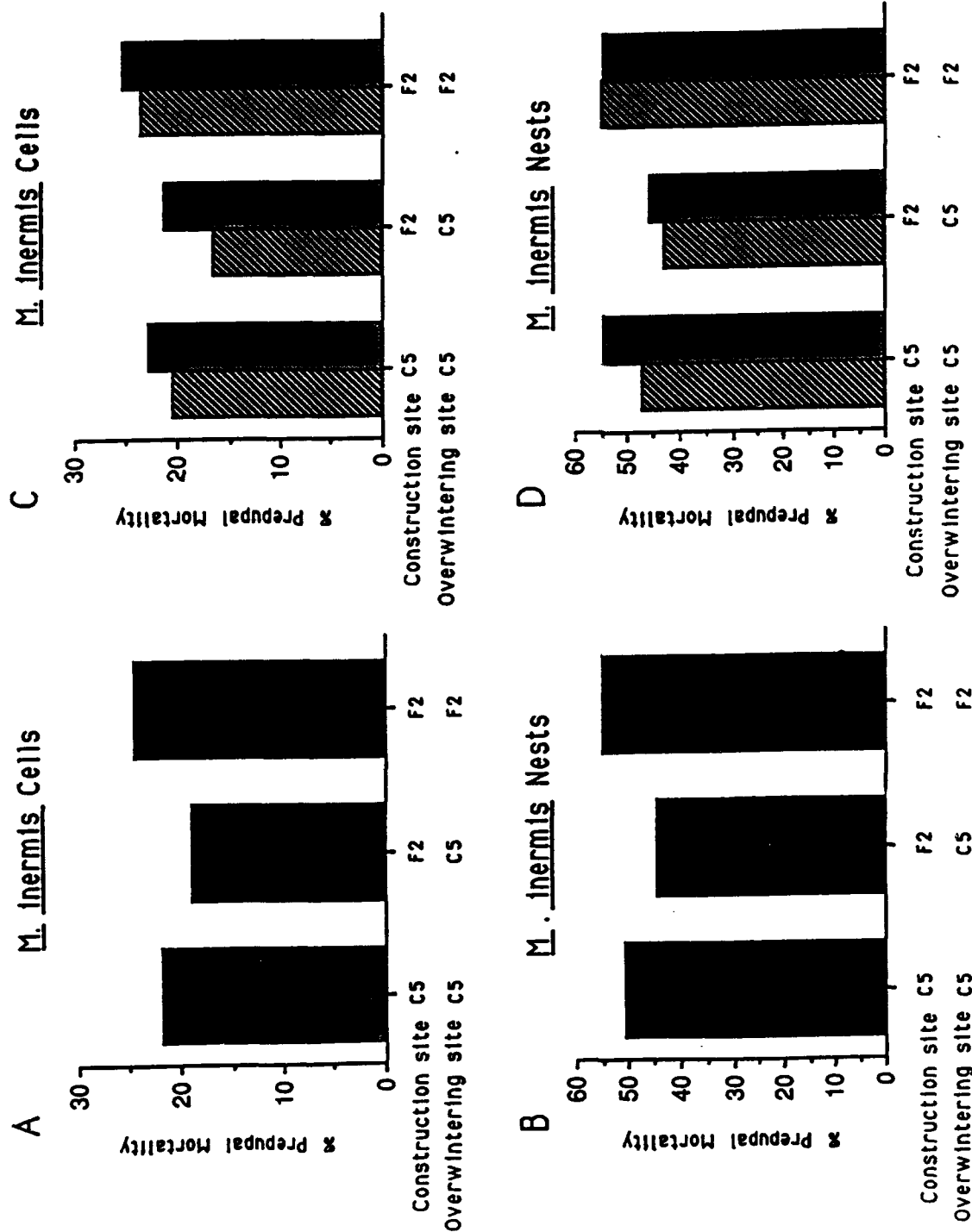


FIGURE 38: Percent prepupal mortality of 1990 *M. inermis* constructed at the C5 or F2 site, and overwintered at the C5 or F2 site. A: Percent cells with prepupal mortality. B: Percent nests with prepupal mortality. C: Percent cells with prepupal mortality by nest entrance orientation. D: Percent nests with prepupal mortality by nest entrance orientation.

Table 39: CATMOD analysis of prepupal mortality of 1990 M. inermis cells and nests by nest entrance orientation.

PREPUPAL MORTALITY OF M. INERMIS CELLS

Source of variation	df	Chi.Square	Prob.
Intercept	1	328.79	0.0001***
Overwintering site (C5 or F2)	1	6.06	0.0138*
Construction site (C5 or F2)	1	1.21	0.2713
Nest direction	1	0.82	0.3640
Ow. Site * direction	1	0.65	0.4202
Const. site * direction	1	0.28	0.5937
Likelihood Ratio	0	0.0	1.0000

PREPUPAL MORTALITY OF M. INERMIS NESTS

Source of variation	df	Chi.Square	Prob.
Intercept	1	1.03	0.3107
Overwintering site (C5 or F2)	1	3.44	0.0635
Construction site (C5 or F2)	1	1.05	0.3047
Nest direction	1	0.42	0.5175
Ow. Site * direction	1	0.09	0.7603
Const. site * direction	1	0.12	0.7336
Likelihood Ratio	0	0.0	1.0000

ELF COMMUNICATION SYSTEM ECOLOGICAL MONITORING PROGRAM

**SMALL VERTEBRATES: THE MICHIGAN STUDY SITE
TASKS 5.6, SMALL MAMMALS, AND 5.12A, NESTING BIRDS**

ANNUAL REPORT: 1991

Subcontract No.: E06595-88-C-006

Subcontracted to:

THE BOARD OF TRUSTEES, MICHIGAN STATE UNIVERSITY

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Principal Investigator: _____ Date: _____

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Professor of Zoology
and The Michigan State University Museum

Dr. Susan D. Hill
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Releasing Authority: _____ Date: _____

Richard Howe, Assistant Director
Contract and Grant Administration

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ABSTRACT

The small mammal and nesting bird biological studies in the western Upper Peninsula of Michigan for the year 1991 are reported. Previous years' data include base-line data from 1983-1985 and data collected during antenna testing from 1986 through 1989, and full operation in 1990 and 1991.

Data on tree swallow fecundity, survival and growth were analyzed according to antenna operation, plot (test or control) and across years. There were no differences among antenna operation or plots for any of the following variables: clutch size, distribution of clutch size, likelihood to hatch, hatch rate, likelihood to fledge, number fledging, growth rates (both nonlinear growth constants and linear rates) and maximum size and age at maximum size of tree swallow nestlings for body mass, leg length (tarsus), arm length (ulna), wing length, age at eye opening and feather eruption. These variables show significant year effects due to weather and also significant effects due to the nest in which they are reared.

A nestling exchange experiment was instituted in 1990 and repeated in 1991 where randomly selected nestlings were transferred to other nests within and among plots at hatching. Their subsequent growth was monitored and compared in an Analysis of Variance. No effect of the transfer or degree of exposure (as egg or as nestling or both) was detected for either year. A significant year effect was found independent of plot or exchange procedure.

An Analysis of Covariance using insect biomass as the covariate failed to show any effect on fecundity measures and could not aid in discerning plot differences. A similar analysis on growth variables could not be conducted due to significant interaction of the covariate with the main factors being tested.

Growth rates, age of incisor eruption and eye opening of young deermice were similar between test and control plots and antenna operation periods. A significant effect of the mother on her nestling's growth and the year was found, paralleling the situation in tree swallows.

The tree swallow homing study was modified to test for the effect of the release site on homing. This was done to see if earlier findings of better return rates and lower return times by birds from the test site was due to the characteristics of the release site. This year we released test birds from the control release site. We found greater numbers of displaced birds returned to test than control plots, confirming a pattern seen in other years. The time required to return to the plot was also less for test than control birds confirming earlier findings from all years. We conclusively reject the difference as being due to the release site. The significant differences between the performance of test and control birds still stands.

Small mammal homing studies indicated no difference in frequency of return for chipmunks or deermice in 1991. We have obtained mixed results over the years, leading us to conclude there is little evidence for an effect due to ELF electromagnetic radiation.

Developmental abnormalities were not different in number on test and control plots in 1991. Egg weight and measured egg volume were also not different among plots. Both variables showed a significant year effect.

Maximum aerobic metabolism was similar on plots and antenna operation period for deermice. Analysis of covariance using body weight as the covariate did not modify these findings. Chickadees showed no effect due to antenna operation, but did reveal a significant plot effect. However, the interaction between antenna operation and plot was not significant which eliminates ELF electromagnetic radiation as the cause of the plot effect. We do not know the cause of the plot effect.

SUMMARY FOR LAY AUDIENCE

The 1991 report contains results from the biological studies of small mammals and birds from the time period preceding antenna construction (1985) and the antenna testing years of 1986 through 1989 with the full operational strength years of 1990 - 1991. While findings must be considered as incomplete until the end of the project in 1992, each year's data is useful in establishing trends in the aspects of small mammal and nesting bird biology at the study sites.

In all years, nesting tree swallows on both test and control plots laid clutches of similar size with a similar likelihood to hatch and fledge on test and control plots. Mortality of eggs, nestlings and nests taken over both stages of nest life have shown higher, lower and no difference on test compared to control plots over the years. Growth and maturation (eye opening, feather appearance) of nestling tree swallows showed no difference on test and control plots or period of antenna operation. Thus, there is no evidence of any effect of the antenna's electromagnetic radiation on any of the variables we measured. As in previous years, parental care seems to greatly influence nestling growth and parents differ greatly in their ability to raise their young. There is also an effect observed due to weather that causes growth and other variables some years to differ from others. Even though there are parental care and weather differences, they are similar on test and control plots.

Growth and maturation of deermice showed no difference between test and control plots or antenna operation period. As with the tree swallows, mothers showed large differences in their ability to raise their offspring and the weather has a large effect on the young.

Homing studies of tree swallows continued to show higher rates of return and faster return times for birds from test plots. In 1991, we released test

plot birds at the same site used for the control plot birds. This was done to control for a potential release site difference. Still, overall times to return were shorter for test plot birds compared to those from control plots, and return rates were better for test birds. These findings eliminate the release site as a factor causing the observed difference. Thus, the difference could be due to the antenna, or to other as yet unidentified factors present at the test plot or in the general region of the plot.

Chipmunks and deermice returned to their home ranges at similar rates on test and control plots in 1991. For chipmunks, we have never detected any difference in homing ability among test and control plot animals. We have observed inconsistent results for deermice in prior years, with some years indicating better return rates for animals displaced on test plots and other years for control plots. These inconsistencies lead us to believe there is no antenna effect on homing.

Abnormalities of tree swallow embryos showed no difference in frequency between test and control plots. Egg weight and volume were also not different between test and control plots or antenna operation periods. A significant effect was found for the year, probably due to weather, and to the parent.

Maximal metabolism of deermice and chickadees showed no difference for test and control plots or for period of antenna operation. Chickadees do show a gradual lowering of their maximal metabolism over time, but we cannot attribute this to the antenna's electromagnetic radiation.

In summary, no effects due to the antenna's electromagnetic radiation has been found for the many variables we are studying, except for homing behavior in tree swallows. We can not at this time be certain that the better performance observed by test plot birds is due to the antenna and not other factors associated with the plot or route of travel.

PREFACE

This report begins with an extensive statement of the rationale for the studies performed (see next section, entitled "Rationale of Studies"). Then a section is provided on the overall research design and research facilities. Individual elements of the work are then described in detail in a series of subsequent sections. Each of the sections on individual work elements consists of three parts: (1) a brief restatement of the purpose (rationale) for the work, (2) a detailed description of research methods, and (3) a presentation of representative results gathered during prior years. The presentations of results include discussions of statistical sufficiency, including projections of the sample sizes required to discriminate between test and control plots in future years.

RATIONALE OF STUDIES

Dozens of species of small birds and mammals are resident near the ELF Communication System, in the upper peninsula of Michigan, and the operation of the Communication System could, in principle, affect any of them in any of countless ways. Even with virtually unlimited resources, it would be impossible to monitor individually all ecologically important aspects of all species for possible effects of the Communication System. Accordingly, we have had to exercise informed judgment in selecting variables for study. In this process, we have been guided by one overriding goal.

Our major goal has been to focus much of our effort on attributes of individual animals that are particularly likely to be susceptible to perturbation by the ELF Communication System. The reason for this focus is that laboratory research indicates that if the ELF Communication System is to have effects on birds or mammals, the effects will likely be small, and thus a statistically robust experimental design will be required to detect them (AIBS 1985). Large numbers of independent measures can be readily obtained on individual attributes, thus facilitating statistical detection of even small effects that the ELF Communication System might have.

In our studies of attributes of individual birds and mammals, we emphasize ecologically significant variables that are especially likely to be susceptible to perturbation. Reproduction and development, for example, receive particular attention because they not only are demographically important but also are more likely to be sensitive to adverse environmental changes than many other animal properties (e.g., Goodposture 1955, Koskimes 1950, Kluijver 1951, Krebs 1971, Lack 1954, 1966, Nice 1954, Perrins 1965,

Perry and Rowlands 1973). Behavior is studied in depth because it is sometimes modified readily and such modifications can have major repercussions on the lives of individuals and populations (e.g., Cohen et al. 1980, Green 1979, Morse 1980, O'Connor 1978, Slobodkin 1968).

In the following paragraphs we describe in detail the rationale for each aspect of our work on individual attributes. This work is concentrated on four particularly abundant species. The species have been carefully selected with a view to maximizing their ecological and taxonomic diversity, so as to maximize the probability of detecting whatever diverse effects the ELF Communication System may have. The four are the tree swallow (Tachycineta bicolor), the woodland deer mouse (Peromyscus maniculatus gracilis), the black-capped chickadee (Parus atricapillus) and the eastern chipmunk (Tamias striatus). To facilitate readability in the remainder of the report, they will be referred to simply as the "tree swallow", "deer mouse", "chickadee" and "chipmunk", respectively.

Behavioral Studies

In view of the established sensitivity of certain types of orientational behavior to alteration by the ELF fields (e.g., Graue 1974, Keeton et al. 1974, Larkin and Sutherland 1977, Southern 1969, 1971, 1972a, 1972b, 1973, 1974, 1975, 1976), orientation and homing in the tree swallow, deer mouse, chipmunk, and certain other mammals are being tested to see if they are affected by the ELF Communication System. Specifically, the ability of animals to return to their home-range or territory after displacement is being assessed. We know that animals are able to find food (Krebs 1971, Royama 1966) and escape predators (Metzgar 1967, Watson 1964) more effectively in

their home-range or territory than in less familiar areas. Thus, any disturbance of their ability to return to their home-range or territory after wandering afar could decrease their probability of survival.

The attentive behavior of parental tree swallows and deermice is being assessed by monitoring visits to the nest containing eggs and young. Disturbance of attentive behavior by the ELF Communication System, if it occurred, could impair development of eggs or nestlings inasmuch as the latter are dependent on parents for both food and warmth (e.g., Balen and Cove 1972, Hill 1972b).

Reproduction, Growth, and Development

The frequency and type of prenatal developmental abnormalities are examined in tree swallows. Mammals are not studied in this respect because reproductive females would have to be killed to examine fetuses, and such deaths could have serious, adverse effects on population demographics. Prenatal developmental stages are especially likely to be susceptible to perturbation (Axelsson 1954). Developing avian embryos have two major periods of sensitivity (Hamilton 1952) which occur during the first 4 days following the onset of incubation and the period just prior to hatching. A majority of the spontaneously occurring developmental abnormalities manifest themselves during these two periods (Riddle 1930, Hutt and Pilkey 1930, Hutt and Greenwood 1929, Hutt and Crew 1929, Landauer 1943, Martin and Insko 1935, Hamilton 1952). During these periods, the embryos are sensitive to changes in naturally occurring environmental agents such as temperature, humidity, CO₂, and O₂ (Alsop 1918, Babott 1937, Pembrey et al. 1894, Romanoff et al. 1938, Taylor et al. 1933). Additional teratological agents include vitamins and

their antagonists (Cravens 1952), hormones (Zwilling 1956), alcohol and ether (Stockard 1914), metal ions (Ridgeway and Karnofsky 1952), narcotics (Reese 1912), various forms of radiation (Windle 1893, 1895, Gilman and Baetjer 1904, Hinrichs 1927, and Dixon 1952) and physical jarring (Stiles and Watterson 1937). Since the onset of this investigation, effects of ELF radiation on chick development have been reported (Delgado et al. 1982, Ubeda et al. 1983, Juutilainen and Sali 1986, Juutilainen et al. 1986) There is, at present, no evidence to demonstrate that electric and magnetic fields of the magnitude generated by the ELF Communication System are capable of directly causing embryonic or fetal developmental defects. However, indirect effects are possible. Should the incubation behavior of parent birds be disturbed by the ELF Communication System, developing eggs might suffer developmental abnormalities by virtue of experiencing abnormal reductions or fluctuations in temperature. (Zwilling 1956, Hamilton 1965).

We monitor aspects of fecundity in both tree swallows and deermice. In the birds, we count the number of eggs produced per female and the number of viable eggs and young per clutch. In the mice we monitor numbers of young per litter. Fecundity is an important variable to study not only because it is demographically significant but also because it reflects on a number of variables that could, in principle, be affected by the ELF Communication System. Alteration of male or female reproductive physiology could affect fecundity. Further, any serious disturbances of prenatal development in mammals or birds would likely be reflected in a decrease in fecundity inasmuch as abnormal embryos frequently fail to be born (i.e., they are resorbed in utero or fail to hatch) or are eaten or discarded by the parents soon after birth.

Postnatal mortality and the growth and development of nestling tree swallows and deermice are also followed. Any effects that the Communication System might exert on the young themselves could be reflected in altered rates of mortality, growth, or development. Alternatively, disturbances of parental attentive behavior could be influential because the rates of mortality, growth, and development of nestlings are dependent on the extent to which parents provide food and warmth (Hill 1972b). The size of nestlings at the time of weaning or fledging is of particular interest because when young become independent of their parents, they must become substantially self-sufficient and their maturity can affect their likelihood of survival. Evidence exists that young birds that are of relatively small size at fledging are significantly less likely to survive than ones that grow to larger size while in the nest (Lack 1966, Murphy 1978, Perrins 1965).

Maximal Aerobic Metabolism

In the region of the ELF Communication System, low temperatures make winter the most physiologically stressful time of year, at least for animals such as chickadees that live wholly or predominantly above the snow. We study physiological variables that affect the ability of chickadees and small mammals to cope with the severity of the winter climate. Deficits in the physiological ability to cope would be expected to decrease the probability of survival to the next reproductive season.

Birds and mammals keep warm in cold environments by producing heat metabolically to offset heat losses. The extent to which they can keep their body temperature above air temperature depends on how rapidly they can produce heat. In other words, the lowest air temperature at which they can maintain

their usual body temperature is a function of their maximal rate of aerobic metabolism (= heat production) (Hart 1957). In view of these principles, we measure the maximal rate of aerobic metabolism of chickadees and deermice during winter. This peak rate of heat production is informative not only because it determines the lowest air temperature at which thermoregulation is possible but also because it likely provides an index of metabolic endurance. The higher an animal's maximal rate of heat production is, the longer the animal will be able to maintain any particular submaximal rate of heat production (Astrand and Rodahl 1977, Wickler 1980). Endurance is important because low air temperatures demanding high heat production can persist for long periods of time.

Beyond its immediate significance for survival in a cold climate, the maximal rate of aerobic metabolism is a valuable variable to measure because it provides an index of physiological health. In fact, peak aerobic metabolism is widely used as such an index in studies of humans. In their classic Textbook of Work Physiology, Astrand and Rodahl (1977) state that "the maximal oxygen uptake is probably the best laboratory measure of a person's physical fitness" if by fitness we mean the capacity of the individual for prolonged heavy work. Brooks and Fahey (1984), in the best of the recent texts on human exercise physiology, state that the maximal aerobic metabolism is "a good measure of fitness for life in contemporary society". Just as peak aerobic metabolism is used as an index of fitness for humans, it can also be so used in studies of animals. A deficit in the peak metabolism among individuals living near the ELF antenna would indicate that some attribute of the all-important systems involved in oxygen supply and use has been adversely affected by the ELF electromagnetic fields. Additional tests would then be

required to determine the particular attribute(s) affected. The ability of the respiratory system to provide oxygen, the ability of the circulatory system to transport oxygen and nutrients to metabolically active tissues, the ability of storage tissues (e.g., adipose tissue) to mobilize stored nutrients, and the enzymatic competence of metabolically active tissues to catabolize nutrients are among the variables that influence an animal's peak rate of aerobic metabolism (Wang 1978). In human studies, peak aerobic metabolism is usually elicited by having individuals run on a treadmill. We elicit peaks by exposing animals to cold, in part because the method is technically simpler than treadmill running (given that animals require extensive training to use a treadmill successfully) and in part because the cold-induced peak is of immediate relevance to understanding winter ecology.

OVERALL RESEARCH DESIGN AND SUPPORT FACILITIES

To detect possible effects of the ELF Communication System, we compare animal attributes on test plots (test sites) with those on paired, spatially separated control plots (control sites).

Test plots, as specified in the original IITRI Request for Proposals, are areas close enough to the Communication System that electric and magnetic fields attributable to the System, and measured in the soil near the earth's surface, will approximate 0.07 volt/meter and 0.03 Gauss, respectively. Furthermore, electric and magnetic fields attributable to ELF sources other than the System are to be at least an order of magnitude lower than those attributable to the System.

Control plots, according to the original Request for Proposals, are areas sufficiently distant from the Communication System that electric and magnetic fields attributable to the System, measured in the soil near the earth's surface, are at least an order of magnitude, and preferably two orders of magnitude, below those at paired test plots. Furthermore, electric and magnetic fields in the air and earth attributable to ELF sources other than the System (especially 60 Hz sources) are not to differ by more than an order of magnitude between the control plots and their paired test plots.

For purposes of experimental design, the test plot(s) used for any particular work element are paired with particular control plot(s). The plots of a pair are matched as closely as possible for vegetation, soil type, drainage, and other such features. By pairing plots in this way, we minimize the likelihood that non-ELF differences between plots will introduce significant confounding effects into our results.

A major strength of our research is the paired plot design. Within a year, we can compare possible ELF effects across plots. The design has an additional strength due to the capability of before and after comparisons for each plot where each plot can be used as its own control through time. We consider three phases of antenna operations: 1) pre-antenna, 1983-1985, 2) antenna testing, 1986-1988, and 3) full antenna operation, 1989-1991.

Different work elements are carried out on different pairs of plots for several reasons. Specific work elements could interfere with other work if both were carried out on the same populations of animals; areas where we artificially remove animals (e.g., bird embryos), for example, are not used for research on natural populations. Another factor that demands the use of different plot pairs for different work elements is that the various species we study do not all occur in similar habitat types; field habitats are required for the swallows, whereas forests are required for the deermice.

To minimize potentially confounding differences between test and control plots, sham corridors have been cut through the forests at the control plots. These corridors are clearings of the same width as the corridors cut for installation of the Communication System antenna near test plots. They were cut with similar equipment, and they have been treated similarly after cutting. In brief, the sham corridors are as identical as possible to the antenna corridor except that antenna poles and wires have not been installed in the shams. Areas for animal study on control plots and those for animal study on test plots are located about the same distance from the sham corridors and antenna corridor, respectively.

Plots were established as matched pairs (Table 1) of test and control plots for the various work elements. Test plots were located along the north-

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south antenna element and control plots were located at varying distances to the west of the antenna (Figure 1). The names given to the plots (Table 1) are the standardized ones we use in all our descriptions of experiments and results. The alpha-numeric codes for plots are those used by IITRI.

Modifications in Project Scope and Statistical Sufficiency

The number of study elements was reduced in March, 1989, when budget cuts were made to meet increased wages of non-faculty employees on the project. The wage increases resulted from a labor settlement at Michigan State University. The following research elements were dropped: small mammal community studies, small mammal parental care, and tree swallow incubation. All remaining research elements were continued at full strength.

We have revised our standards for statistical sufficiency for the research program based on our years of experience with the various study elements to date. We originally established the standard of statistical sufficiency in our work that we predicted would provide a 90% certainty of detecting a 20% difference between test and control sites at the 5% level of significance. While we can still meet these standards on some of our work, we clearly can not for others, such as growth of both tree swallows and deermice (see Tables dealing with growth). Variation among nests unrelated to plot is the principal reason. These unexpectedly high variances lead to projections of sample sizes beyond the possible scope of our research. We must therefore relax our standards of statistical sufficiency. We have decided to report the actual level of detectable difference in means achieved in a test and the difference we could detect if we relaxed the level of certainty (power) to 70%. The reader will therefore be able to judge for each test the particular

statistical confidence that can be met. Literature values for detectable differences or power are not currently known to us for comparison. It seems that most authors do not report either value. For discontinuous variables, we have used different procedures to determine sample size (see Gill 1978, p. 82). Therefore we do not propose changes in statistical sufficiency since we appear to be able to meet the stricter requirements with these data. Discussion of sample size and power of test are presented with the data for each study element (see below).

Our base of operations for the on-site field and laboratory studies is a large house rented in Crystal Falls, MI (801 Crystal Ave.). The physiology laboratory is installed there. The holding facility for temporary housing of animals used in the physiology experiments is located approximately 3.5 miles south of Crystal Falls, MI in an area with minimal electromagnetic interference. We have a shop for construction and maintenance of field equipment and a large shed for storage of traps, cages, construction materials, and seasonal field equipment. We also have a well-established data management system housed there (see below), and living space is provided for employees. We rent and maintain three pick-up trucks to provide transportation between our base of operations and field research sites in all weather conditions on a year-round basis. In addition, we rent a snowmobile to gain access to our more remote sites during winter and spring when traveling the entire distance by truck becomes impossible.

For data management we employ an IMS (now LF Technologies) computer system at the MSU Museum in East Lansing. The system is multi-user and allows storage of data on fixed and removable media. Zenith (AT-class) computers are used at the field laboratory in Crystal Falls. Data transfer and analysis are

accomplished using both systems. Field data are collected by NEC PC-8201A portable computers. We have developed software to standardize and error check field data as it is recorded. Collected data are transferred directly into an AT computer at the field laboratory each day. Transferred data are immediately edited and stored on removable and fixed disks for later analysis. Certain data are analyzed as soon as they are collected. This data management design allows us to collect and analyze large amounts of data very efficiently and accurately. In addition, in 1987, we added high speed tape backup systems to aid in recovery of data should either computer system fail, and for archiving the now voluminous data sets for the various study elements. The large sample sizes required in many of our study elements necessitate the careful and accurate data handling the system provides.

Other major equipment is described in connection with individual work elements in the sections that follow.

Measurements on 60 and 76 Hz fields. Engineers provided by IITRI have measured 60 Hz electric and magnetic field intensities every year starting in 1983 on our test and control plots, and all the pairs we now use adequately meet the standards for field intensities already described. Electric and magnetic fields produced by the antenna system (76 Hz) were measured starting in 1986, when low amperage testing began. Measurements have continued as the antenna has become operational. A summary of the data 1983-1990 is provided in Tables 2 - 9. Data for 1991 are not yet available. Details of the results of the field-intensity measurements and the measurement techniques can be found in Enk and Gauger (1985), Brosh et al. (1985 and 1986), and Haradem et

al. (1987, 1988, 1989 and 1991). Earlier discussion of measures and plot pairings are outlined in the 1984 annual report (Beaver et al. 1985, pp. 3-9).

In all years, measures were made in September or October by IITRI personnel on our test and control plots during antenna operation. The distribution of operation hours by month for 1986, 1987 and 1988 for the north-south and east-west antennas were concentrated in the months of June through November in 1986 and 1987. Continuous operation began in 1988, but the antenna was shut down for repairs during most of the months of January, February and March, 1989, during our winter studies. Continuous operation occurred through out the remainder of 1989 and all of 1990 and 1991 (Haradem and Gauger 1991, and personal communication). During these years, the amperage of antenna operation varied from 3 to 150 amperes. Schedules of research activities in the spring and summer fell within the times of heaviest antenna operation in all years. Operation of the antenna was conducted on a 33% time rotation schedule in which the east-west antenna was on for 5 min, then the north-south antenna for 5 min, followed by both antennas off for 5 min. The percentage of time the MTF was on varied from 1.8% (1986) to nearly 100% (1990). The antenna was off for repair and maintenance for about 5 hours twice per week in 1990 (Haradem and Gauger 1991).

60 Hz Fields - Background measures. Measurement of background 60 Hz fields on control and test plots began in 1983. These fields are produced by existing power lines near the study plots. Plots were chosen to have minimal values for 60 Hz fields and to be matched as control and test plots, within the standard of one order of magnitude. Transverse electric fields were initially at or near the lower limits of measurability on all plots (Table 2). Low power testing of the antenna began in 1986 and continued through 1988 at

increasing amperage. Values for transverse electric fields then increased on one test plot (1T2) in 1987, and the all test plots through 1990. Control plots remained unaffected. Apparently the fields produced by near by power lines couple to the antenna and re-radiate as 60 Hz fields (Gauger, personal communication).

Averaged values for longitudinal electric and magnetic 60 Hz fields (Tables 3 and 4) were higher on test compared to control plots in most years. Control test plot ratios varied from about 1 to over 27 fold for longitudinal fields, with the high value coming from 1988 for 1T6 vs 1C4 (Table 3). Longitudinal electric fields averaged highest on control plots in 1984 and on test plots in 1988. Magnetic fields remained relatively constant on controls but increased from 1986 through 1988 and then appear steady to 1990. On test plots, magnetic fields increased from 1986 to 1988 and then decreased in 1989, and 1990 (Table 4).

Among sites within the control plot, 1C1 and 1C3 (Michiganme North and South) were consistently higher for 60 Hz longitudinal electric fields (Table 3). Test plots 1T5 and 1T6 (Ford River North and South) were higher than other test sites in most years (Table 3). Magnetic fields show larger values for site 1C6 but no patterns in other control plots. plots 1T2-1T6 all increase in 1986, 1987, and 1988 (Table 4) but then decreased in 1989 and 1990. Site 1T1 shows a smaller increase and then a decrease in these years.

The control release location (1D3) and Panola Plains (1C4) control site for tree swallow homing shows small differences in field strength for electric and magnetic fields (Tables 2-4). However, much larger ratios appear on test release locations (1D1 and 1D2) and their corresponding test sites (1T2, 1T4) for transverse, longitudinal and magnetic fields (Tables 2-4).

Measurement of 60 Hz fields were also conducted in the laboratory where measurement of maximal metabolic scope was done. A number of sites near equipment and in the holding facilities were measured by IITRI personnel. Shielding was provided for animal containers and laboratory locations where animals had direct exposure. The shielding significantly reduced the strength of electric and magnetic fields (Tables 5a,b).

76 Hz Fields. In 1986, 1987 and 1988, measurements were made on 76 Hz fields produced by the antenna during testing. Variation of 76 Hz fields was examined among control plots to see if they were homogeneous. Control plots were all uniform with respect to transverse electric (Table 6) and magnetic fields (Table 8). For longitudinal electric fields (Table 7), sites 1C1 and 1C3 were significantly greater than 1C4 and 1C6.

Among test plots, 1T5 was greater than other sites for transverse electric fields (Table 6), and 1T6 was greater than other sites for longitudinal electric fields (Table 7). No other patterns emerged. The control plots 1C1 and 1C3 are closer to the antenna system by several Km, perhaps explaining their higher values. Test site longitudinal electric fields differ from each other because of varying distances to the antenna wire and because of variations in soil conductivity between and across sites.

Longitudinal electric and magnetic 76 Hz fields were significantly different for test and controls (Tables 6-8), indicating that low amperage testing produced a "treatment" condition on test plots, compared to controls. This raises the question as to when the antenna was actually operational. We must know this in order to group data in pre- versus post-operation. We have been informed by IITRI that a panel studying this question has determined that

pre-operation will be defined as years through 1989 and post-operation will be years 1990 and thereafter.

The release sites for tree swallow homing studies compared to their respective study plots show low ratios for control sites and higher ratios for test (Tables 6-8). Ratios generally increase from 1986 to 1990, although transverse fields show a drop in 1988 and increase again in 1989 and 1990 (Tables 6-8).

Comments on Ambient Monitoring

We have elected to use weather station data from several nearby sites to monitor the effects of climatic conditions impinging on the plots. The plots are relatively close to each other and therefore experience the same major weather patterns. Minor differences probably exist due to variations in storm tracks, local topography and vegetative features. These differences will produce some degree of variability in response in our study animals, but in most cases we expect this to be small and random in direction. It is therefore our judgment that the greatest value of station weather data will be for examination of year-to-year effects, rather than within a year among plots.

There is one instance where we have become aware of an effect that is probably based on micro-climatic differences among the plots. The abundance of aerial insects that are preyed upon by tree swallows is greater on control plots (see section on tree swallow growth). However, test plots may be less affected by cold weather due to the adjacent forest than control plots. We instituted a program to sample aerial prey, in cooperation with Dr. D. Hussell in Ontario, Canada, in 1986. The program is given in greater detail below in

the sections dealing with population statistics and growth of tree swallows. This year we have the first results available, and we report on our findings in the section on tree swallow growth.

STUDY OF SMALL MAMMAL COMMUNITIES

I. Purpose

The small mammal community study has not been conducted since 1988. As we have stated in previous annual reports, differences between plots from year to year appear to be site specific and variable. Such variability does not allow us to examine ELF effects within the levels of our stated statistical goals. Therefore we felt the year-to-year variability, coupled with new budgetary constraints in 1989, would not allow us to adequately detect effects due to ELF. We therefore elected not to continue the small mammal community study.

PARENTAL AND NESTLING BEHAVIOR, AND FECUNDITY,
GROWTH AND MATURATION STUDIES - TREE SWALLOWS

I. Purpose

The purpose of these studies is to characterize several aspects of the reproductive process in tree swallows at test and control sites and to test for possible effects of the ELF Communication System on these variables. Specifically, the following aspects of the reproductive process are compared between test and control sites and for each site from year to year: numbers of eggs per clutch, hatching success within clutches, rates of growth and development of hatchlings, and nestling mortality. All of these work elements are described together in this one section because they are all conducted on the same population of birds.

II. Methods

These studies were conducted in natural or artificial clearings where we have erected arrays of nest boxes. The boxes were made of cedar lumber and mounted on posts, 1.5m above the ground. Tree swallows readily elected to nest in the boxes, although higher occupancy rates were recorded on control plots (Table 9). We think this is due to their larger area and relatively smaller edge of unsuitable vegetation. Adults at the nest tolerated considerable disturbance by investigators. The boxes could be opened to permit inspection and weighing of young. Sheets of high-density polyethylene wrapped around the posts prevented access by terrestrial predators.

When possible, adults were captured on the nest after incubation was completed and banded with U. S. Fish and Wildlife Service bands for identification. Since it has been shown that certain reproductive variables are affected by the age of the female (DeSteven 1978), most of our effort was

placed on capturing females so we could determine their age. In addition, as many young as possible were banded before fledging.

Active nests were checked daily or every other day to determine the dates that eggs were laid, how many were laid, the dates the young hatch, and overall hatching success. During hatching, nests were checked twice daily to determine time of hatching with greater accuracy as well as the spread of hatching over time. Monitoring of the nests for nestling growth and mortality then continued until all young reached 15-16 days of age. Young tend to fledge unusually early if disturbed beyond day 16. Therefore, to minimize disturbance after day 16, nest checks to estimate fledging success were done every other day.

For studies of growth and development, nestlings were weighed every other day with a Pesola spring scale accurate to 0.1 g. The lengths of the tarsus, ulna, and wing (all from the right side of the body) were measured with dial calipers accurate to 0.1 mm. Since it was impossible for one observer to measure all nestlings we had at least two observers collecting growth data. However, we have noticed that observers differ slightly in their techniques for measuring weights and body parts. Therefore we had all observers rotate among the plots so that every nestling was eventually measured by all observers. Regularly rotating the observers in this way has the effect of submerging the variance in measurement, due to observers, into the error in each nestling's growth curve. This measurement protocol unfortunately prevents us from being able to block observer effects in the statistical design. However, as we show below, when we use data from each individual bird's growth curve, even the significant effects of differences in observer

technique do not prevent us from being able to detect small differences in patterns of growth.

For analysis of growth data, we used the procedure for fitting growth data to models of growth proposed by Ricklefs (1967, 1983) and used previously for tree swallows by Zach and Mayoh (1982). Briefly, the data for each nestling were subjected to curve fitting using an exponential or logistic model in a linear regression routine in SYSTAT (Wilkinson 1988). The model of best fit, as judged by having the highest value of R^2 , was used in subsequent analyses to obtain the rate of growth, the intercept, and the inflection point. The model of best fit every year, including 1991, has been the logistic. We also tested values for maximum size attained for weight, tarsus and ulna (wing is still growing at fledging). We also computed a linear growth rate for ages 3 to 11 days (the period of linear growth) to compare to our other measures of growth. These measures have been shown by Zach (1988) be less variable than fitted values, as our data also show.

In past years we have detected significant differences in growth rates of young tree swallows between test and control plots. Recent evidence suggests that food availability on a plot can have a significant effect on both clutch sizes and growth rates of tree swallows (Hussell and Quinney 1987, Quinney et al. 1986). In order to determine what degree of variation between test and control plots in growth rates is the result of food resource availability, we have undertaken steps to quantify the flying insect abundance at each site. We have worked with Dr. Hussell of the Ontario Ministry of Natural Resources and have designed a sampling scheme based on his earlier work (see Hussell and Quinney 1987, for detailed methodology). At each tree swallow site we collected flying insects during the daylight hours in two suspended conical

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nets which terminate in alcohol traps. These nets were located among the nest boxes and were constructed to face passively in the wind so as to continually sample insects which either flew or were blown into the nets. Previous studies showed an excellent relationship between the insects collected in this type of system and the insects delivered to young swallows in the nest by their parents (Quinney and Ankney 1985). Sampling began before the initiation of any egg laying and ended when all young from the plot had fledged. After insects were sorted into size classes we computed an index of the biomass of flying insects determined from daily catches on each plot. This allowed us to compare the prey abundances between test and control plots in order to look for explanations in differences in clutch size, hatching and fledging success, and growth rates between plots. These data may further refine our abilities to detect possible subtle differences in tree swallow reproductive measures due to electromagnetic fields associated with the Communication System. We now have the first completed data sets of insect biomass for the years 1986 through 1989. We present our findings in the section on growth below.

Nestling Transfer Experiment. In 1990, we designed a nestling transfer experiment to test for effects of short-term exposure to ELF radiations. The experiment was repeated in 1991. We report the results for the first time in this report. The rationale for the experiment was that the most powerful test of ELF effects would be to select a subset of individuals from the same nest and have them grow to independence in a nest on the other plot. Thus, individuals hatched on the test plot and transferred to the control plot would experience ELF radiations only as eggs, and nestlings transferred to the test plot from the control would only have experienced ELF radiations as nestlings. Controls were established for the effect of being raised by different parents

and for transferring the young out of the nest. The procedure was to select nests at the same stage of development (they had to hatch on the same day). Nests were then assigned at random to a control, within plot exchange or across plot exchange. Next nestlings were toe-marked with ink to indicate nestling 1 through 5 (nests were selected with five or six nestlings; all were standardized to five nestlings). Then a random set of three nestlings were chosen to be the transferred ones; the other two nestlings remained in their nest. In the control situation, the set of three selected nestlings were taken from the nest, but then immediately replaced, simulating the same procedure of moving nestlings among nests. In the within plot exchanges, the set of three nestlings were exchanged with another nest on the same plot. In this case, nestlings were either unexposed (control plot) but exchanged, or exposed (test plot) but exchanged for their entire nestling life. In the across plot exchanges, the set of three nestlings were exchanged with a set from the opposite plot. In this case, a set hatched on the control plot would be transferred to the test plot and the set hatched on the test plot was transferred to the control plot. These individuals were not exposed as eggs but were as nestlings (control to test plot) or were exposed as eggs but not as nestlings (test to control plot). In both years, the setup of the experiment and coding of young was done by supervisory project personnel. Workers measuring growth of the experimental young had no knowledge of which young had been exchanged and therefore were "blind" to the experimental designations. Growth statistics were later matched to young by use of codes set up in the original design. The treatment levels in the design were then 1) no exposure with sham exchange, 2) no exposure with exchange, 3) exposure as eggs but nestlings raised without exposure, 4) not exposed as eggs but

raised as nestlings with exposure, 5) full exposure with no exchange, 6) fully exposed with exchange with other exposed nests. The effect of being reared by different parents in exchanged young was included in the error term. We are continuing to consult with statisticians to see if a suitable design can be found to account for the parental effect.

A Note on Analysis of Variance Tests. This year we report for the first time Analyses of Variance taking into account antenna operation, years, plot and nests in a single test. The model used has two main fixed effect terms: OPERATION and PLOT. There are two random nested effects: YEAR(OPERATION) and NEST(PLOT), and the other terms of the model include interactions of the main effects and the nested effects. The appropriate error term for testing main effects is complicated by the presence of the nested effects. We have followed the procedures in Zar (1984, pages 470-476) for determining the appropriate error term. In general, the error term for the PLOT effect was the $NEST(PLOT) + PLOT*YEAR(OPERATION) - ERROR$ mean squares, and for OPERATION effect, YEAR(OPERATION) mean square. Degrees of freedom were estimated using the formula provided by Zar (1984, page 473).

III. Results - 1991

With increased return rates of nesting adults observed each year we have established plots which will provide adequate sample sizes for all of the tasks reported on below. Starting in 1986, we conducted all aspects of the research program on specific plots established for each individual task (see Table 1) and will continue with this protocol as originally proposed.

The age of adults breeding on the plots was quantified in earlier years by categorizing a bird as an adult if it had a high percentage of its dorsal plumage colored iridescent green. Younger birds have mostly a gray back

plumage with little green (Husse'l 1983a). In 1985, we found many more young birds nesting on control than test plots (Beaver et al 1986). In 1986, we were not able to make as complete a determination because many birds abandoned their nests due to inclement weather prior to the time we designated to assess age of adults. However, we did keep records of birds we saw on our daily visits to the plots. Less than 10% of nesting birds were young birds and there appeared to be equal numbers of them on test and control. In 1987, less than 20% of nesting birds were young birds, with greater numbers of young birds on the control plots. Of the nesting birds observed in 1989, 11% were known to be young females. In 1991, as in 1990, 14% of the nesting birds were young birds with the majority noted on the control plots. This large number of young birds on the control plots may be reflective of an inherent difference in habitat quality between the two plots. Even if this is true, the collection of data from test and control both before and after antenna activation should enable us to sort out antenna effects and habitat effects by categorizing effects on young versus older birds and their nests.

Fecundity. Summarized fecundity data for tree swallows in 1991 and previous years (1985-1990) show that test and control plots have nearly equal clutch sizes while hatching and fledging rates are slightly lower on the control plot (Table 10). These data exclude any renesting attempts and analyses on fledging success exclude any nests manipulated for the swapping experiments (see tree swallow growth section). Mean clutch sizes in 1991 were essentially the same at Tachycineta Meadows control (5.2 eggs/nest) compared to clutches at Pirlot Road test (5.1 eggs/nest, $t = 0.473$, $P = 0.637$). These values are within the range of clutch sizes reported elsewhere for tree swallows (Chapman 1955, DeSteven 1979, Zach and Mayoh 1982, Hussell 1983b).

In addition, there was no difference in the distribution of clutch sizes between test and control plots in 1991 (bottom Table 10, G-test of independence, $G = 1.90$, $P > 0.5$).

Data on clutch size from all years of the fecundity study (1985-1991) were subjected to a nested analysis of variance to investigate the potential effects due to PLOT (test vs. control), antenna OPERATION (pre-operational 1985-1989, operational 1990 and 1991, as defined by IITRI), YEAR (nested within OPERATION), and the interaction terms of PLOT*OPERATION and PLOT*YEAR. Results of this analysis (Table 12) show no significant effects due to plot ($F = 0.18$, $P = 0.674$), antenna operation ($F = 0.06$, $P = 0.809$), or year ($F = 1.10$, $P = 0.362$). There was a significant interaction detected between plot and operation ($F = 4.75$, $P = 0.030$). This interaction is due to mean clutch sizes decreasing slightly on the test plot over time (5.26 eggs/nest preoperational vs. 5.10 eggs/nest operational), whereas mean clutch sizes on the control plot increased slightly over time (5.19 eggs/nest pre-operational vs. 5.34 eggs/nest operational).

We have suspected that there may be differences in available food at the test and the control plots and this could be influencing clutch sizes, a finding reported for tree swallows in Canada by Hussell and Quinney (1987). We have been cooperating with David Hussell in determining indices of prey biomass at our sites and now have data from 1986-1989. Results from 1990 and 1991 are presently being calculated, and we will have to wait for these data before investigating the possibility of using these indices as covariates in our full model comparing the operational status of the antenna. For the four years we do have data, we have examined the usefulness of the estimate of aerial insect biomass as covariate in accounting for differences in fecundity.

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We examined three variables associated with reproduction: clutch size, number of eggs hatching and number of young fledging. The covariate used with clutch size was the summed preceding 15 daily values of insect biomass indexed on the date of the first egg laid in each nest. For number of eggs hatching, we summed the 15 days preceding the date of the first egg hatching. For number fledging, the covariate was the summed 15 days preceding the first young fledged in each nest. The results of these analyses (Table 15) indicate that the covariates in each case do not account for a significant amount of variation in the statistical model nor among the main effects, such as PLOT or YEAR, except for YEAR for the number hatched. The effect of YEAR occurred in the absence of the covariate (see Table 13), and since the covariate itself does not account for a significant amount of variation in the model, we conclude the difference in YEAR is not affected by the covariate for the number of young hatched. However, the significant effect of year for clutch size and number fledged seen without the covariate (Table 12 & 14) in the model disappears when the covariate is included (Table 15). In these cases, we conclude the covariate is in fact accounting for the bad weather years that also produced smaller clutches and fewer fledged young. Our data do support the general finding in the literature of an effect of prey availability on reproductive variables, although weakly. Perhaps the reason we do not see a stronger relationship with the covariate is that our plots have only slightly different levels of insect biomass whereas the reports in the literature are comparing plots with very large differences in insect biomass (Hussell and Quinney 1987). The biggest disappointment for our studies is that the insect biomass covariate does not seem to be of much value in accounting for

differences among our study plots in comparing the effects of ELF radiation on reproductive variables.

The number of young hatched per nest in 1991 (Table 10) was not different between the Pirlot Road test plot (4.4 young/nest) and Tachycineta Meadows control plot (4.3 young/nest, t-test, $t = -0.198$, $P = 0.844$). In addition, the proportion of eggs which hatched on the test plot (86.3%) was not different from the proportion hatching on the control plot (83.9%, G-test of independence, $G = 0.347$, $P > 0.5$). This has been the case for all years of the study except in 1986 when a significantly greater proportion of eggs hatched on the test plot when compared to the control. These values for hatching success are within the range reported elsewhere for tree swallows (Low 1933, Paynter 1954).

Data on hatching success from all years of the fecundity study (1985-1991) were subjected to a nested analysis of variance to investigate the potential effects due to PLOT (test vs. control), antenna OPERATION (preoperational 1985-1989, operational 1990 and 1991), YEAR (nested within operation), and the interaction terms of PLOT*OPERATION and PLOT*YEAR. Results of this analysis (Table 13) show no significant effects due to plot ($F = 0.91$, $P = 0.342$), antenna operation ($F = 0.50$, $P = 0.511$) or the interaction terms. There is, however, a significant effect due to year ($F = 4.19$, $P = 0.001$) which is a result of higher numbers hatched per nest in 1986, 1988 and 1990 on both test and control plots when compared to other years (Tables 10 and 11). This effect is most likely attributed to the weather pattern in those years.

The number of young fledged per nest in 1991 was slightly higher at Tachycineta Meadows control plot (3.1 young/nest) when compared to Pirlot Road

test plot (2.6 young/nest), but these results are not significantly different (t-test, $t = 0.963$, $P = 0.340$). The same trend in proportion of young fledged was observed, with 61.4% fledging at the control plot and 51.4% fledging at the test plot (Table 11). Likelihood to fledge was also not different between test and control (G-test, $G = 2.760$, $P > 0.05$).

Data on fledging success from all years of the fecundity study (1985-1991) were subjected to a nested analysis of variance to investigate the potential effects due to PLOT (test vs. control), antenna OPERATION (preoperational 1985-1989, operational 1990 and 1991), YEAR (nested within operation), and the interaction terms of PLOT*OPERATION and PLOT*YEAR. Results of this analysis (Table 14) show no significant effects due to plot ($F = 1.18$, $P = 0.278$), antenna operation ($F = 0.46$, $P = 0.527$) or the interaction terms. There is, however, a significant effect due to year ($F = 17.24$, $P = 0.0001$) which is a result of very high mortality of young on both test and control plots due to inclement weather during 1986, 1989 and to a lesser extent in 1991.

In summary, we can detect no significant differences in these fecundity variables due to antenna operation or treatment (plot) throughout the study. Covariates based on an index of daily insect biomass also were not useful in comparing treatment (plot), but may account for the effect of years with bad weather on these variables since insect biomass is also suppressed then.

Mortality. In addition to the intensive study of fecundity variables at the Pirlot Road test and Tachycineta Meadows control plots, we monitored all active nests at two additional test plots (North Turner and Cleveland Homestead) and one additional control plot (Panola Plains). Thus, three test plots pooled and two control plots pooled provide the basis for an analysis of

overall nesting success based on the Mayfield method (Mayfield 1961, 1975). This method takes into account the exposure of each egg and nestling to mortality factors over the number of days which the nest is observed. The nest as a whole can be examined in the same manner so we also present data grouped by nest. As examples of these two approaches to the analysis of mortality, one nest with five eggs observed for four days would represent 20 egg days of exposure when the level of analysis is the individual egg. Continuing with this example, for analysis of egg mortality we compared the frequency of egg days with mortality to the frequency of egg days without mortality between all nests on test and control plots. The parallel example, using the nest as the unit of exposure, would be a comparison of the frequency of days without mortality for entire nests compared to those that experienced mortality on test and control plots. We first present the data for individual eggs and nestlings (Table 16, EGGS and NESTLINGS) and then for entire nests (Table 16, OVERALL NESTS).

The number of exposure days with egg mortality was not different between test and control plots during 1991 (Table 16, $G = 1.668$, $P > 0.5$). This is the same result obtained in 1989. However, during 1987, 1988 and 1990 there were significant differences observed. During all three years the test plots showed higher percentages of egg mortality than the control plots.

The number of exposure days with nestling mortality was not different between test and control plots during 1991 (Table 16, $G = 0.397$, $P > 0.5$). This is the same result obtained in both 1989 and 1987, whereas significant differences were found in 1988 and 1990. During both years when significant differences were reported the test plots showed higher percentages of nestling mortality than the control plots.

The number of exposure days with whole nest failure (OVERALL NESTS) was not different between test and control plots during 1991 (Table 17, $G = 0.267$, $P > 0.5$). This is the same result obtained in 1989, but not during 1987, 1988 and 1990 when we reported significant differences. During all three years when significant differences were detected the test plots showed higher percentages of days with whole nest failure than the control plots.

We can also separate the mortality of nests into two phases: during the time of egg laying and incubation and during the time when nestlings are present in the nest. This helps identify mortality factors which may be greater during one phase of activity. For example, the feeding of young greatly increases the amount of activity around the nest by the adults and may attract more predators.

During 1991 there was no difference in nest mortality between test and control plots during the INCUBATION PHASE (Table 17, $G = 0.002$, $P > 0.5$). This is the same result obtained during all years except 1987 when a significant difference between test and control plots was reported. During 1987 test plots showed higher INCUBATION PHASE nest mortality than the control plots.

There was also no difference in 1991 between test and control plots for NESTLING PHASE nest mortality (Table 17, $G = 0.501$, $P > 0.1$). This is the same result obtained for all years except 1988 when a significant difference between test and control plots occurred. In 1988 test plots showed higher NESTLING PHASE nest mortality than control plots.

Summarizing incubation and nestling phase mortality, during 1991 there were no significant differences between test and control plots. In all years when differences between test and control plots were detected, it was the test

plots which exhibited the higher mortality. We attribute this to the house wren (Troglodytes aedon), which seems to be in higher abundance on the test plots. The test plots are smaller in physical area than the control plots and thus have a greater amount of habitat edge. House wrens, which are abundant in this type of edge habitat, interfere with tree swallow nesting by destroying eggs and young in attempts to take over nest boxes for their own use. This degree of interference declines as the distance from the edge increases (Rendell and Robertson 1990).

Landmark growth events. The mean number of days to eye opening in 1991 (Table 18) was longer at the Pirlot Road test plot (5.1 days) than at Tachycineta Meadows control (4.7 days); however, these differences were not significant in analysis of variance (Table 19, $P > 0.25$). Neither was there a difference detected for OPERATION or PLOT*OPERATION (Table 19, $P = 0.2365$ and $P = 0.39$, respectively). We did detect a significant effect of YEAR(OPERATION) which we interpret as a weather effect, NEST(PLOT) due to variation of eye opening among nests, and PLOT*YEAR(OPERATION) which is a weather and plot interaction (Table 19, all $P < 0.01$). These factors are unrelated to ELF radiation and appear to impact test and control plots equally, with the possible exception of PLOT*YEAR(OPERATION) interaction. However, we are interpreting this interaction as due to the greater buffering to weather effects afforded by test plots by the closeness of the surrounding forest.

The scoring of eyes closed or open in the field is somewhat subjective and may be biased depending upon observer, lighting conditions and other factors. In addition, we only observe the young on an every-other-day basis. The resulting increase in the variance further reduces our ability to detect subtle differences in age of eye opening. Still, the differences in when

nestlings achieve open eyes varies enough among nests and years that we consistently register significant differences. Differences among plots or operational periods are too small to be detected at the level of variation we currently have in these data.

Mean number of days to feather eruption in 1991 (Table 18) was similar to other years and very similar among plots (Table 20, $P > 0.386$). No significant effects of plot have been noted for any other years either (Table 17). As with age at eye opening, there is a significant effect of weather and of nest on the age at feather eruption (Table 17, $\text{YEAR}(\text{OPERATION})$, $\text{NEST}(\text{PLOT})$, $P = .0001$). In addition, a significant $\text{PLOT} * \text{OPERATION}$ interaction occurred (Table 17, $P = 0.0012$). We feel this result is due to bad weather years which occurred in 1986 and 1989 during the pre-operational period and was more severe on control plots due to their more exposed setting. No significant bad weather has occurred during the operational period.

Comparing feather eruption with eye opening, the eruption of primary feathers is about as variable as eye opening (Table 18). It is much less subjective in the field when the actual scoring takes place. It is clear that variation in feather eruption is strongly influenced by weather and the nest (or parent) environment, but not ELF exposure.

Statistical sufficiency - fecundity and maturation. We have examined the statistical power of test and minimum detectable difference for the measures of fecundity and maturation discussed above (Tables 21, 22). We are currently able to detect changes of less than 10% of the mean for the variables measured, but the power of these tests are very low. If we set the power of the test at 70% certainty, we are still able to detect differences of less

than 10% for clutch size and hatch success, but only about 18% for fledging success (Table 21).

Minimum detectable differences are larger for eye opening and feather eruption, but still are all below 17%, with power again less than 30% (Table 22). With the power set to 70%, minimum detectable differences increase to greater than 25% and less than 45%, depending on the year (Table 22). We can therefore be less confident of rejecting the hypothesis of no difference in plots for these variables.

Adult Return Rates. In 1991, 401 adults were captured; 218 (54.4%) were new individuals and 183 (45.6%) were returning birds banded by us during previous seasons. The number of returning adults in 1991 was greater than previous years; 41.3% in 1990, 43.5% in 1989, 33.8% in 1988, 12.3% in 1987, 29.7% in 1986 and 16.6% in 1985. As many young as possible are banded before fledging; in 1991, 828 young were banded in the nest. In 1989, as in 1986, nest abandonment by the adults and the high mortality of young, caused by inclement weather, reduced the number of birds available for banding. The low number of returning birds in 1987 during nesting may be a reflection of the 1986 cold weather. We have now accumulated enough data to begin assessing the return rates of adults to control and test plots. These results will be presented in future annual reports.

Growth. Curve fitting to growth data for individual birds during 1991 for body mass, tarsus and ulna growth was accomplished using the logistic model while wing growth was fit by the exponential model. These models produce the highest R^2 values, on average, compared to other growth models (see Ricklefs 1983, and Zach and Mayoh 1982, for discussion of various models). In addition, linear regression of growth data for weight, tarsus and

ulna between the ages of 3 and 11 days were used to estimate growth rate. These days of growth are essentially linear. The maximum values attained in growth for these variables and the age they were attained were also used to assess growth of nestlings on control and test plots. As noted earlier, maximum values have been found by other researchers to be less variable than curve-fitted ones (Zach, 1988), as we have also found. We include these more sensitive measures along with the curve-fit values.

The logistic model was fitted to the data using a NONLIN procedure (Ricklefs 1983, Wilkinson 1988). The procedure estimates values for the growth rate constant and the inflection point for body mass, tarsus and ulna growth. The NONLIN procedure was also used to fit wing growth data to an exponential model of growth. A growth constant was estimated, but no inflection point occurred since the wing was still growing at the time of fledging. The growth and inflection point variables for each nestling were included in the data set if there was a significant correlation between the variable and age. The data were then analyzed using nested analysis of variance (NANOVA), with main effects of operational period and plot and their interaction and with the effect of years nested within period of operation and the effect of nests included within plots. Thus, the model may be written as:

$$Y_{ijkl} = \mu + \alpha_i + b_j + \alpha\beta_{ij} + \Gamma_{ik} + \Delta_{jl} + \Theta_{ij} + \Phi_{ilk} + e_{ijkl}$$

where Y_{ijkl} is the l th observation in the k th and j th subgroups of the i th group, μ is the parametric mean of the population, α_i is the fixed effect of the i th group (plots), β_j is the fixed effect of the j th group (operation period), and the other terms represent interaction of the main

effects ($\alpha\beta_{ij}$), the nested effects of nest within plot and years within operation (Γ_{ik} , Δ_{jl}) and interaction of the nested effect of plot and years within operation ($\alpha\theta_{ijl}$). e_{ijk} is the error term. A nested model was used to account for the known effect of parents on the growth of their nestlings. Ricklefs and Peters (1981) studying the European starling (Sturnus vulgaris) in Pennsylvania found the most significant contribution of variance to total variance in growth was due to the parents rather than variation in individual nestling growth or inherited growth traits. Our data on tree swallows show similar partitioning of the variance in growth. We also include years as nested with operation since the years 1985-89 are entirely within the pre-operation period and the years 1990-92 are in the operation period. The appropriate mean square ratio for computing the value of F for a treatment (plot) effect is the mean square due to plot + the mean square due to plot and years within operation interaction minus the mean square error (Zar 1984). This reduces the effective sample N to the number of nests within years and operation rather than the number of nestlings, and has some important impacts on the power of the test. This will be discussed in detail below after summarizing the findings for 1991.

In general, growth constants and inflection points from the curve-fitted data and linear growth rates, maximum values and ages at the maximum values were most strongly affected by nests within plots and least by plot (Tables 23-38). These results will be examined in turn below.

For body mass, growth constants (Table 23), inflection points (Table 24), linear growth rate (Table 25), maximum weight attained (Table 26), and age at maximum weight (Table 27) showed no significant plot or operational period effects. Nest and year factors are highly significant for all measures. For

For growth of the tarsus (Tables 28-32), we also find no effect due to plot or operation period. Highly significant effects due to nest and year are again present. We interpret these effects in the same vein as for weight growth. Interaction of plot and operation show mixed significance depending on the variable. We are presently examining the means for these variables to interpret the meaning of the interaction.

An examination of ulna growth indicates that there were no plot or operational period effects (Tables 33-37). We again find consistent, highly significant effects due to nest and year. The interaction of plot and operation is significant for some ulna variables and not others. The interaction of plot and years is highly significant for all but the growth constant. We are presently examining the means (Tables 39-43) for these variables to interpret the meaning of these interactions.

Growth of the wing was examined by fitting data to an exponential model to produce a growth constant. The wing does not have a linear phase during growth in the nest and growth is still underway when nestlings fledge. Accordingly, we have only measures of the fitted growth constant to examine for possible ELF effects. No effects of plot or operation were detected, but as for the other growth measures, significant effects for nest and year were

detected as well as interactions of plot and operation with the other factors (Table 38). We are presently examining the means (Tables 39-43) for these variables to interpret the meaning of these interactions.

Summary of growth measures. The data on growth consistently show there is no detectable effect due to exposure to ELF electromagnetic radiations on plots or over time on the same plot. The interaction effects we have detected are in most cases not directly attributable to any one cause. A careful study of the means may allow us to make an interpretation of the interactions. However, the most we may be able to do is identify a set of factors that could be causing the interaction. We will probably not be able to single out any factor as the main cause of the interaction.

Statistical Sufficiency - growth. We have examined the power of each performed test yearly and the difference in means that can be detected with our current data (Zar, 1984, p 260). For the first time we report here AOV tests that incorporate operational period of the antenna, and years along with tests of plots and nests. These new AOV models require a more complex method to ascertain the power of test for each factor and the minimum detectable difference of treatment means. We have not as yet satisfied ourselves that we are using the correct power model. Accordingly, we do not present power of test for the full AOV models. We do present power of test results for AOVs done on the curve-fit growth variables using our past AOV approach (Tables 44-45) to assure ourselves that no radical changes have occurred. Single AOVs were not calculated for 1991 for linear growth rates, maximum values and maximum ages and we do not present power data for these variables.

Power and minimum detectable values for the curve-fit growth variables (Table 44-45) indicate 1991 was similar to other years. Values for wing

indicated both power and minimum detectability were better than in previous years. As in previous years, growth constants provide smaller detectable differences than inflection points.

Analysis of Covariance - Growth and Insect Biomass. We attempted the same type of analysis for growth variables as we used for fecundity measures earlier in this report. The index of insect biomass was again the covariate but for this analysis, daily insect biomass was summed for the 15 days preceding hatching (incubation period) to form the covariate INCU and for the 15 days following hatching (nestling period) to form the covariate YOUNG. The first step in the analysis was to examine the slopes of the covariates in relation to the main factors in the AOV model: PLOT, OPERATION and YEAR. The regression of the growth variable on the covariate for each main factor must yield lines that are parallel--that is, there must be no interaction between the main factors and the covariate. Significant interaction precludes the use of the covariate in the analysis (Sokal and Rohlf 1981). Unfortunately, we have found significant interactions of the main effects with the covariates INCU and YOUNG for all our growth variables. Transformation of the data did not eliminate these interactions. We therefore can not perform the long-awaited analysis that we had hoped would help control for differences in available food among our research plots. We are currently looking at other ways we may use these data to correct for differences among our research plots.

Results of Nestling Transfer Experiment. Nestling transfers were made in 1990 and 1991 following the methods described earlier. Analysis of Variance was used to examine the effect of TREATMENT with six levels and YEAR with two levels since the experiment was repeated in 1991. The three variables

examined were maximum weight, tarsus, and ulna because these have the lowest coefficients of variation of any growth variables and should provide a sensitive test. No effect of the treatment could be detected for any variable (Table 49), nor could we detect differences in various combinations of means in post hoc tests. There was a highly significant year effect (Table 49) due to larger size for all variables in 1990 compared to 1991. This effect was uniform across treatments resulting in no interaction between TREATMENT and YEAR for weight or tarsus. However, a significant interaction was obtained for ulna (Table 49). The least-squares means (Table 50 - also called "adjusted cell means" in some statistical texts) indicate this interaction was due to the treatments alternating from larger to smaller in 1990 and 1991. Overall, the experiment does not detect any effect on growth due to ELF exposure. It should be noted that the sample N is variable among treatments due to predation (a bear destroyed some nests in 1990) and other accidents. In all treatments with swapped young, the original sample N was 12. In treatments without swapping, the sample N was 34 on control plots and 26 on test plots. The high mortality on the test plot was due mostly to predation in both years.

PARENTAL AND NESTLING BEHAVIOR, AND FECUNDITY,
GROWTH, AND MATURATION STUDIES - DEERMICE

I. Purpose

The purpose of these studies is to characterize several aspects of the reproductive process in deermice at test and control sites and to test for possible effects of the ELF Communication System on these variables. Specifically, the rates of growth and development of nestlings are compared between test and control sites and for each site from year to year. All of these work elements are described together in this one section because they are all performed on the same families of mice.

II. Methods

These studies were conducted within enclosures because free-ranging mice have been found not to remain resident in nest boxes for long enough periods for us to obtain the data desired. The enclosures are large: 6.1 by 5.8 m. Ten enclosures have been constructed within mixed deciduous forests at both the test and control plots. They are open at the top to allow free passage of atmospheric electromagnetic fields and free exposure to weather. Furthermore, they were constructed primarily of acrylic plastic sheeting, which is permeable to atmospheric electric fields according to IITRI engineers. Briefly, the walls of the enclosures consist of acrylic sheeting attached to cedar posts extending about 60 cm above ground and projecting about 15 cm below ground to prevent mice from digging out. A 51-cm-wide sheet of acrylic placed horizontally along the top of each wall prevented animals from climbing over the wall. Tree trunks were sheathed with sheets of high-density polyethylene to prevent mice from climbing in or out of the enclosures via the

trees. Each enclosure was provided with a nest box and a feeding and watering station. The nest box can be opened to permit access to the mice.

Small enclosures (termed holding facilities or "hotels") built according to the same design, but measuring just 1.2 by 1.2 m, were also constructed at the same sites. These enclosures were used as holding facilities for mice awaiting study in the large enclosures. The mice to be studied were captured in mixed deciduous forest near the enclosure sites. They were set up as male-female pairs. Later the females were transferred into the large enclosures when visibly pregnant. They gave birth in the enclosures and reared their young to the age of weaning.

Newborn young were toe-clipped for identification when 4 days old. From then until they were 22 days old, their growth was followed by weighing every other day to an accuracy of 0.1 g using a Pesola scale. Initial litter size and subsequent deaths were recorded. The age of eye-opening and incisor eruption was recorded as an index of developmental rate.

III. Results - 1991

The growth and development of four litters from four females at Pirlot test plot and four litters from four females at Michigamme control plot were monitored during 1991. Of the 18 females which dropped litters at Pirlot Road test plot, 11 died in captivity, two females escaped and five females were released alive. At the Michigamme control plot, 18 females produced young; however, 11 died in captivity, six females escaped and one female was released alive. The high female mortality rate resulted in a high death rate among litters where young died due to lack of maternal care. Overall, four litters were cannibalized by the maternal female. Adequate food and water were

available at all times. Litters dropped later than the first week of June appear to be at highest risk. Efforts to decrease mortality through partial burying of nest boxes to reduce heat stress and keeping the area clean to reduce disease have met with minimal success. Cool weather appears to substantially increase our chances of obtaining complete data sets on litters dropped in enclosures. At this writing, we feel the high mortality of females in the enclosures significantly impairs our ability to obtain samples of growth large enough to meet our statistical goals. Variance in growth parameters is high on both plots. Thus, while we do not report any significant differences due to treatment, these results must be tempered by the high (but equal among plots) mortality suffered by the mice in the enclosures.

Growth of Young. A perusal of the growth in body mass of nestlings indicates that growth curves often appear non-linear. Although litter mates consistently exhibit similarly shaped growth curves, there are apparent differences in curves among litters of different females as well as differences between litters of the same female (i.e., some are exponential, some sigmoidal, etc.). While this variability in the shape of growth curves among (but not within litters) is interesting, it precludes the use of any particular non-linear model (e.g., logistic growth model) to estimate and compare growth rates in these mice. Therefore, growth rates have been estimated using linear regression analyses for growth of each individual up to the time of weight recession which appears to be correlated with weaning (Table 51). Analysis of Variance of growth rate with main effects of OPERATION and PLOT, and nested effects due to mothers nested within plot (MOTHER(PLOT)) and years nested within operation (YEAR(OPERATION)) yielded no significant

effects of antenna operation or plot (Table 52). Significant nested effects occurred as did the interaction of operation and plot and plot by year within operation. At this writing, we do not have any hypotheses as to the nature of the mother effect, although it could be related to the number of nestlings in the litter. The year within operation effect seems to be due to the several years of severe drought experienced through 1990. The interaction terms are more difficult to interpret and require a thorough analysis of the means. We are currently in progress on this analysis.

Maturation of young. Age at eye opening was over three days earlier at the Pirlot Road test plot in 1991 (Table 54). Ages at incisor eruption were similar between plots in 1991 as in other years (Table 54). Age at eye opening and age at incisor eruption was not significantly different among plots or among operation period (Table 55, 56, PLOT, OPERATION). A highly significant effect due to MOTHER and YEAR was present as were effects due to plot and operation interaction and plot by year within operation interaction for age an eye opening. The latter interaction was not significant for incisor eruption (Table 55, 56). These results parallel those of maturation in the tree swallow. We are currently studying the means to assess the meaning of the interactions found in the AOV tests.

Statistical sufficiency. The power of the test and the detectable differences were estimated for each year from 1986 to 1991 (Table 53 - data from 1991 are taken from an AOV done following the same procedures in earlier years, not from the more inclusive model presented in Table 52). The minimum detectable difference ranged from about 11% in 1988 to a high of about 62% in 1989. Minimum detectable differences at 70% power are very large and variable from year to year, much more so than growth for tree swallows. Perhaps this

reflects problems in field measurement, but we think it is more a function of the response of the deermice to captivity and handling. They are much more sensitive to handling than the birds.

In general, power of the test for eye opening and incisor eruption were less than or equal to 30% and minimum detectable differences ranged from about 7% to 57% (Table 57). At 70% power, minimum detectable differences vary from about 32% to over 167%. We therefore have relatively poor ability to see small changes in these variables that may result from ELF fields generated by the antenna.

Measurement problems. Much of the variation in growth and maturation of young mice can be attributed to the frequency of visits we make to obtain the data (every other day) and also the apparently inherent response to disturbance caused while obtaining measurements. Thus an animal categorized as not having eyes open on a particular day will not be checked again for two days. This produces a built in error of two days. Thus, we do not feel we can obtain fine enough resolution for these variables to meet our statistical criteria without increasing the frequency of visits, yet it is also clear that handling is a major factor affecting growth of the nestlings.

HOMING STUDIES - TREE SWALLOWS

I. Purpose

The purpose of these studies is to measure the homing success of tree swallows at test and control sites and to test for possible effects of the ELF Communication System on such success. Variables measured are the proportions of swallows that successfully return home after displacement from their nest and the time required for each bird to return home. Birds returning to their nest box within 300 minutes from release are considered successful.

II. Methods

Adult birds were captured at the nest box using a passive nest box trapping device (Magnusson 1984). Captures took place between 0800 and 1100 to allow adequate feeding of the young in the nest prior to capture. Following capture, each bird was sexed (using the presence of a cloacal protuberance for males and brood patch for females) and aged using plumage characteristics (Hussell 1983a). Birds were banded using a standard U.S. Fish and Wildlife band and were color marked on the breast using "magic markers" to provide rapid and positive identification while in flight. Birds were placed in wire cages which were covered with black cloths, and then driven to the release sites.

In our first studies of swallow homing in 1984 and 1985, we released birds at all four cardinal compass directions (east, west, north, south) at test and control sites. The results revealed no differences in homing success from one compass direction to another. Furthermore, because tree swallows probably home without regard to habitats they fly over, and they are not likely to be exposed to any different hazards (predators, etc.) in homing from one direction as opposed to another, we feel justified displacing birds in just one compass direction. This protocol is more efficient in terms of personnel effort than the use of four displacement directions and also permits adequate sample sizes to be obtained.

The release points are located in open areas that are at a distance of 30 km from the nest sites and at a compass direction 20 degrees NE of the nest sites (Figure 1). This distance was chosen because it is greater than the distance corresponding to a drop of two orders of magnitude of potential electromagnetic fields given off by the Communications System. The direction

of the release points in relation to the nest sites was chosen so that birds attempting to return to the test site in a straight line will cross both east-west legs of the antenna configuration, areas that would supposedly be maximally influenced by ELF electromagnetic fields. Upon release, the time, vanishing vector, and weather conditions were noted. Observers located near the nest boxes recorded the time at which the birds return. Birds at each release site were released singly, with the subsequent bird released when the first had disappeared from sight (approximately 3 minutes).

III. Results - 1991

Results from the first five years (1986-1990) of the tree swallow homing study have shown that, overall, birds from the test plots are more likely to return than control birds (94.5% return for test birds, 78.7% return for control birds). In addition test birds return significantly more rapidly, taking on average 39 minutes less time.

In 1990 we attempted to understand these differences without altering our original design, by investigating properties possibly unique to the Panola Plains control site which could be contributing to the observed differences. We compared the likelihood to return and return speeds for birds displaced from Panola Plains (our normal control birds) to a sample of birds from Tachycineta Meadows control, a site not previously used for homing. Birds from both plots were displaced and released from the normal Panola Plains release site which effectively controlled for any release site characteristics. Likelihood to return was shown to be independent of plot ($G = 2.276$, $P > 0.1$) even though 76.9% returned to Panola Plains while only 53.8% returned to Tachycineta Meadows. The distances travelled by the

returning birds was slightly shorter to Tachycineta Meadows (27 km) compared to Panola Plains (30 km), so return speed in km/hour was used for comparison rather than minutes to return. Speeds were shown to be significantly faster for birds returning to Panola Plains (11.4 km/hr) than to Tachycineta Meadows (8.6 km/hr, t-test, $t = 2.037$, $P = 0.049$).

These results suggest differences in plot characteristics between Panola Plains and Tachycineta Meadows rather than a release site effect, but the number of birds displaced from Tachycineta Meadows represents too small of a sample to make this analysis conclusive. Even if a larger sample gave the same conclusion, these results did not help explain the observed differences over five years between test and control plots.

Due to reviewers comments on these 1990 and previous results we changed protocols for the tree swallow homing study during 1991. One of the major criticisms in the past has been the fact that our observed differences may be due to release point differences rather than differences inherent to the test and control plots themselves.

The ideal experiment to examine the release site effect would be to take samples of birds from both test and control and displace them to their normal release points as well as the other plot's release point. For example, samples of control birds from Panola Plains would be released simultaneously at the normal control release site as well as the test release site. There were several problems which prevented us from using this approach. First, the distances between nest and release point would differ greatly for control compared to test birds. The normal displacement distance is 30 km; test birds released at the control point would be displaced 27 km and control birds released at the test point would be displaced 56 km. Secondly, test birds

displaced to the control release site would be taken out of the area of electromagnetic influence produced by the antenna, whereas control birds displaced to the test release site would be taken into this area of influence.

As a second choice, reviewers suggested using a common release point for birds displaced from both test and control plots. This was the approach taken; we released a sample of test birds from the control release site. Following this protocol, if test birds still show a greater likelihood to return and also return faster, then we can conclude that there was no effect of the release site. In selecting a common release for both groups of birds, it was found that the best site was actually only 3km from the original control release site. Because of this it was decided to continue using the original control release site which would allow us to continue to compare at least our control data from year to year. The 3km shorter distance for test birds would be taken into account in comparing return times.

A total of 74 birds were displaced in 1991 (35 test, 39 control). Whereas 97.1% returned on the test plot, only 61.5% returned on the control plot (Table 58). These marked differences in likelihood to return are significant ($G = 15.69$, $P < 0.001$) and are similar to results from 1990 and 1987. No significant differences in likelihood to return were found during 1989, 1988, or 1986.

Mean return speed was also shown to be different for the two plots, return speeds for test birds (14.7 km/hr) being significantly faster than control birds (11.0 km/hr, t-test, $t = -3.03$, $P = 0.0038$). Faster speeds on the test plots represent a continuation of a trend shown every year of the study to date (Table 59).

Data on return speeds from 1986-1991 are assessed in an analysis of variance (Table 60) using the factors PLOT (test and control), OPERATION as the status of the antenna (operational during the years 1990 and 1991, preoperational 1986-1989), YEAR nested within operation, and the interaction terms of plot by operation and plot by year. Results show a significant effect due to plot ($F = 40.32$, $P = 0.0001$) which is due to return speed being faster on the test plots during every year of the study. Also shown is a significant year effect ($F = 2.98$, $P = 0.019$) which is due to return speeds being different to approximately the same magnitude between test and control every year even though overall means fluctuate from year to year.

Overall, analyses from 1991 show that birds from the test plots were more likely to return and that test birds also had faster return speeds. Our changed protocol for 1991 has ruled out the possibility of a release site difference, but it does not provide any further information as to why these observed differences occur. Our efforts to determine the reasons for these observed differences will continue.

Power of the test of return time yields a detectable difference of about 24% at a power of greater than 99% (Table 62). If we apply our relaxed standard of 70% power, then differences as small as 10% in returns should be detectable using our current sample sizes and research protocol.

HOMING STUDIES - SMALL MAMMALS

I. Purpose

The purpose of these studies is to measure the homing success of small mammals at test and control sites and to test for possible effects of the ELF Communication System on such success. Variables measured are the proportions

of individuals that successfully return home after displacement and the time required for each individual to return home. The principal species studied are deermice and chipmunks.

II. Methods

During our initial studies on mammal homing in 1985 (Beaver, et al. 1986), we displaced chipmunks and deermice in all four cardinal directions in order to investigate any directional biases in homing ability. No such biases were found even though animals displaced west and north on the control and test plots had to cross the sham corridor or actual antenna corridor, as well as somewhat different habitat types. However, our sample sizes were small for any particular displacement direction (maximum of 10 animals) and we therefore could not be certain of the robustness of our tests. Thus, in contrast to the work on swallow homing, we decided to reduce the number of displacement directions to two rather than one. Reducing the number of directions from four to two increases efficiency of sampling. By using two directions rather than one, however, we maintained the diversity of habitats and corridor crossings at each site, thus helping to insure that we are further able to examine the effects of habitat conditions as well as potential effects of ELF on homing behavior.

The small mammal homing study was conducted on two trapping grids, one at the Pirlot road test site and the other at the Michigamme control site. Due to the low chipmunk and deermouse populations found in 1985 and 1986, the size of the trapping grid was increased in 1987. Each grid contained 100 stations spaced 15 meters apart rather than ten meters, increasing the area covered to 1.8 ha versus 0.81 ha. One Leathers live-trap was placed at each station,

baited with peanut butter and rolled oats. The grids were situated on the east side of both the ELF ROW and the sham ROW. A habitat buffer between each ROW and its respective trapping grid was increased in 1987 to 50 meters, rather than the 10 meters of 1985. This increase helped insure that both the grids and their displacement lines were located in more uniform habitat, a continuous mixed deciduous forest dominated by sugar maple (Acer saccharum).

Trapping began on 6 July and ended on 29 July, 1991. Traps were checked twice daily (ca. 0800 and 1900) and re-baited with rolled oats and peanut butter as necessary. Each unique animal was weighed, sexed, and toe-clipped upon first capture for individual identification. Reproductive condition, station number, and capture time were also recorded. Individuals were kept for displacement after their third capture; such animals were deemed to be residents of the area where the trapping grid was established which, hopefully, insured their detection by continued recapture on the trapping grid upon returning from displacement. Before being displaced, each animal was kept in a laboratory cage supplied with nesting material, lab chow, and water. Cages were placed in screened-in storage sheds located near each site. Displacements took place during, or just prior to, the next activity period following capture; deermice (nocturnal) were displaced at dusk (ca. 1900) and chipmunks (diurnal) were displaced in the morning (ca. 0800). Each animal was displaced 450 m from the trap it was captured at when kept for displacement. Displacements took place to the south and west of the home grids. The exact point of release was adjusted to reflect the point of capture on the home grid; this way all individuals were displaced exactly the same distance from their capture point. Trapping continued for five days after the last animal was displaced to detect late returns.

The displacements to the south were through continuous forest, whereas those to the west required returning animals to cross the antenna corridor at the test site and the sham corridor at the control site. Use of the two displacement directions thus specifically allowed us to test for directional differences in return rates which might occur due to the fact that animals returning from the west must pass beneath the antenna line, potentially the area of greatest electromagnetic disturbance.

III. Results - 1991

The following analyses are based only on the antenna operational years of 1989 - 1991. Previous years of 1986, 1987, and 1988 represent times of pre-operational antenna testing as well as smaller sample sizes available for the homing studies due to low small mammal population numbers.

A total of 21 chipmunks (13 test, 8 control) and 57 deermice (38 test, 19 control) were displaced in 1991 (Tables 63 and 64). No differences in likelihood to return were detected between the two displacement directions for either species, with the exception of chipmunks at the Michigamme control plot. Chipmunk numbers were very low again this year at the control plot and only four individuals were displaced in either direction. During the latter half of the trapping session we experienced some trap predation at the control plot which also contributed to the low numbers. With so few displacements it is difficult to have a great deal of confidence in the lack of independence shown, so data from both displacement directions were pooled.

For deermice, no significant difference in likelihood to return was detected in 1991 ($G = 1.380$, $P > 0.1$). This is the same result obtained in

1986, 1987 and 1988 (Table 63). There were significant differences in likelihood to return shown in 1990 and 1989, but the results for those two years are contrary to one another. In 1990 a higher percentage of displaced deermice returned to the control plot, whereas in 1989 a higher percentage returned to the test plot (Table 63). Reasons for these detected differences are unclear and we are presently working on multidimensional contingency table analyses which will allow simultaneous assessment of possible effect due to plot, year, and antenna operational status.

For chipmunks, no significant difference in likelihood to return was detected in 1991 ($G = 0.141$, $P > 0.5$). This is the same result obtained for all years of the study (1986-1991, Table 64). As is the case with deermice, a more detailed analysis which will include all possible factors is being planned.

DEVELOPMENTAL STUDIES

I. Purpose

The purpose of these studies is to characterize aspects of normal development in tree swallows and to investigate potential effects of ELF radiation on development. Specifically, early embryological development of tree swallows is being characterized, developmental abnormalities in field populations of tree swallows are being described and their incidence in test and control plots is being determined, and the sizes of eggs from test and control plots is being compared.

II. Methods

Tree swallow eggs were collected from nests during late May and early June. Entire clutches were removed from 15 nests in control plots TMC and PPC and 17 nests in test plots FST and FNT exposed to ELF radiation. Eggs were

collected on the fifth day following the appearance of the last egg. One hundred and fifty-four eggs were inspected.

Collection of eggs and subsequent analyses were carried out by different investigators to avoid bias. Each nest was coded in such a way that the investigator carrying out the analysis was unaware of the test or control status of eggs until analysis was completed.

Egg sizes were determined in three ways. Eggs were weighed to two decimal places on a Sybron Digimetric balance. Measurements of egg volumes were obtained by water displacement. Finally, length and breadth of eggs were measured using vernier calipers.

All embryos were dissected off the yolk into Howard Chick Ringers solution (Johnson and Volpe, 1973), analyzed briefly by microscopic examination, and fixed in either Bouin's solution for further observation and histological study or 2.5% glutaraldehyde in phosphate buffer for scanning electron microscopy.

Embryos placed in Bouin's solution were fixed for 24 hours and dehydrated through a graded series of ethanols. Young embryos were stained as whole mounts with either an alcoholic eosin solution or an alcoholic carmine solution (Watterson and Shoenwolf, 1984), dehydrated and cleared in methyl salicylate. All embryos were then carefully observed with an Olympus stereoscope using transmitted light and a photographic record of any suspected abnormality was obtained. The use of methyl salicylate as a clearing agent allows material to be observed as a whole mount and stored without undue tissue hardening. Subsequently, material can be embedded in paraffin and used for routine histology. It has been found in previous years that embryos that

have reached stage 24 and beyond can be best observed if the tissues are not cleared. Accordingly, such embryos were maintained in 70% ethanol.

All embryos were staged using the chick embryo series of Hamburger and Hamilton (1951) as a reference. Abnormalities were tabulated and characterized as completely as possible.

III. Results

Normal development. The early embryology of the tree swallow closely parallels that of the chick as described by Hamburger and Hamilton (1951). By the fifth day of incubation, many embryos had reached stages 25 and 26 and a few were stage 27. As reported previously (Beaver, Hill and Asher, 1984; Beaver, Hill and Hill, 1990) an asynchrony of development is observed in this species. The last egg to be laid routinely lags several stages behind nest mates and hatches approximately a day later than the rest of the clutch. This asynchrony seems to depend on the nesting behavior of females who are frequently observed to spend time on the nest before the clutch is complete. Such behavior is not restricted to tree swallows but is common among small, altricial passerines (Clark and Wilson, 1985).

Abnormal development. As in previous years, embryos were checked carefully for abnormalities of the developing head, including brain, eye and ear, branchial arches, heart, spinal cord and somites, limb buds, extra-embryonic membranes, and flexion and rotation of the embryo. In 1991, 19 embryos or 12.4% are considered to show developmental patterns which fall outside those recognized as normal. Of these 19, 9 were collected from test plots and were exposed to ELF radiation; 10 were collected from control plots. (One test plot egg, in which the embryo was grossly abnormal, was eliminated from the data set because the egg was cracked on collection. Experiments last

year (Beaver, Hill and Hill, 1990) indicated that cracked shells could result in abnormal development.) No difference in frequency of abnormalities occurring in test and control plots was found (Table 65, $\chi^2 = 0.05$ with a contingency coefficient of 0.02).

Several reports now occur of ELF magnetic fields adversely affecting development, specifically of chick eggs experimentally exposed to ELF fields in incubators (Ubeda et al., 1983; Juutilainen et al., 1986; Juutilainen et al., 1987; Martin, 1988). Differences between our results and those obtained in the various laboratories could result from any of the following conditions.

1) Field strengths and wave forms at the egg/embryo level are obviously different in the various experiments. 2) There may be an actual species difference, with embryos of chicks being more susceptible to ELF radiation than are those of tree swallows. 3) Chick embryos in incubators receive a more direct dose of ELF radiation than tree swallow embryos which may be shielded much of the time by the body of the incubating parent (although this may not be the case for magnetic fields). 4) Finally, a delay of 3 stages in the Hamilton-Hamburger series is considered abnormal in chicks (Martin, 1988). In tree swallow embryos, because of the developmental delay described earlier and because of the variation that we see in normal developmental times among control clutches of eggs as well as test clutches, a delay of three stages is not grounds for considering embryos abnormal.

In 1991, 6 of the abnormalities (32% of the abnormalities) involved the brain, 4 (21%) involved the back and spine (the "dented" back which we described in earlier reports (Beaver, Hill and Hill, 1989), 2 (11%) involved the limbs, and 1 (5%) was primarily a mandible-branchial arch abnormality. Six

eggs (32% of the abnormalities) from 5 nests showed no or very abortive development (Table 66).

A 12% abnormality rate is in keeping with our reports of previous years and with the failure-to-hatch frequency that we usually find.

In addition to the six eggs which failed to develop, 3 clutches lagged far behind normally developing eggs. Only one embryo appeared abnormal. The rest appeared normal but very delayed, indicating that the parents may have deserted the nest. One clutch was indeed reported to be cold on collection. All 3 nests were located in test plots. In 1990, 2 nests, both in test plots, contained very undeveloped eggs. In 1989, no nests lagged behind while in 1988, one nest from a control site was severely delayed. At present we have insufficient data to evaluate the significance of these findings. We will continue to be alert to the possibility that the antenna, operating at full capacity, may affect parental attentiveness to eggs.

Inclusion of these nests in the group of eggs which we predict would not hatch raises the percentage of abnormalities to 19%. This high percentage is in agreement with the failure-to-hatch reported by other investigators studying tree swallows. Paynter (1954) found a 15% hatching failure in tree swallows on Kent Island, New Brunswick; and Chapman (1955) found an average failure to hatch of 20.5% in a 12-year study of a tree swallow colony in Princeton, New Jersey. Martin (1988) reports that the hatchery from which he obtained fertilized chick eggs for ELF studies provided information indicating 90+% hatchability (or a 10% failure to hatch due to infertility and abnormalities).

Size of eggs. Since avian embryos develop in a closed system, the resources allocated to each offspring during oogenesis could have a marked influence in determining chick survival. If females forage less effectively

in some situations than in others, eggs may be of lower nutrient value and chick survival compromised. To determine whether ELF radiation affects the amount of nutrient deposited in eggs, each egg, at the time of collection, was measured in three ways. First, each was weighed. Second, volume measurements were obtained using a water displacement method. Third, length (L) and breadth (B) of each egg was measured using vernier calipers.

Weights of eggs from test and control plots have now been compared since 1985 using nested ANOVA's. Basic statistics (Table 68) and ANOVA results (Table 67) indicate while nest and year effects are present, no difference in weights was found between test and control plots.

Egg volume is measured as a second method of determining egg size. Because eggs lose weight after they are laid because of evaporative water loss and as a result of metabolic activity as development proceeds, the first egg laid has lost considerably more weight than the last by the time the eggs are collected. Consequently, volume may provide a more accurate measure of size than weight. In 1990 and 1991, volumes of eggs were measured directly in addition to length and breadth measurements (Table 70). Analysis of Variance of egg volume for the two years with data indicated no plot effect, but did yield a significant year and nest effect (Table 69).

Prior to the development of an effective measuring device to determine volume in 1989, only the length and breadth of eggs was determined. Using the formula $V_{egg} = K_B^3 L$ (Beaver, Hill and Hill, 1989; Hoyt, 1979), we have now determined K values for all of the eggs measured in 1990 and 1991. K values for eggs from test and control plots for both years were compared using a nested ANOVA. No difference was found between test and control eggs (Table

71). We will now use K and length and breadth measurements to determine the volumes of eggs collected prior to 1989.

Comparisons with other species. The development of the domestic chick is the standard against which most other species are measured. Early tree swallow development closely parallels chick development although some differences are seen. These include the constriction of the eye stalk during eye formation, the timing of pigmentation of the retina, the relative size of wing buds compared to leg buds, and the development of feather tracts. A further comparison of these events in the two species is underway.

STUDIES OF MAXIMUM AEROBIC METABOLISM

I. Purpose

The purpose of these studies is to measure the peak aerobic metabolism of animals during winter at test and control sites and to test for possible effects of the ELF Communication System on peak metabolism. The principal species studied are chickadees and deermice.

II. Methods

Collection and care of birds. To attract chickadees for study, feeding stations were established in December and kept stocked throughout the winter with sunflower seeds. Chickadees were mist netted as needed from these stations. Upon capture, birds were weighed to the nearest 0.1 g using a Pesola spring scale and marked with a colored plastic leg band for individual identification. When released from captivity, they were banded using a standard U.S. Fish and Wildlife Service band for permanent marking. Birds were housed singly in wire mesh cages (28 x 18 x 31 cm). Shelled sunflower

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seeds and snow or water were available ad libitum. In addition, each morning and late afternoon, meal worms were provided in excess. The cages were kept in a screened outdoor holding facility, which provided natural lighting and temperature conditions.

Collection and care of mammals. Trap shelters were established in late November, prior to any substantial snowfall. The shelters were located along wandering lines situated approximately 75-250 m from the antenna or sham corridor. The habitat was northern hardwoods dominated by maple, basswood, and elm, typical of the area. Each shelter was a plastic waste container placed upside-down on top of the ground layer, with a covered top opening which provided the researcher access to the ground layer once snow was present. Mice entered the shelters through the interface between the ground layer and the wall of the shelter. One Leathers live trap was placed in the bottom of the shelter and baited with rolled oats, peanut butter, and sunflower seeds. Polyester batting was provided in the trap for nesting material. Traps were pre-baited and left open one month prior to actual trapping to insure that small mammals would include the stations in their subnivean runways. Researcher travel on the sites was by snowshoe along a single trail to minimize disturbance of the subnivean air spaces which are critical to small mammal movements.

Trapping was begun at the start of January and continued intermittently, according to need for animals, through March. Work was focused primarily on the deermouse. Upon capture, individuals were toe-clipped for identification, sexed and weighed to the nearest 0.1 g with a Pesola spring scale. Once at the lab, animals were transferred to standard plastic lab cages (29 x 18 x 13 cm) with wire lids and provided with wood shavings, polyester batting, and a diet

of sunflower seeds, lab chow, and apple and snow for moisture. Cages were housed in an open outdoor facility which provided natural lighting and temperature conditions.

Laboratory methods. To elicit a peak rate of oxygen consumption, we used a refined version of the helium-oxygen (helox) method first introduced to the study of small-animal physiology by Rosenmann and Morrison (1974). Placing an animal in a helium-oxygen atmosphere at a given ambient temperature greatly increases the individual's rate of heat loss by comparison to the rate in air (mostly nitrogen-oxygen), due to the relatively much higher thermal conductivity of helox. Thus, the animal must produce heat more rapidly in helox than air if it is to maintain a stable body temperature.

Whether the rate of oxygen consumption measured in helox is, in fact, a true peak metabolic rate depends partly upon the ambient temperature. Identifying the true peak for an individual therefore entails studying the animal at a series of ambient temperatures. Specifically, study at a minimum of three ambient temperatures is required for a definitive determination: there should be a measurement at the temperature that elicits the peak, and also there should be measurements at temperatures higher and lower, demonstrating that the rate of oxygen consumption in helox falls off if the temperature is either raised or lowered from that eliciting the peak. Of course, the temperatures of interest are unknown at the onset of work on an individual. Thus, in principle, many measurements would have to be made on an individual before its peak would be definitively identified. In practice, experience often permits us to know in advance the temperature at which the peak will occur. Therefore, we often need to test an animal at just three temperatures to establish its peak definitively. The spacing we have used

between temperatures is 5°C. Thus, if we test an animal in helox at three ambient temperatures that are 5°C apart (e.g. -10, -5, 0°C) and if the highest measured rate of oxygen consumption occurs at the middle temperature, we conclude that we have identified the animal's peak rate definitively.

Tests were not carried out on the day of capture to reduce any effect of capture stress. To further avoid adverse effects of stress, animals were tested only once on any given day.

Prior to a test animals were weighed to the nearest 0.1 g on an Ohaus triple-beam balance, and their body temperature (T_b) was measured by inserting a copper-constantan thermocouple probe 2-3 cm colonically. Then each animal was placed into a metabolic chamber. Chambers were constructed from new one-half gallon paint cans, with inflow and outflow ports in the lid. The inside surfaces were painted with 3M ECP-2200, for an emissivity of nearly 1.0. A 0.5-inch-mesh hardware cloth floor covered with Dip-It plastic coating was used to elevate the animal above the bottom of the can, thus helping to insure proper airflow around the animal and permitting urine and feces to drop away so as not to wet the animal. The outflow port of each chamber houses a 36-gauge copper-constantan thermocouple to monitor chamber temperature, which is maintained by immersion of the can in a Forma Scientific 2325 water bath using ethanol as antifreeze. All temperature probes are connected to a Leeds and Northrup 250 Series Multipoint recorder which can be read to the nearest 0.1°C.

Measurements were carried out during daylight hours. Food was provided during measurements. Specifically, apple was provided for the mammals, and shelled sunflower seeds and a mealworm were provided for the chickadees. The metabolism chambers for the birds were equipped with a small light that

provided dim illumination; without this light, the chickadees (which are diurnal feeders) would not eat. Our decision to provide food during tests is based on extensive preliminary experimentation and is predicated on the following considerations: (1) Animals in nature are able to feed during the day; the birds are diurnal foragers, and the mammals can feed from caches. (2) In the mice, the variance in results is lower when food is provided than when it is denied. (3) In the birds, there is evidence that fasting during these types of experiments increases the probability of death.

Oxygen consumption was measured using an open-flow system. Briefly, gas (air or helox) was pumped through the metabolic chamber at a measured flow rate, and the reduction in its oxygen content was measured. From these data, the rate of oxygen use of the animal could be calculated. The oxygen content of gases was measured with an Applied Electrochemistry S3A oxygen analyzer and recorded on a Houston Superscribe potentiometric recorder. Gas flow rates were measured with Brooks 1110 rotameters. The rate of oxygen consumption was calculated according to the formulas in Hill (1972a, method B), taking cognizance of the mathematical relationship between gas composition and the output of the S3A analyzer. We have empirically verified that the S3A analyzer reads oxygen levels in helox with the same accuracy as in air.

Animals were provided with air during an initial adjustment period (0.7-1.5 hr) and then switched to helox. Flow rates were 600 ml/min in air and 900 ml/min in helox. The adjustment period in air was terminated once the metabolic rate remained approximately stable for 15 to 20 minutes. Upon switching to helox, a rapid transition to the new gas was made by purging the metabolic chamber at a rate of 5 liters/min for two minutes. Then the rate of flow was reduced to the 900 ml/min already mentioned. The maximal rate of

oxygen consumption under the test conditions was generally achieved within 15-20 minutes after the switch to helox, and animals were rarely exposed to helox for more than 25 minutes. Following the measurement in helox, animals were quickly removed from the metabolic chamber, and a final T_b and weight were recorded. All thermocouples have been calibrated against thermometers whose calibration is traceable to the National Bureau of Standards. Flowmeters have been calibrated against a Brooks Volumeter also having a NBS-traceable calibration.

The one aspect of the measurement procedure that is open to significant subjective judgment is the determination of the particular time interval over which the maximum oxygen consumption occurred in each experiment. Because of the subjectivity involved in this determination, a "blind" procedure will be used once the Communication System antenna has been turned on and high-resolution comparisons of test and control sites are being carried out. The relevant raw data, as earlier noted, are recorded using a potentiometric recorder. These records are not marked as to the origin of the animals (test or control site) but instead are identified simply by arbitrary, randomly assigned numbers. The final and definitive reading of the records will be carried out by a person who knows only these arbitrary numbers.

III. Results - 1991

Measures of peak metabolic rate were obtained on 24 deermice and 25 chickadees in the winter of 1991. All these measures were obtained within the first week after capture.

The data were analyzed as specified in the 1988 annual report. It will be recalled that measures of peak metabolic rate are assigned to 10 quality rating classes. Classes 1, 2, 3, and 4 represent peak determinations of

highest quality. Classes 0 and 5-9 represent peak determinations rated as acceptable but nonideal. Statistical comparisons of sets of peak metabolic rates have been carried out using an analysis of covariance design unless otherwise specified. The logarithm of whole-body peak metabolic rate has been used as the dependent variable, and the logarithm of body weight has been used as the covariate. The reasons for the use of analysis of covariance and those for performing the analysis in the logarithmic domain are detailed in the 1988 annual report. Normality of the logarithmically transformed data for peak metabolic rates and body weights was assessed using probit plots, and homogeneity of variances was evaluated with Bartlett's test. Both normality and homogeneity of variances were found to be acceptable in all analyses.

Analysis of peak metabolic rates of deermice in 1991. The first step in this analysis was to determine if a difference existed between measures of peak metabolic rate that were rated in quality classes 1-4 (primary quality) and measures that were rated in the other quality classes (secondary quality). This was done by pooling all data from both test and control plots into an analysis of covariance with a single factor: primary versus secondary quality rating. As in all past years, the difference between the quality rating categories for deermice proved nonsignificant ($P = 0.30$). Thus, for analysis of plot effects, all peaks were pooled regardless of their quality rating. A single-factor analysis of covariance was performed on these pooled peaks, the factor being plot (test versus control). The effect of the covariate (body weight) was highly significant ($P = 0.001$). However, there was no significant difference between test and control plots ($P = 0.21$). Summary statistics are given in Table 72. We conclude that, for the deermice, peak metabolic rates

measured in the first week after capture did not differ between test and control plots in 1991.

Analysis of peak metabolic rates of chickadees in 1991. The peak metabolic rate for one bird [17.7 mL O₂/(g X hr)] was much lower than that for all the others and was rejected from statistical consideration as an outlier. Following that determination, the first step in the analysis was again to determine if a difference existed between measures of peak metabolic rate that were rated in quality classes 1-4 (primary quality) and measures that were rated in the other quality classes (secondary quality). This was done, as for deermice, by pooling all data from both plots into an analysis of covariance with a single factor: primary versus secondary quality rating. As in 1990 but unlike the case in all years before 1990, the difference between the quality rating categories for chickadees proved to be nonsignificant (P = 0.11), and thus, all peaks were pooled regardless of their quality rating for analysis of plot effects. In that analysis, the effect of the covariate (body weight) was nonsignificant (P = 0.55). There was no significant difference between plots (P = 0.37). Summary statistics are given in Table 72. We conclude that, for the chickadees, peak metabolic rates measured in the first week after capture did not differ between test and control plots in 1991.

Summary of data for preoperational and fully operational years. As documented in the annual report for 1990, we have data for two winters in which the ELF Communications System was not operational at all: 1986 and 1987. Now we have data for two winters in which it was operational at full power and in modulated mode for most of the time: 1990 and 1991. The data for 1986-7 (preoperational years) and 1990-1 (fully operational years) are summarized in Tables 73 and 74 for deermice and chickadees, respectively. All peak

metabolic rates measured for deermice are included, regardless of quality class, because in all the years concerned there was no significant difference between data placed in different quality classes. For chickadees, data classed in the "secondary-quality" classes (0 and 5-9) are excluded for 1986-7 because in those years the data in the secondary-quality classes were not homogeneous with those in the primary-quality classes.

The summary data in Tables 73 and 74 have been analyzed by two-way analysis of covariance. The dependent variable in the analyses was whole-body peak metabolic rate. The factors in each analysis were time (1986-7 versus 1990-1) and plot (test versus control). As described above, the analyses were carried out in the logarithmic domain. In this domain, the pooled data are beautifully normal and variances are robustly homogeneous. The data set for each species was unbalanced. Thus, for each species, each of the two possible hierarchical analyses of covariance was carried out (time first, plot second; plot first, time second). Unless otherwise noted, the two hierarchical analyses agreed in statistical outcome.

For deermice the two time periods differed ($P = 0.01$ in both hierarchical analyses). Rates tended to be lower in 1990-1 than in 1986-7. The two plots did not differ ($P = 0.14-0.15$), and there was no significant interaction between time and plot ($P = 0.98$). Thus, there is no evidence that operation of the Communications System has altered the peak metabolic rates of deermice. The reason for the overall decrease in rates on both plots between 1986-7 and 1990-1 is unknown.

For chickadees the two time periods again differed ($P < 0.001$), and in the same direction as for deermice. The plots also differed significantly ($P = 0.06$ if the effect of time was removed prior to analysis of plot, $P = 0.02$ if

plot was analyzed first). Birds on the control plot tended to have higher peak metabolic rates than those on the test plot, a circumstance that was already evident in our earlier summary analysis of chickadee data in the 1988 annual report. The all-important interaction between plot and time was robustly nonsignificant ($P = 0.44$). Thus, even though the plots apparently differ, this is not attributable to operation of the Communications System. No explanation can be offered for the decline in peak metabolic rates with time on both plots or for the difference between plots, which has remained about the same even as rates have dropped with time.

Overall, at this point in our study we find no effect of the operation of the Communications System on the peak metabolic rates of either mice or birds.

CONCLUSION

In conclusion, we have made our first statistical appraisals accounting for preoperational and operational status of the antenna, test and control plots, years of data collected in the periods of antenna operation and nests on the plots. We have also completed analyses of covariance using insect biomass as a factor in measures of fecundity and growth, and of initial body mass in the metabolism of deermice and chickadees. We also report on a two-year experiment where we exchanged nestlings of tree swallows among test and control plots. All of these studies were directed to an assessment of the effect of the ELF antenna system on the various variables we measure on our study animals. Our findings to date show, for the most part, that operation of the antenna system has not measurably changed the fecundity, mortality, growth and maturation or development of our study animals. We have also not found an antenna effect on small mammal homing or peak metabolism of deermice or chickadees. Only for homing return time and frequency in tree swallows have we found a potential effect of the antenna, with birds returning faster and more often to the test sites. We plan careful examination of future data to further assess these findings. In other cases, we have found differences with no discernible relation to the antenna. We will continue to evaluate these findings as well.

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LITERATURE CITED

- AIBS 1985. Biological and human health effects of extremely low frequency electromagnetic fields. Report of the committee on biological and human health effects of extremely low frequency electromagnetic fields. Arlington, Virginia. American Inst. of Bio. Sci.
- Alsop, F.M. 1918. The effect of abnormal temperatures upon the embryogeny of chick embryos. Anat. Rec. 15:307- 331.
- Astrand, P.O., and K. Rodahl 1977. Textbook of work physiology. New York. McGraw-Hill.
- Axelsson, J. 1954. Influence of size of eggs on growth rate of embryos and chicks. World's Poultry Congr., Proc. 10th., 1954:65-66.
- Babott, H.G. 1937. Effect of temperature, humidity and other factors on hatch of hen's eggs and on energy metabolism of chick embryos. U.S.D.A. Tech. Bull. 553:1-45.
- Balen, J.H., and A.J. Cove. 1972. Survival and weight loss of nestling Great Tits (Parus major) in relation to brood size and air temperature. In E.J. Brill and Leiden (eds): Proc. XVth International Ornithol. Congr.
- Beaver, D.L., R.W. Hill, and J.H. Asher, Jr. 1985. U.S. Navy extremely low frequency communications system ecological monitoring program, small mammals and nesting birds, Annual Report, 1984. (Submitted to Illinois Institute of Technology Research Institute and the U.S. Navy).
- Beaver, D.L., R.W. Hill, and J.H. Asher, Jr. 1986. U.S. Navy extremely low frequency communications system ecological monitoring program, small

- mammals and nesting birds, Annual Report, 1985. (Submitted to Illinois Institute of Technology Research Institute and the U.S. Navy).
- Beaver, D.L., R.W. Hill, and J.H. Asher, Jr. 1987. U.S. Navy extremely low frequency communications system ecological monitoring program, small mammals and nesting birds, Annual Report, 1986. (Submitted to Illinois Institute of Technology Research Institute and the U.S. Navy).
- Beaver, D.L., R.W. Hill, and J.H. Asher, Jr. 1988. U.S. Navy extremely low frequency communications system ecological monitoring program, small mammals and nesting birds, Annual Report, 1987. (Submitted to Illinois Institute of Technology Research Institute and the U.S. Navy).
- Beaver, D.L., R.W. Hill, and J.H. Asher, Jr. 1989. U.S. Navy extremely low frequency communications system ecological monitoring program, small mammals and nesting birds, Annual Report, 1988. (Submitted to Illinois Institute of Technology Research Institute and the U.S. Navy).
- Beaver, D.L., R.W. Hill, and S.D. Hill. 1990. U.S. Navy extremely low frequency communications system ecological monitoring program, small mammals and nesting birds, Annual Report, 1989. (Submitted to Illinois Institute of Technology Research Institute and the U.S. Navy).
- Brooks, G.A., and T.D. Fahey 1974. Maximal oxygen consumption. In G.A. Brooks (ed): Exercise Physiology: Human Bioenergetics and its applications. New York. John Wiley & Sons. pp. 9-10.
- Brosh, R.M., J.R. Gauger, and J.E. Zapotosky. 1985. ELF communications system ecological monitoring program: measurements of ELF electromagnetic fields for site selection and characterization - 1984. Tech. Report E06549-14, IIT Research Institute, Chicago, IL.

- Brosh, R.M., J.R. Gauger, and J.E. Zapotosky. 1986. ELF communications system ecological monitoring program: Electromagnetic fields measurements and engineering support -- 1985. Tech. Report E06549-24, IIT Research Institute, Chicago, IL.
- Chapman, L.B. 1955. Studies of a tree swallow colony. Bird-Banding 26:45-70.
- Clark, A.B., and Wilson, D.S. 1985. The onset of incubation in birds. Amer. Natur. 125:603-611.
- Cohen, M.N., R.S. Malpass, and H.G. Klein 1980. Biosocial mechanisms of population regulation. New Haven. Yale University Press.
- Cravens, W.W. 1952. Vitamin deficiencies and antagonists. Ann. N.Y. Acad. Sci. 5:188-195.
- Delgado, J.M.R., J. Leal, J.L. Monteagudo and M. Garcia. 1982. Embryological changes induced by weak, extremely low frequency electromagnetic fields. J. Anat. 134:533-551.
- DeSteven, D. 1978. The influence of age on the breeding biology of the Tree Swallow Iridoprocne bicolor. Ibis 120:516-523.
- Dixon, F.J. 1952. The effects of radiation on the chick embryo. Ann. N.Y. Acad. Sci. 55:216-220.
- Enk, J.O. and J.R. Gauger. 1985. ELF communications system ecological monitoring program: measurements of ELF electromagnetic fields for site selection and characterization - 1983. Tech. Report E06549-10, IIT Research Institute, Chicago, IL.
- Garrison, J.C., and Wyttenbach, C.R. 1985. Notochordal development as influenced by the insecticide dicrotophos (Bidrin). J. Exp. Zool. 234:243-250.

- Gill, J.L. 1978. Design and analysis of experiments. Ames, Iowa. The Iowa State Univ. Press
- Gilman, P.K., and F.H. Baetjer. 1904. Some effects of the Rontgen ray on the development of embryos. Amer. J. Physiol. 10:222-224.
- Goodposture, K.A. 1955. Recovery of a chickadee population from the 1951 ice storm. Migrant 26(2):21-33.
- Graue, L.C. 1974. Orientation of Homing Pigeons (Columbia livia) exposed to electromagnetic fields at project Sanguine's Wisconsin test facility, final report. Washington, D.C., USN, Office of Naval Research p. 23.
- Green, R.H. 1979. Sampling design and statistical methods for environmental biologists. New York. Wiley.
- Hamburger, V., and Hamilton, H.L. 1951. A series of normal stages in the development of the chick embryo. J. Morphol. 88:49-92.
- Hamilton, H.L. 1952. Sensitive periods during development. Ann. N.Y. Acad. Sci. 55:177-187.
- Hamilton, H.L. 1965. Lillie's development of the chick. New York. Holt, Rinehart and Winston.
- Haradem, D.P., J.R. Gauger, and J.E. Zapotosky. 1987. ELF communications system ecological monitoring program: Electromagnetic fields measurements and engineering support -- 1986. Tech. Report E06549-37, IIT Research Institute, Chicago, IL.
- Haradem, D.P., J.R. Gauger, and J.E. Zapotosky. 1988. ELF communications system ecological monitoring program: Electromagnetic fields measurements and engineering support -- 1987. Tech. Report E06595-1, IIT Research Institute, Chicago, IL.

- Haradem, D.P., J.R. Gauger, and J.E. Zapotosky. 1989. ELF communications system ecological monitoring program: Electromagnetic fields measurements and engineering support -- 1988. Tech. Report E06595-5, IIT Research Institute, Chicago, IL.
- Haradem, D.P. and J.R. Gauger. 1991. ELF communications system ecological monitoring program: Electromagnetic fields measurements and engineering support -- 1990. 64pp, IIT Research Institute, Chicago, IL.
- Hart, J.S. 1957. Climatic and temperature induced changes in the energetics of homeotherms. Rev. Can. Biol. 16:133-174.
- Hill, R.W. 1972a. Determination of oxygen consumption by use of the paramagnetic oxygen analyzer. J. Appl. Physiol. 33:261-263.
- Hill, R.W. 1972b. The amount of maternal care in Peromyscus leucopus and its thermal significance for the young. J. Mamm. 53:774-790.
- Hinrichs, M.A. 1927. Modification of development on the basis of differential susceptibility to radiation. IV. Chick embryos and ultraviolet radiation. J. Exp. Zol. 47: 309-342.
- Hoyt, D.F. 1979. Practical methods of estimating volume and fresh weight of bird eggs. Auk 96:73-77.
- Hussell, D.J.T. 1983a. Age and plumage color in female tree swallows. J. Field Ornith. 54:312-318.
- Hussell, D.J.T. 1983b. Longevity and fecundity records in the Tree Swallow. North American Bird Bander 7:154.
- Hussell, D.J.T., and T.E. Quinney. 1987. Food abundance and clutch size of tree swallows Tachycineta bicolor. Ibis 129:243-258.

- Hutt, F.B., and C. Crew. 1929. Studies in embryonic mortality in the fowl. I. The frequency of various malpositions of the chick embryo and their significance. Proc. Roy. Soc. Edinburgh 49:118-130.
- Hutt, F.B., and A.W. Greenwood. 1929. Studies in embryonic mortality in the fowl. III Chick monsters in relation to embryonic mortality. Proc. Roy. Soc. Edinburgh 49:145-155.
- Hutt, F.B., and A.M. Pilkey. 1930. Studies in embryonic mortality in the fowl. IV. Comparative mortality rates in eggs laid at different periods of the day and their bearing on theories of the origin of monsters. Poultry Science 9:194-203.
- Johnson, L.G., and Volpe, E.P. 1973. Patterns and Experiments in Developmental Biology. W.C. Brown Co.
- Juutilainen, J., M. Harri, K. Saali and N. T. Lahtinen. 1986. Effects of 100-Hz magnetic fields with various wave forms on the development of chick embryos. Radiat. Environ. Biophys. 25:65-74.
- Juutilainen, J., E. Laala and K. Saali. 1987. Relationship between field strength and abnormal development in chick embryos exposed to 50 Hz magnetic fields. Int. J. Radiat. Biol. 52:787-793.
- Juutilainen, J. and K. Saali. 1986. Development of chick embryos in 1 Hz to 100 kHz magnetic fields. Radiat. Environ. Biophys. 25:135-140.
- Keeton, W.T., T.S. Larkin, and D.M. Windsor 1974. Normal fluctuations in the earth's magnetic field influence pigeon orientation. J. Comparat. Physiol. 95:95-104.
- Kluijver, H.N. 1951. The population ecology of the Great Tit, Parus m. major, L. Ardea 39:1-135.

- Koskimes, J. 1950. The life of the Swift, Micropus apus (L.), in relation to the weather. *Annales Academia Scientiarum Fennicae, Series A, IV, Biologica* 12:1-151.
- Krebs, J.R. 1971. Territory and breeding density in the Great Tit, Parus major. *Ecology* 52:2-22.
- Lack, D. 1954. The natural regulation of animal numbers. London. Oxford University Press.
- Lack, D. 1966. Population studies of birds. Oxford, England. Clarendon Press.
- Landauer, W. 1943. Sex and season in relation to malformations of chicken embryos. *Anat. Rec.* 86:365-372.
- Larkin, R.P., and D.J. Sutherland 1977. Migrating birds respond to Project Seafarer's electromagnetic field. *Science* 195:777-778.
- Low, S.H. 1933. Further notes on the nesting of the Tree Swallows. *Bird-banding* 4:76-87.
- Magnusson, A. 1984. My fangsmetod for holkfaglar. *Var Fagelvarld* 4:318.
- Mahoney, S.P., and Threlfall, W. 1981. Notes on the eggs, embryos and chick growth of common guillemots Uria aalge in Newfoundland. *Ibis* 123:211-218.
- Martin, H. 1988. Magnetic fields and time dependent effects on development. *Bioelectromagnetics* 9:393-396.
- Martin, J.H. and W.M. Insko, Jr. 1935. Incubation experiments with turkey eggs. *Kentucky Agr. Exp. Sta. Bull.* 359:151-177.
- Mayfield, H. 1961. Nesting success calculated from exposure. *Wilson Bulletin* 73:255-261.
- Mayfield, H. 1975. Suggestions for calculating nesting success. *Wilson Bulletin* 87:456-465.

- Metzgar, L.H. 1967. An experimental comparison of Screech Owl predation on resident and transient White-Footed Mice Peromyscus leucopus. J. Mamm. 48: 387-391.
- Morse, D.H. 1980. Behavioral Mechanisms in Ecology. Cambridge. Harvard University Press.
- Murphy, E.C. 1978. Seasonal variation in reproductive output of house sparrows: the determination of clutch size. Ecology 59:1189-1199.
- Nice, M.M. 1954. Problems of incubation in North American birds. Condor 56:173-197.
- O'Connor, R.J. 1978. Nest-box insulation and the timing of laying in the Wytham woods population of Great Tits Parus major. Ibis 120:534-537.
- Paynter, R.A. 1954. Interrelations between clutch-size, brood-size, prefledging survival, and weight in Kent Island Tree Swallows. Bird-Banding 25:35-58, 102-110, 136-148.
- Pembrey, M.S., M.H. Gordon, and R. Warren. 1894. On the response of the chick, before and after hatching, to changes of external temperature. J. Physiology 17:331-348
- Perrins, C.M. 1965. Population fluctuations and clutch size in the Great Tit, Parus major. J. Anim. Ecol. 34:601-647.
- Perry, J.S., and I.W. Rowlands 1973. The environment and reproduction in mammals and birds. J. Repr. Fert. Suppl. No. 19.
- Quinney, T.E., and C. Ankney 1985. Prey selection by Tree Swallows. Auk 102:245-250.
- Quinney, T.E., D.J.T. Hussell, and C.D. Ankney 1986. Sources of variation in growth of Tree Swallows. Auk 103:389-400.

- Reese, A.M. 1912. The effects of narcotics upon the development of the hen's eggs. *Science* 35:633-634.
- Rendell, W.B. and R.J. Robertson. 1990. Influence of forest edge on nest-site selection by Tree Swallows. *Wilson Bulletin* 102:634-644.
- Ricklefs, R.E. 1967. A graphical method of fitting equations to growth curves. *Ecology* 48:978-983.
- Ricklefs, R.E. and S. Peters. 1981. Parental components of variance in growth rate and body size in nestling European Starlings (*Sturnus vulgaris*) in eastern Pennsylvania. *Auk*, 98:39-48.
- Ricklefs, R.E. 1983. Avian postnatal development. Pages 1-83 in D.S. Farner and J.R. King, Editors, *Avian Biology*. Volume VII. Academic Press, New York, USA.
- Riddle, O. 1930. Studies on the physiology of reproduction in birds. XXVII. The age distribution of mortality in bird embryos and its probable significance. *Amer. J. Physiol.* 94:535-547.
- Ridgeway, L.P., and D.A. Karnofsky. 1952. The effects of metals on the chick embryo: toxicity and production of abnormalities in development. *Ann. NY. Acad Sci.* 55:203-215.
- Romanoff, A.L., L.L. Smith, and R.A. Sullivan. 1938. Biochemistry and biophysics of the developing hen's egg. III. Influence of temperature. *Mem. Cornell Univ. Agrl. Exp. Sta.* 216:1-42.
- Rosenmann, M., and P.R. Morrison 1974. Maximum oxygen consumption and heat loss facilitation in small homeotherms by $He-O_2$. *Amer. J. Physiol.* 226:490-495.
- Royama, T. 1966. Factors governing feeding rate, food requirement and brood size of nesting Great Tits, *Parus major*. *Ibis* 108:313- 347.

- Slobodkin, L.B. 1968. Aspects of the future of ecology. Bioscience 18:16-23.
- Sokal, R.R., and F.J. Rohlf 1981. Biometry. New York. W. H. Freeman and Company.
- Southern, W.E. 1969. Orientation behavior of Ring-billed Gull chicks and fledglings. Condor 71:418-425.
- Southern, W.E. 1971. Gull orientation by magnetic cues: a hypothesis revisited. Annals New York Acad. Sci. 188:295-311.
- Southern, W.E. 1972. Magnets disrupt gull orientation during first-flights. Bioscience 22:476-479.
- Southern, W.E. 1972. Influence of disturbances in the earth's magnetic field on Ring-billed Gull orientation. Condor 74:102-105.
- Southern, W.E. 1973. Orientation behavior of Ring-billed Gull chicks (Larus delawarensis) exposed to project Sanguine's electric and magnetic fields. Office Naval Res., Dept. of Navy.
- Southern, W.E. 1974. The effects of superimposed magnetic fields on gull orientation. Wilson Bulletin 86:256-271.
- Southern, W.E. 1975. Orientation of gull chicks exposed to Project Sanguine's electromagnetic field. Science 189:143-145.
- Southern, W.E. 1976. Migrational orientation in Ring-billed Gull chicks. Auk 92(1):78-85.
- Stiles, K.A., and R.L. Watterson. 1937. The effects of jarring upon the embryogeny of chick embryos. Anat. Rec. 70:7-12.
- Stockard, C. 1914. The artificial production of eye abnormalities in the chick embryo. Anat. Rec. 8:33-41.

- Taylor, L.W., C.A. Gunns, and B.D. Moses. 1933. The effects of current interruption in electrical incubation. Bull. Univ. Calif. Col. Agrl. Exp. Sta. 550:1-19.
- Ubeda, A., J. Leal, M.A. Trillo, M.A. Jimenez and J.M.R. Delgado. 1983. Pulse shape of magnetic fields influences chick embryogenesis. J. Anat. 137:513-536.
- Wang, L.C.H. 1978. Factors limiting maximum cold-induced heat production. Life Sci. 23:2089-2098.
- Watson, A. 1964. Aggression and population regulation in Red Grouse. Nature 202:506-507.
- Watterson, R.L., and Schoenwolf, G.C. 1984. Laboratory studies of Chick, Pig, and Frog Embryos. Guide and Atlas of Vertebrate Embryology. Fifth ed. Burgess Publishing Co.
- Wickler, S.J. 1980. Maximal thermogenic capacity and body temperatures of White-Footed Mice (Peromyscus) in summer and winter. Physiol. Zool. 53:338-346.
- Wilkinson, L. 1988. The system for statistics. Evanston, IL: SYSTAT, Inc.
- Wilkinson, L. 1990. The system for statistics. Evanston, IL: SYSTAT, Inc.
- Windle, B.C.A. 1893. On certain early malformations of the embryo. J. Anat. Physiol. 27:436-453.
- Windle, B.C.A. 1895. On the effects of electricity and magnetism on development. J. Anat. Physiol. 29:346-351.
- Wytenbach, C.R., and Hwang, J.D. 1984. Relationship between insecticide-induced short and wry neck and cervical defects visible histologically shortly after treatment of chick embryos. J. Exp. Zool 229:437-446.

Zach, R. 1988. Growth curve analysis: a critical reevaluation. Auk 105: 208-209.

Zach, R., and K.M. Mayoh 1982. Weight and feather growth of nestling tree swallows. Can. J. Zool. 60:1080-1090.

Zar, J.H. 1984. Biostatistical analysis. Englewood Cliffs, NJ. Prentice-Hall.

Zwilling, E. 1956. Teratogenesis. pp. 699-719. In B. Willier, P.A. Weiss, and V. Hamburger (eds): Analysis of development. Philadelphia. W.B. Saunders.

APPENDIX A - TABLES AND FIGURES

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Table 1. Test-control plot pairings for the various work elements for small mammals and nesting birds. Plot code designations are those used by IITRI.

STUDY ELEMENT	TEST PLOT	CONTROL PLOT
Deermouse Growth & Maturation	PIRLOT ROAD (1T1)	MICHIGAMME NORTH (1C1)
Small Mammal Homing	PIRLOT ROAD (1T1)	MICHIGAMME SOUTH MICHIGAMME NORTH (1C3, 1C1)
Deermouse Winter Physiology	PIRLOT ROAD (1T1)	MICHIGAMME SOUTH (1C1)
Tree Swallow Growth & Maturation	PIRLOT ROAD (1T1)	TACHYGINETA MEADOW (1C6)
Tree Swallow Homing (Home Plots)	CLEVELAND HOMESTEAD (1T2)	PANOLA PLAINS (1C4)
	NORTH TURNER ROAD (1T4)	PANOLA PLAINS (1C4)
(Displacement Plots)	CLEVELAND HOMESTEAD DISPLACEMENT (1D1)	-
	NORTH TURNER DISPLACEMENT (1D2)	-
	-	PANOLA PLAINS DISPLACEMENT (1D3)
Tree Swallow Embryology	CLEVELAND HOMESTEAD (1T2)	TACHYGINETA MEADOW (1C6)
	FORD RIVER NORTH (1T5)	PANOLA PLAINS (1C4)
	FORD RIVER SOUTH (1T6)	
Black-capped Chickadee Winter Physiology	PIRLOT ROAD (1T1)	MICHIGAMME NORTH (1C1)

Note: Cleveland Homestead, Ford River North and Ford River South plots are small. Therefore they have been designated solely as tree swallow embryology study sites.

Table 2. Mean values for 60 Hz transverse electric fields (V/m) on control and test plots paired by research activity. The values in parentheses are the sample n. Values listed by IITRI as <0.001 are treated as equal to 0.001. Data for 1991 are not yet available.

PLOT	1983-1985	1986	1987	1988	1989	1990
Control						
1C1	0.001 (4)	0.001 (2)	0.001 (2)	0.001 (2)	0.001 (2)	0.001 (2)
1C3	0.001 (5)	0.001 (2)	0.001 (2)	0.001 (2)	0.001 (2)	0.001 (2)
1C4	0.001 (7)	0.001 (3)	0.001 (3)	0.001 (3)	0.001 (3)	0.001 (3)
1C6	<u>0.001 (4)</u>	<u>0.001 (3)</u>	<u>0.001 (3)</u>	<u>0.001 (3)</u>	<u>0.001 (3)</u>	<u>0.001 (3)</u>
Average	0.001 (20)	0.001 (10)	0.001 (10)	0.001 (10)	0.001 (10)	0.001 (10)
Tree Swallow release site						
1D3	-	0.001 (1)	0.001 (1)	0.001 (1)	0.001 (1)	0.001 (1)
Test						
1T1	0.001 (11)	0.001 (14)	0.001 (14)	0.028 (18)	0.015 (8)	0.005 (18)
1T2	0.001 (3)	0.001 (4)	0.046 (5)	0.013 (5)	0.004 (5)	0.017 (5)
1T4	0.001 (4)	0.001 (5)	0.001 (10)	0.014 (10)	0.002 (10)	0.031 (10)
1T5	0.001 (5)	0.001 (6)	0.001 (9)	0.037 (9)	*	0.046 (9)
1T6	<u>0.001 (4)</u>	<u>0.001 (1)</u>	<u>0.001 (7)</u>	<u>0.078 (7)</u>	<u>*</u>	<u>0.037 (7)</u>
Average	0.001 (27)	0.001 (30)	0.025 (45)	0.034 (49)	0.007 (23)	0.027 (49)
Tree Swallow release sites (Averaged)						
1D1 & 1D2	-	1.251 (2)	0.001 (2)	4.601 (2)	0.372 (2)	0.678 (2)

* = measurement precluded by antenna operation.

KEY TO RESEARCH ACTIVITIES AND PLOT PAIRS:

Growth and Maturation - Tree swallows	1C6 and 1T1
Deermice	1C1 and 1T1
Embryology of Tree Swallows	1C4 and 1T2
	1C6 and 1T5 + 1T6
Homing - Tree Swallows	1C4 and 1T2 + 1T4
Deermice + Chipmunks	1C1 + 1C3 and 1T1
Winter Maximal Metabolism - Chickadees	1C1 and 1T1
Deermice	1C1 + 1C3 and 1T1

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Table 3. Mean values for 60 Hz longitudinal electric fields (mV/m) on test and control plots for years 1983 to 1990. The values in parentheses are the sample n. Plot 1D3 is the release site for tree swallows used in homing studies on control plots, and plots 1D1 and 1D2 are release sites used for test plots. Data for 1991 are not yet available.

PLOT	1983-1985	1986	1987	1988	1989	1990
CONTROL						
1C1	0.093 (5)	0.100 (2)	0.114 (2)	0.338 (2)	0.137 (2)	0.056 (2)
1C3	0.158 (5)	0.080 (2)	0.148 (2)	0.117 (2)	0.178 (2)	0.110 (2)
1C4	0.039 (7)	0.065 (3)	0.047 (3)	0.048 (3)	0.024 (3)	0.022 (3)
1C6	<u>0.079 (4)</u>	<u>0.068 (3)</u>	<u>0.089 (3)</u>	<u>0.041 (3)</u>	<u>0.079 (3)</u>	<u>0.066 (3)</u>
Average	0.092 (20)	0.076 (10)	0.100 (10)	0.136 (10)	0.105 (10)	0.064 (10)
Tree Swallow homing release site						
1D3	-	0.052 (1)	0.156 (1)	0.053 (1)	0.290 (1)	0.260 (1)
TEST						
1T1	0.116 (11)	0.070 (14)	0.070 (14)	0.252 (18)	0.080 (8)	0.068 (18)
1T2	0.196 (3)	0.074 (4)	0.059 (5)	0.075 (5)	0.047 (5)	0.051 (5)
1T4	0.174 (4)	0.086 (5)	0.076 (10)	0.110 (10)	0.046 (10)	0.167 (10)
1T5	0.253 (5)	0.079 (6)	0.078 (9)	0.159 (9)	*	0.181 (9)
1T6	<u>0.569 (3)</u>	<u>0.230 (1)</u>	<u>0.297 (7)</u>	<u>1.324 (7)</u>	*	<u>0.406 (7)</u>
Average	0.262 (26)	0.080 (30)	0.108 (45)	0.384 (49)	0.058 (23)	0.175 (49)
Tree Swallow homing release sites						
1D1 & 1D2	-	5.035 (2)	1.280 (2)	0.715 (2)	1.695 (2)	1.275 (2)
(Averaged)						

* = measurement precluded by antenna operation.

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Table 4. Mean values for 60 Hz magnetic fields (Mg) on test and control plots for years 1983 to 1990. The values in parentheses are the sample n. Values listed by IITRI as <0.001 are treated as equal to 0.001. Plot 1D3 is the release site for tree swallows used in homing studies on control plots, and plots 1D1 and 1D2 are release sites used for test plots. Data for 1991 are not yet available.

PLOT	1983-1985	1986	1987	1988	1989	1990
CONTROL						
1C1	0.001 (4)	0.001 (2)	0.001 (2)	0.001 (2)	0.001 (2)	0.001 (2)
1C3	0.002 (5)	0.001 (2)	0.001 (2)	0.001 (2)	0.001 (2)	0.001 (2)
1C4	0.002 (7)	0.001 (3)	0.002 (2)	0.001 (3)	0.001 (3)	0.002 (3)
1C6	<u>0.003 (4)</u>	<u>0.003 (3)</u>	<u>0.003 (3)</u>	<u>0.002 (3)</u>	<u>0.003 (3)</u>	<u>0.003 (3)</u>
Average	0.002 (20)	0.002 (10)	0.002 (9)	0.001 (10)	0.002 (10)	0.002 (10)
Tree Swallow homing release site						
1D3	-	0.003 (1)	0.002 (1)	0.002 (1)	0.013 (1)	0.009 (1)
TEST						
1T1	0.003 (11)	0.009 (14)	0.010 (14)	0.052 (18)	0.018 (8)	0.008 (18)
1T2	0.001 (3)	0.025 (4)	0.018 (5)	0.010 (5)	0.006 (5)	0.018 (5)
1T4	0.001 (4)	0.012 (5)	0.021 (10)	0.018 (10)	0.007 (10)	0.033 (10)
1T5	0.001 (5)	0.018 (6)	0.026 (9)	0.047 (9)	*	0.038 (9)
1T6	<u>0.001 (3)</u>	<u>0.020 (1)</u>	<u>0.033 (7)</u>	<u>0.094 (7)</u>	*	<u>0.035 (7)</u>
Average	0.001 (26)	0.014 (30)	0.020 (45)	0.044 (49)	0.010 (23)	0.026 (49)
Tree Swallow release sites						
1D1 & 1D2	-	0.057 (2)	0.080 (20)	0.023 (2)	0.078 (2)	0.073 (2)
(Averaged)						

* = measurement precluded by antenna operation.

Table 5a. 60 Hz Transverse electric field intensities (V/m) at the laboratory site where maximal metabolic measures were being taken. Data for 1991 not yet available.

Site No., Meas. Pt.	1986	1987	1988	1989	1990	
					Before Shielding	After
1L1-1	/	--	--	--	--	--
1L1-2	0.94	0.96	--	--	--	--
1L1-3	0.79	0.034	/	/	/	0.58
1L1-4	0.042	0.047	0.062	/	/	/
1L1-5	-	-	-	/	/	/
1L1-6	-	-	-	/	/	/
1L1-7	-	-	-	8.1	8.5	1.34
1L1-8	-	-	-	0.88	0.76	0.037
1L1-9	-	-	-	60.0	18.1	3.90*
1L1-10	-	-	-	-	/	0.010

- = measurement point not established. -- = measurement point dropped.
/ = data not taken. * = 4.0 V/m with humidifier on.

Table 5b. 60 Hz magnetic flux densities (Mg) made at the laboratory where maximal metabolic measures were being made. Data for 1991 are not yet available.

Site No., Meas. Pt.	1986	1987	1988	1989	1990
1L1-1	9.13	--	--	--	--
1L1-2	0.179	0.156	--	--	--
1L1-3	0.080	0.143	/	/	0.071
1L1-4	0.114	0.118	0.080	0.075	/
1L1-5	-	-	-	14.1 ^a 21.0 ^b	5.200 ^c 0.620 ^d
1L1-6	-	-	-	3.2 ^a 44.0 ^b	2.400 ^c 0.195 ^d 0.081 ^e
1L1-7	-	-	-	0.65	1.69
1L1-8	-	-	-	1.46	0.88
1L1-9	-	-	-	48.0	0.86
1L1-10	-	-	-	-	0.75

^a measurement made in vertical orientation only in an open, unshielded can, submerged to its rim.

^b measurement made above the bath surface.

^c measurement made in closed, unshielded, fully submerged can.

^d measurement made in closed, shielded, fully submerged can.

^e measurement made in closed, shielded, fully submerged can with motor and pump shielding.

- measurement point not established.

-- measurement point dropped.

/ data not taken.

Table 6. Mean values for 76 Hz transverse electric fields (V/m) on test and control plots for years 1986 (4 amperes), 1987 (15 amperes), 1988 (75 amperes), 1989 - 1990 (150 amperes). The value in parentheses is the sample N. NS refers to the north-south antenna segment. Standard phasing occurs in 1989 - 1990. All measures on test plots were made on the NS segment, except for displacement plots 1D1 and 1D2, which are located north of the northernmost EW segment. All values reported by IITRI as <0.001 were set to 0.001. Data from 1991 are not yet available.

PLOT	TRANSVERSE FIELDS (V/m)				
	1986 (4 amps)	1987 (15 amps)	1988 (75 amps)	1989 (150 amps)	1990 (150 amps)
CONTROL					
1C1	0.001 (2)	0.001 (2)	0.001 (2)	0.001 (2)	0.001 (2)
1C3	0.001 (2)	0.001 (2)	0.001 (2)	0.001 (2)	0.001 (2)
1C4	0.001 (2)	0.001 (3)	0.001 (3)	0.001 (3)	0.001 (3)
1C6	<u>0.001 (3)</u>	<u>0.001 (3)</u>	<u>0.001 (3)</u>	<u>0.001 (3)</u>	<u>0.001 (3)</u>
Average	0.001 (9)	0.001 (10)	0.001 (10)	0.001 (10)	0.001 (10)
Tree Swallow homing release site					
1D3	0.001 (1)	0.001 (1)	0.001 (1)	0.001 (1)	0.001 (1)
TEST					
1T1	0.078 (14)	0.264 (14)	0.897 (18)	1.834 (18)	2.000 (18)
1T2	--	0.301 (5)	1.710 (5)	2.540 (5)	2.819 (5)
1T4	0.140 (5)	0.424 (10)	1.936 (10)	3.851 (10)	4.373 (10)
1T5	0.283 (5)	0.790 (9)	3.614 (9)	6.531 (9)	11.002 (9)
1T6	<u>0.182 (1)</u>	<u>0.544 (7)</u>	<u>2.458 (7)</u>	<u>5.275 (7)</u>	<u>7.070 (7)</u>
Average	0.171 (25)	0.465 (45)	2.123 (49)	4.006 (49)	5.453 (49)
Tree Swallow release sites					
1D1 & 1D2 (Averaged)	0.001 (2)	0.001 (2)	0.001 (2)	0.009 (2)	0.012 (2)

-- = measurement point not established.

Table 7. Mean values for 76 Hz longitudinal electric fields on test and control plots for years 1986 (4 amperes), 1987 (15 amperes), 1988 (75 amperes), 1989 - 1990 (150 amperes). The value in parentheses is the sample N. NS refers to the north-south antenna segment. Standard phasing occurred in 1989 - 1990. All measures on test plots were made on the NS segment, except for displacement plots 1D1 and 1D2, which are located north of the northernmost EW segment. All values reported by IITRI as <0.001 were set to 0.001. Data for 1991 are not yet available.

PLCT	LONGITUDINAL FIELDS (Mv/m)				
	1986 (4 amps)	1987 (15 amps)	1988 (75 amps)	1989 (150 amps)	1990 (150 amps)
CONTROL					
1C1	0.021 (1)	0.085 (2)	0.430 (2)	1.505 (2)	1.185 (2)
1C3	0.022 (1)	0.068 (2)	0.335 (2)	0.960 (2)	0.895 (2)
1C4	0.001 (1)	0.003 (3)	0.013 (3)	0.046 (3)	0.044 (3)
1C6	<u>0.001 (1)</u>	<u>0.005 (3)</u>	<u>0.020 (3)</u>	<u>0.079 (3)</u>	<u>0.074 (3)</u>
Average	0.011 (4)	0.040 (10)	0.200 (10)	0.648 (10)	0.550 (10)
Tree Swallow homing release site					
1D3	0.008 (1)	0.053 (1)	0.210 (1)	0.850 (1)	0.890 (1)
TEST					
1T1	1.089 (14)	4.244 (14)	19.900 (18)	40.606 (18)	39.433 (18)
1T2	--	7.500 (5)	34.600 (5)	76.200 (5)	73.600 (5)
1T4	2.162 (5)	7.390 (10)	36.300 (10)	74.400 (10)	72.300 (10)
1T5	1.670 (5)	6.600 (9)	28.444 (9)	63.222 (9)	62.333 (9)
1T6	<u>5.400 (1)</u>	<u>18.457 (7)</u>	<u>83.857 (7)</u>	<u>162.286 (7)</u>	<u>181.714 (7)</u>
Average	2.580 (25)	8.838 (45)	40.620 (49)	83.343 (49)	85.876 (49)
Tree Swallow homing release sites					
1D1 & 1D2 (Averaged)	0.068 (2)	0.320 (2)	1.365 (2)	8.650 (2)	8.150 (2)

-- = measurement point not established.

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Table 8. Mean values for 76 Hz magnetic fields (Mg) on test and control plots for years 1986 (4 amperes), 1987 (15 amperes), 1988 (75 amperes), 1989 - 1990 (150 amperes). The value in parentheses is the sample N. NS refers to the north-south antenna segment. Standard phasing occurs in 1989 - 1990. All measures on test plots were made on the NS segment, except for displacement plots 1D1 and 1D2, which are located north of the northernmost EW segment. All values reported by IITR as <0.001 were set to 0.001. Data for 1991 are not yet available.

PLOT	MAGNETIC FIELDS (mG)				
	1986 (4 amps)	1987 (15 amps)	1988 (75 amps)	1989 (150 amps)	1990 (150 amps)
CONTROL					
1C1	0.001 (1)	0.001 (2)	0.003 (2)	0.007 (2)	0.007 (2)
1C3	0.001 (1)	0.001 (2)	0.003 (2)	0.008 (2)	0.008 (2)
1C4	0.001 (1)	0.001 (3)	0.001 (3)	0.002 (3)	0.002 (3)
1C6	<u>0.001 (1)</u>	<u>0.001 (3)</u>	<u>0.001 (3)</u>	<u>0.004 (3)</u>	<u>0.004 (3)</u>
Average	0.001 (4)	0.001 (10)	0.002 (10)	0.005 (10)	0.005 (10)
Tree Swallow homing release site					
1D3	0.001 (1)	0.001 (1)	0.002 (1)	0.008 (1)	0.008 (1)
TEST					
1T1	0.143 (14)	0.530 (14)	2.251 (18)	4.921 (18)	4.593 (18)
1T2	--	1.164 (5)	5.538 (5)	11.800 (5)	10.860 (5)
1T4	0.278 (5)	1.050 (10)	5.410 (10)	10.700 (10)	10.160 (10)
1T5	0.408 (5)	1.409 (9)	6.600 (9)	13.678 (9)	13.256 (9)
1T6	<u>0.400 (1)</u>	<u>1.043 (7)</u>	<u>4.889 (7)</u>	<u>9.843 (7)</u>	<u>10.114 (7)</u>
Average	0.307 (25)	1.039 (45)	4.938 (49)	10.188 (49)	9.797 (49)
Tree Swallow homing release sites					
1D1 & 1D2 (Averaged)	0.001 (2)	0.002 (2)	0.007 (2)	0.090 (2)	0.105 (2)

-- = measurement point not established.

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Table 9. Tree swallow plots, number of boxes, and percent with egg laying activity on test and control sites for 1985 through 1991. Egg laying activity is defined as at least two eggs laid before abandonment or continuation of nesting.

PLOT NAME	# OF BOXES	% ACTIVITY						
		1985	1986	1987	1988	1989	1990	1991
CLEVELAND HOMESTEAD TEST	39	58	62	66	74	68	51	49
FORD NORTH TEST	16	30	47	41	47	41	50	56
FORD SOUTH TEST	21	25	55	70	55	70	67	43
NORTH TURNER TEST	53	23	60	70	68	60	62	70
PIRLOT ROAD TEST	36	75	72	78	75	83	86	81
PANOLA PLAINS CONTROL	164	43	77	87	85	90	84	87
TACHYGINETA MEADOWS CONTROL	75	43	69	79	85	92	81	84
TOTALS TEST	165	44	61	68	68	66	64	62
CONTROL	239	43	73	83	85	90	83	86
OVERALL	404	44	67	76	77	80	75	88

Table 10. Tree swallow fecundity data for years 1985-1991. Data are from the Pirlot Road test plot and Tachycineta Meadows control plot and excludes any renests which may have occurred.

Variable	Year	TEST					CONTROL				
		N	$\bar{X}$	SD	SE	CV%	N	$\bar{X}$	SD	SE	CV%
Clutch Size ^a	1991	27	5.1	0.85	0.16	16.7	62	5.2	0.93	0.12	17.9
	1990	31	5.1	0.98	0.18	19.2	61	5.5	0.72	0.09	13.1
	1989	27	5.1	0.91	0.18	17.8	69	5.4	0.84	0.10	15.6
	1988	26	5.4	0.81	0.16	15.0	61	5.3	0.85	0.11	16.0
	1987	24	5.0	0.75	0.15	15.0	55	5.2	0.81	0.11	15.6
	1986	23	5.3	0.88	0.18	16.6	48	4.9	1.01	0.16	22.5
	1985	21	5.4	0.87	0.19	16.1	19	4.8	0.86	0.20	17.9
Hatch Rate ^b	1991	23	4.4	1.27	0.26	28.9	41	4.3	1.52	0.24	35.4
	1990	24	5.1	0.97	0.20	19.0	41	5.0	1.24	0.19	24.8
	1989	20	4.3	1.29	0.29	30.0	51	4.2	1.37	0.19	32.6
	1988	18	5.0	0.84	0.20	16.8	43	4.8	1.23	0.19	25.6
	1987	15	4.2	1.32	0.34	31.4	40	4.2	1.25	0.20	29.8
	1986	14	5.1	1.54	0.41	30.2	30	4.4	1.35	0.25	30.7
	1985	11	4.4	1.12	0.34	25.5	10	4.3	1.06	0.34	24.7
Fledge Rate ^c	1991	21	2.6	1.99	0.43	76.5	37	3.1	1.95	0.32	62.9
	1990	15	3.7	1.91	0.49	51.6	30	3.0	2.17	0.40	72.3
	1989	20	0.8	1.45	0.33	185.0	50	0.9	1.73	0.25	192.2
	1988	16	4.3	1.49	0.37	34.7	37	3.3	2.14	0.35	64.8
	1987	14	3.1	1.99	0.53	64.2	39	3.1	1.85	0.30	59.7
	1986	14	1.3	2.27	0.61	174.6	27	1.2	2.00	0.39	166.7
	1985	10	3.6	0.84	0.27	23.3	7	2.6	1.90	0.72	73.1
Test of Frequency of Clutch Size ^d		Year	G	df	P						
		1991	1.9	3	>0.5						
		1990	2.6	2	>0.1						
		1989	1.5	2	>0.1						
		1988	0.3	2	>0.3						
		1987	2.6	2	>0.1						
		1986	3.3	4	>0.3						
		1985	5.4	3	>0.1						

^a Clutch size is the maximum number of eggs laid in a nest.

^b Hatch rate is the number of eggs which hatch of those available to hatch, not always the maximum number of eggs in the nest due to occasional predation.

^c Fledge rate is the number of young that fledge from the eggs which hatch, and only include those nests which were followed to completion.

^d Categories of clutch size with fewer than 5 nests were not included.

Table 11. Likelihood to hatch and fledge for tree swallows for 1985 through 1991. Data are from the Pirlot Road test plot and Tachycineta Meadows control plot.

Year	Plot	HATCHING SUCCESS		% Hatching
		Hatch	Not Hatch	
1991	Test	101	16	86.3
	Control	177	34	83.9
1990	Test	22	7	94.6
	Control	203	22	90.2
1989	Test	85	17	83.3
	Control	216	43	83.4
1988	Test	90	8	91.8
	Control	206	21	90.7
1987	Test	63	11	85.1
	Control	166	32	83.8
1986	Test	71	5	93.4
	Control	132	25	84.1
1985	Test	48	8	85.7
	Control	43	5	89.6

Year	Plot	FLEDGING SUCCESS		% Fledging
		Fledge	Not Fledge	
1991	Test	55	52	51.4
	Control	116	73	61.4
1990	Test	56	17	76.7
	Control	89	60	59.7
1989	Test	15	70	17.6
	Control	47	165	22.2
1988	Test	69	12	85.2
	Control	123	55	69.1
1987	Test	44	17	72.1
	Control	122	39	75.8
1986	Test	18	53	25.4
	Control	32	86	27.1
1985	Test	36	7	83.7
	Control	18	13	58.1

Table 12. Nested ANOVA for clutch size in tree swallows. Tested are the effects of PLOT (test and control), OPERATION (pre-operation 1985-1989, operation 1990 and 1991), YEAR (nested within operation), and the interactions of PLOT and OPERATION and PLOT and YEAR. See text for method used to determine the proper error mean square to test the main effects in the model.

SOURCE	DF	SS	MS	F	P > F
PLOT	1	0.130	0.130	0.18	0.674
OPERATION	1	0.052	0.052	0.06	0.809
YEAR(OPERATION)	5	4.036	0.807	1.10	0.362
PLOT*OPERATION	1	3.500	3.500	4.75	0.030
PLOT*YEAR(OPERATION)	5	6.843	1.369	1.86	0.100
ERROR	541	398.686	0.737		

Table 13. Nested ANOVA for hatching success of tree swallows. Tested are the effects of PLOT (test and control), OPERATION (pre-operation 1985-1989, operation 1990 and 1991), YEAR (nested within operation), and the interactions of PLOT and OPERATION, and PLOT and YEAR. See text for method used to determine the proper error mean square to test the main effects in the model.

SOURCE	DF	SS	MS	F	P > F
PLOT	1	1.486	1.486	0.91	0.342
OPERATION	1	3.446	3.446	0.50	0.511
YEAR(OPERATION)	5	34.352	6.870	4.19	0.001
PLOT*OPERATION	1	0.075	0.075	0.05	0.831
PLOT*YEAR(OPERATION)	5	3.654	0.731	0.45	0.816
ERROR	372	609.945	1.640		

Table 14. Nested ANOVA for fledging success in tree swallows. Tested are the effects of PLOT (test and control), OPERATION (pre-operation 1985-1989, operation 1990 and 1991), YEAR (nested within operation), and the interactions of PLOT and OPERATION, and PLOT and YEAR. See text for method used to determine the proper error mean square to test the main effects in the model.

SOURCE	DF	SS	MS	F	P > F
PLOT	1	4.242	4.242	1.18	0.278
OPERATION	1	28.550	28.550	0.46	0.527
YEAR(OPERATION)	5	309.448	61.890	17.24	0.0001
PLOT*OPERATION	1	0.881	0.881	0.25	0.621
PLOT*YEAR(OPERATION)	5	22.169	4.434	1.23	0.292
ERROR	326	1170.393	3.590		

Table 15. Analysis of Covariance for clutch size, number of eggs hatching and number of young fledging in tree swallows. Tested are the effects of PLOT (test and control), YEAR (1986 through 1989), and the interactions of PLOT and YEAR. The covariate is summed insect biomass. See text for details of methods used to obtain the value for the covariates.

CLUTCH SIZE SOURCE	DF	SS	MS	F	P > F
PLOT	1	0.049	0.049	0.088	0.768
YEAR	3	2.033	0.678	1.217	0.305
PLOT*YEAR	3	2.241	0.747	1.342	0.262
PRE {COVARIATE}	1	0.261	0.261	0.469	0.494
ERROR	171	261.054	1.527		

NUMBER HATCHING SOURCE	DF	SS	MS	F	P > F
PLOT	1	1.449	1.449	0.960	0.328
YEAR	3	15.130	5.043	3.342	0.021
PLOT*YEAR	3	5.979	1.993	1.321	0.269
PRE {COVARIATE}	1	2.086	2.086	1.383	0.241
ERROR	175	264.057	1.509		

NUMBER FLEDGING SOURCE	DF	SS	MS	F	P > F
PLOT	1	0.025	0.025	0.006	0.937
YEAR	3	3.548	1.183	0.295	0.829
PLOT*YEAR	3	21.334	7.111	1.772	0.157
PRE {COVARIATE}	1	9.687	9.687	2.413	0.123
ERROR	105	421.490	4.014		

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Table 16. Exposure data and frequency of mortality of EGGS, NESTLINGS, and OVERALL NESTS during 1991 calculated using the Mayfield method (Mayfield 1961, 1975). Data are pooled from all test and control sites and were compared using G-tests (Sokal and Rohlf 1981).

EGG EXPOSURE DAYS

PLOT	without mortalities	with mortalities	%
TEST	6300	134	2.08
CONTROL	15045	344	2.24

G = 1.668
P > 0.5

NESTLING EXPOSURE DAYS

PLOT	without mortalities	with mortalities	%
TEST	4243	98	2.26
CONTROL	11547	247	2.09

G = 0.397
P > 0.5

OVERALL NEST EXPOSURE DAYS

PLOT	without nest failures	with nest failures	%
TEST	2509	38	1.49
CONTROL	6639	91	0.35

G = 0.267
P > 0.5

Table 17. Exposure data and frequency of total nest failure during the INCUBATION PHASE, and NESTLING PHASE during 1991 calculated using the Mayfield method (Mayfield 1961, 1975). Data are pooled from all test and control sites and were compared using G-tests (Sokal and Rohlf 1981).

INCUBATION PHASE - NEST EXPOSURE DAYS

PLOT	without nest failures	with nest failures	%
TEST	1458	21	1.42
CONTROL	3586	51	1.40

G = 0.002
P > 0.05

NESTLING PHASE - NEST EXPOSURE DAYS

PLOT	without nest failures	with nest failures	%
TEST	1051	17	1.59
CONTROL	3053	40	1.29

G = 0.501
P > 0.1

Table 18. Age in days at landmark events of eye opening and primary feather eruption in 1986 through 1991. Data are from the Pirlot Road test plot and Tachycineta Meadows control plot. Sample sizes are numbers of individual young. Day of hatching is defined as day zero.

Year	Plot	Eye Opening					Primary Eruption				
		N	X	SD	SE	CV%	N	X	SD	SE	CV%
1991	Test	32	5.1	1.15	0.20	22.6	32	8.3	0.82	0.15	9.9
	Control	56	4.7	1.03	0.14	21.9	56	7.8	1.18	0.16	15.1
1990	Test	64	6.0	1.29	0.16	21.5	64	7.7	1.25	0.16	16.2
	Control	73	6.4	1.44	0.17	22.5	73	7.5	1.05	0.12	14.0
1989	Test	25	8.6	1.16	0.23	13.5	25	9.1	1.69	0.34	18.6
	Control	32	7.8	0.93	0.16	11.9	32	9.6	1.06	0.19	11.0
1988	Test	76	7.3	1.36	0.16	18.6	76	8.2	1.21	0.14	14.8
	Control	74	6.7	1.38	0.16	20.6	74	8.8	1.25	0.15	14.2
1987	Test	44	7.4	1.84	0.28	24.9	44	8.5	1.13	0.17	13.3
	Control	66	6.7	1.48	0.18	22.1	66	8.5	1.40	0.17	16.5
1986	Test	18	5.1	1.02	0.24	20.0	18	8.8	1.11	0.26	12.6
	Control	42	6.0	0.73	0.13	12.2	42	9.1	1.52	0.24	16.7

Table 19. Nested ANOVA for age of eye opening in tree swallows. Tested are the effects of PLOT (test or control), and nests (NEST) within a plot (PLOT) for 1986 through 1991. See text for method used to determine the proper error mean square to test the main effects in the model.

SOURCE	DF	SS	MS	F	P > F
OPERATION	1	145.7125	145.7125	1.94	0.2365
PLOT	1	2.1227	2.1227	0.18	0.25
YEAR(OPERATION)	4	301.0641	75.2660	46.54	0.0001
NEST(PLOT)	30	125.6928	4.1898	2.59	0.0001
OPERATION*PLOT	1	1.1675	1.1675	0.72	0.3959
PLOT*YEAR(OPERATION)	4	37.6160	9.4040	5.82	0.0001
ERROR	560	905.6020	1.6171		

Table 20. Nested ANOVA for primary feather eruption in tree swallows. Tested are the effects of PLOT (test or control), and nests (NEST) within a plot (PLOT) for 1986 through 1991. See text for method used to determine the proper error mean square to test the main effects in the model.

SOURCE	DF	SS	MS	F	P > F
PLOT	1	0.7378	0.7378	0.07	0.25
OPERATION	1	71.3894	71.3894	4.46	0.1023
YEAR(OPERATION)	4	64.0205	16.0051	12.94	0.0001
NEST(PLOT)	30	235.0503	7.8350	6.34	0.0001
PLOT*OPERATION	1	13.1221	13.1221	10.61	0.0012
PLOT*YEAR(OPERATION)	4	18.4031	4.6008	3.72	0.0053
ERROR	560	692.4505	1.2365		

Table 21. Detectable differences and power for tree swallow fecundity variables: clutch size, hatch success and fledging success for data combined for 1985-1991. N = number of nests per treatment for test or control (smaller number used). Differences presented in units of variable with % of grand mean following.

Variable	N	Actual Detectable Difference (%)	Actual Power	Detectable Difference at 70% Power (%)
Clutch size eggs(%)	227	0.069(1.3)	<0.30	0.20(3.7)
Hatch success eggs(%)	155	0.029(0.6)	<0.30	0.35(6.9)
Fledging success young(%)	135	0.303(9.4)	<0.30	0.57(17.6)

Table 22. Detectable differences and power for tree swallow landmark events; eye opening and feather eruption, for years 1986 through 1991. N = number of nests per treatment for test or control. Differences presented in days with % of grand mean following.

Variable	Year	N	Actual Detectable Difference(%)	Actual Power	Detectable Difference at 70% Power (%)
Eye opening days(%)	1991	9	0.83(17.0)	<0.30	2.20(45.0)
	1990	13	0.52(8.4)	<0.30	2.20(35.4)
	1989	8	0.83(10.1)	<0.30	2.08(25.5)
	1988	14	0.73(10.4)	<0.30	2.55(36.4)
	1987	12	0.43(6.2)	<0.30	3.15(45.1)
	1986	6	0.90(15.7)	<0.30	1.84(32.1)
Feather eruption days(%)	1991	9	0.465(5.8)	<0.30	2.70(34.0)
	1990	13	0.763(10.1)	<0.30	2.25(29.6)
	1989	8	0.885(9.4)	<0.30	2.85(30.4)
	1988	14	1.168(13.7)	<0.30	2.35(27.6)
	1987	12	1.009(11.9)	<0.30	2.65(31.2)
	1986	6	1.439(16.0)	<0.30	4.05(45.0)

Table 23. Nested ANOVA for weight growth constant for nestling tree swallows. Tested are the effects of PLOT (test vs. control), and nest (NEST) within a plot (PLOT) for 1985 through 1991. See text for method used to determine the proper error mean square to test the main effects in the model.

SOURCE	DF	SS	MS	F	P > F
OPERATION	1	0.0022	0.0022	0.09	0.25
PLOT	1	0.0354	0.0354	0.75	0.4262
YEAR(OPERATION)	5	0.2362	0.0472	13.18	0.0001
NEST(PLOT)	42	0.7125	0.0170	4.73	0.0001
OPERATION*PLOT	1	0.0002	0.0002	0.06	0.8084
PLOT*YEAR(OPERATION)	5	0.0577	0.0115	3.22	0.0070
ERROR	660	2.3665	0.0036		

Table 24. Nested ANOVA for the inflection point of growth of weight in nestling tree swallows. Tested are the effects of PLOT (test vs. control), OPERATION (pre- and operational periods) and nested effects NEST(PLOT) and YEAR(OPERATION) and interaction terms for 1985 through 1991. See text for method used to determine the proper error mean square to test the main effects in the model.

SOURCE	DF	SS	MS	F	P > F
OPERATION	1	10.2227	10.2227	0.63	0.4640
PLOT	1	0.0531	0.0531	0.01	0.25
YEAR(OPERATION)	5	81.4036	16.2807	23.96	0.0001
NEST(PLOT)	42	113.9758	2.7137	3.99	0.0001
PLOT*OPERATION	1	5.6665	5.6665	8.34	0.0040
PLOT*YEAR(OPERATION)	5	34.1464	6.8293	10.05	0.0001
ERROR	660	448.4399	0.6795		

Table 25. Nested ANOVA for the slope from linear regression of weight increase in nestling tree swallows between ages 3 and 11 days. Tested are the effects of PLOT (test vs. control), OPERATION (pre- and operational periods) and nested effects NEST(PLOT) and YEAR(OPERATION) and interaction terms for 1985 through 1991. See text for method used to determine the proper error mean square to test the main effects in the model.

SOURCE	DF	SS	MS	F	P > F
OPERATION	1	0.9294	0.9294	1.64	0.2561
PLOT	1	0.0684	0.0684	0.24	0.6286
OPERATION*PLOT	1	0.3690	0.3690	3.77	0.0526
YEAR(OPERATION)	5	2.8283	0.5657	5.78	0.0001
NEST(PLOT)	41	11.8070	0.2880	2.94	0.0001
PLOT*YEAR(OPERATION)	5	1.3884	0.2777	2.84	0.0152
ERROR	696	68.1646	0.0979		

Table 26. Nested ANOVA for the maximum weight attained by nestling tree swallows. Tested are the effects of PLOT (test vs. control), OPERATION (pre- and operational periods) and nested effects NEST(PLOT) and YEAR(OPERATION) and interaction terms for 1985 through 1991. See text for method used to determine the proper error mean square to test the main effects in the model.

SOURCE	DF	SS	MS	F	P > F
OPERATION	1	3.8075	3.8075	0.13	0.7360
PLOT	1	15.9818	15.9818	0.59	0.25
OPERATION*PLOT	1	0.1076	0.1076	0.03	0.8701
YEAR(OPERATION)	5	149.8118	29.9624	7.45	0.0001
NEST(PLOT)	41	521.5729	12.7213	3.16	0.0001
PLOT*YEAR(OPERATION)	5	92.2166	18.4433	4.59	0.0004
ERROR	692	2781.8991	4.0201		

Table 27. Nested ANOVA for the age of maximum weight attained by tree swallow nestlings. Tested are the effects of PLOT (test vs control), OPERATION (pre- and operational periods) and nested effects NEST(PLOT) and YEAR(OPERATION) and interaction terms for 1985 through 1991. See text for method used to determine the proper error mean square to test the main effects in the model.

SOURCE	DF	SS	MS	F	P > F
OPERATION	1	5.1431	5.1431	0.14	0.7207
PLOT	1	0.2501	0.2501	0.019	0.50
YEAR(OPERATION)	5	179.6051	35.9210	18.45	0.0001
NEST(PLOT)	41	341.5474	8.3304	4.28	0.0001
PLOT*OPERATION	1	2.5299	2.5299	1.30	0.2547
PLOT*YEAR(OPERATION)	5	34.5609	6.9122	3.55	0.0035
ERROR	693	1349.1232	1.9468		

Table 28. Nested ANOVA for tarsus growth constant in tree swallows. Tested are the effects of PLOT (test vs control), OPERATION (pre- and operational periods) and nested effects NEST(PLOT) and YEAR(OPERATION) and interaction terms for 1985 through 1991. See text for method used to determine the proper error mean square to test the main effects in the model.

SOURCE	DF	SS	MS	F	P > F
OPERATION	1	0.0624	0.0624	0.27	0.6259
PLOT	1	0.0089	0.0089	0.11	0.25
YEAR(OPERATION)	5	1.1575	0.2315	33.90	0.0001
NEST(PLOT)	43	1.5901	0.0370	5.42	0.0001
PLOT*OPERATION	1	0.0607	0.0607	8.89	0.0030
PLOT*YEAR(OPERATION)	5	0.2557	0.0511	7.49	0.0001
ERROR	699	4.7733	0.0068		

Table 29. Nested ANOVA for the inflection point of tarsus growth in tree swallows. Tested are the effects of PLOT (test vs. control), OPERATION (pre- and operational periods) and nested effects NEST(PLOT) and YEAR(OPERATION) and interaction terms for 1985 through 1991. See text for method used to determine the proper error mean square to test the main effects in the model.

SOURCE	DF	SS	MS	F	P > F
OPERATION	1	24.8794	24.8794	1.57	0.2658
PLOT	1	0.2484	0.2484	0.05	0.25
YEAR(OPERATION)	5	79.3138	15.8628	42.34	0.0001
NEST(PLOT)	43	84.3696	1.9621	5.24	0.0001
PLOT*OPERATION	1	9.2802	9.2802	24.77	0.0001
PLOT*YEAR(OPERATION)	5	15.2538	3.0508	8.14	0.0001
ERROR	699	261.8972	0.3747		

Table 30. Nested ANOVA for the slope of the linear regression of tarsus growth (between the ages of 3DPH and 11 DPH) in nestling tree swallows. Tested are the effects of PLOT (test vs. control), OPERATION (pre- and operational periods) and nested effects NEST(PLOT) and YEAR(OPERATION) and interaction terms for 1985 through 1991. See text for method used to determine the proper error mean square to test the main effects in the model.

SOURCE	DF	SS	MS	F	P > F
OPERATION	1	0.0421	0.0421	0.15	0.7128
PLOT	1	0.0007	0.0007	0.02	0.50
OPERATION*PLOT	1	0.0026	0.0026	0.12	0.7346
YEAR(OPERATION)	5	1.3844	0.2769	12.03	0.0001
NEST(PLOT)	38	1.7902	0.0471	2.05	0.0004
PLOT*YEAR(OPERATION)	5	0.0363	0.0073	0.32	0.9036
ERROR	472	10.8673	0.0230		

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Table 31. Nested ANOVA for the maximum length of tarsus attained by nestling tree swallows. Tested are the effects of PLOT (test vs. control), OPERATION (pre- and operational periods) and nested effects NEST(PLOT) and YEAR(OPERATION) and interaction terms for 1985 through 1991. See text for method used to determine the proper error mean square to test the main effects in the model.

SOURCE	DF	SS	MS	F	P > F
OPERATION	1	13.2034	13.2034	0.75	0.4257
PLOT	1	0.0061	0.0061	0.003	0.50
OPERATION*PLOT	1	0.5469	0.5469	1.46	0.2276
YEAR(OPERATION)	5	87.8889	17.5778	46.88	0.0001
NEST(PLOT)	43	28.3890	0.6602	1.76	0.0023
PLOT*YEAR(OPERATION)	5	7.4184	1.4837	3.96	0.0015
ERROR	712	266.9928	0.3750		

Table 32. Nested ANOVA for the age at maximum length of tarsus attained by tree swallow nestlings. Tested are the effects of PLOT (test vs. control), OPERATION (pre- and operational periods) and nested effects NEST(PLOT) and YEAR(OPERATION) and interaction terms for 1985 through 1991. See text for method used to determine the proper error mean square to test the main effects in the model.

SOURCE	DF	SS	MS	F	P > F
OPERATION	1	20.7155	20.7155	0.73	0.4326
PLOT	1	0.4303	0.4303	0.005	0.50
YEAR(OPERATION)	5	142.3325	28.4665	5.53	0.0001
NEST(PLOT)	43	568.8530	13.2291	2.57	0.0001
PLOT*OPERATION	1	64.3782	64.3782	12.50	0.0004
PLOT*YEAR(OPERATION)	5	397.6609	79.5322	15.44	0.0001
ERROR	712	3666.7050	5.1499		

Table 33. Nested ANOVA for ulna growth constant in tree swallows. Tested are the effects of PLOT (test vs. control), OPERATION (pre- and operational periods) and nested effects NEST(PLOT) and YEAR(OPERATION) and interaction terms for 1985 through 1991. See text for method used to determine the proper error mean square to test the main effects in the model.

SOURCE	DF	SS	MS	F	P > F
OPERATION	1	0.0002	0.0002	0.00	0.9499
PLOT	1	0.0049	0.0049	0.52	0.25
YEAR(OPERATION)	5	0.2078	0.0416	18.77	0.0001
NEST(PLOT)	34	0.2853	0.0084	3.79	0.0001
PLOT*OPERATION	1	0.0089	0.0089	4.01	0.0458
PLOT*YEAR(OPERATION)	5	0.0159	0.0032	1.43	0.2103
ERROR	641	1.4192	0.0022		

Table 34. Nested ANOVA for the inflection point of ulna growth in tree swallows. Tested are the effects of PLOT (test vs. control), OPERATION (pre- and operational periods) and nested effects NEST(PLOT) and YEAR(OPERATION) and interaction terms for 1985 through 1991. See text for method used to determine the proper error mean square to test the main effects in the model.

SOURCE	DF	SS	MS	F	P > F
OPERATION	1	26.7691	26.7691	1.17	0.3279
PLOT	1	0.2992	0.2992	0.04	0.25
YEAR(OPERATION)	5	113.9435	22.7887	35.64	0.0001
NEST(PLOT)	34	82.0714	2.4139	3.78	0.0001
PLOT*OPERATION	1	7.7648	7.7648	12.14	0.0005
PLOT*YEAR(OPERATION)	5	29.0768	5.8154	9.09	0.0001
ERROR	641	409.8627	0.6394		

Table 35. Nested ANOVA for the slope of the linear regression of ulna growth (between the ages of 3 DPH and 11 DPH) in nestling tree swallows. Tested are the effects of PLOT (test vs. control), OPERATION (pre- and operational periods) and nested effects NEST(PLOT) and YEAR(OPERATION) and interaction terms for 1985 through 1991. See text for method used to determine the proper error mean square to test the main effects in the model.

SOURCE	DF	SS	MS	F	P > F
OPERATION	1	1.1436	1.1436	0.46	0.5270
PLOT	1	0.1498	0.1498	0.36	0.50
OPERATION*PLOT	1	0.0104	0.0104	0.12	0.7330
YEAR(OPERATION)	5	12.3836	2.4767	27.69	0.0001
NEST(PLOT)	39	8.6982	0.2230	2.49	0.0001
PLOT*YEAR(OPERATION)	5	1.4244	0.2849	3.19	0.0075
ERROR	683	61.0820	0.0894		

Table 36 Nested ANOVA for the maximum length of ulna attained by nestling tree swallows. Tested are the effects of PLOT (test vs. control), OPERATION (pre- and operational periods) and nested effects NEST(PLOT) and YEAR(OPERATION) and interaction terms for 1985 through 1991. See text for method used to determine the proper error mean square to test the main effects in the model.

SOURCE	DF	SS	MS	F	P > F
OPERATION	1	7.1847	7.1847	0.20	0.6762
PLOT	1	22.4976	22.4976	0.93	0.25
OPERATION*PLOT	1	0.0225	0.0225	0.01	0.9199
YEAR(OPERATION)	5	182.9430	36.5886	16.47	0.0001
NEST(PLOT)	42	303.6197	7.2290	3.25	0.0001
PLOT*YEAR(OPERATION)	5	95.8589	19.1718	8.63	0.0001
ERROR	712	1582.1602	2.2221		

Table 37. Nested ANOVA for the age at maximum length of ulna attained by tree swallow nestlings. Tested are the effects of PLOT (test vs. control), OPERATION (pre- and operational periods) and nested effects NEST(PLOT) and YEAR(OPERATION) and interaction terms for 1985 through 1991. See text for method used to determine the proper error mean square to test the main effects in the model.

SOURCE	DF	SS	MS	F	P > F
OPERATION	1	0.1582	0.1582	0.001	0.949
PLOT	1	18.6297	18.6297	1.07	0.25
OPERATION*PLOT	5	177.8620	35.5724	11.99	0.0001
YEAR(OPERATION)	42	378.7041	9.0168	3.04	0.0001
NEST(PLOT)	1	27.9968	27.9968	9.44	0.0022
PLOT*YEAR(OPERATION)	5	56.9664	11.3932	3.84	0.0019
ERROR	712	2112.1222	2.9665		

Table 38. Nested ANOVA for wing growth in tree swallows. Tested are the effects of PLOT (test vs. control), OPERATION (pre- and operational periods) and nested effects NEST(PLOT) and YEAR(OPERATION) and interaction terms for 1985 through 1991. See text for method used to determine the proper error mean square to test the main effects in the model.

SOURCE	DF	SS	MS	F	P > F
OPERATION	1	0.00003	0.00003	0.00	0.9547
PLOT	1	0.0007	0.0007	0.18	0.25
YEAR(OPERATION)	5	0.0374	0.0075	28.26	0.0001
NEST(PLOT)	42	0.0584	0.0014	5.26	0.0001
OPERATION*PLOT	1	0.0039	0.0039	14.75	0.0001
PLOT*YEAR(OPERATION)	5	0.0144	0.0029	10.90	0.0001
ERROR	691	0.1827	0.0003		

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Table 39. Tree swallow growth constants derived from fitted growth curves. Data are from test (Pirilot Road) and control (Tachycineta Meadows) sites for 1985 through 1991. N = number of nestlings *

Variable	Year	TEST				CONTROL			
		N	$\bar{X}$	SD	CV%	N	$\bar{X}$	SD	CV%
Weight	1991	31	0.50	0.07	14.62	56	0.52	0.04	7.71
	1990	60	0.46	0.08	16.39	60	0.44	0.06	14.10
	1989	21	0.44	0.06	13.20	30	0.47	0.06	13.05
	1988	69	0.47	0.07	13.99	60	0.46	0.05	11.76
	1987	42	0.46	0.06	12.30	61	0.49	0.07	14.31
	1986	21	0.44	0.10	22.14	42	0.44	0.07	14.70
	1985	102	0.48	0.08	15.93	61	0.44	0.06	14.54
Tarsus	1991	31	0.44	0.10	21.68	56	0.48	0.09	19.14
	1990	64	0.36	0.07	19.79	70	0.37	0.07	17.83
	1989	22	0.36	0.06	15.45	31	0.30	0.07	23.91
	1988	75	0.46	0.14	30.73	69	0.47	0.10	20.48
	1987	44	0.37	0.10	26.12	67	0.41	0.08	19.98
	1986	21	0.36	0.06	17.12	42	0.36	0.09	23.98
	1985	98	0.42	0.10	23.54	66	0.36	0.09	25.28
Ulna	1991	29	0.38	0.02	6.32	56	0.40	0.03	7.84
	1990	64	0.33	0.05	15.26	69	0.34	0.05	16.29
	1989	22	0.34	0.04	13.27	30	0.32	0.04	13.96
	1988	74	0.37	0.06	15.94	68	0.37	0.04	10.58
	1987	44	0.38	0.05	12.83	59	0.39	0.06	14.99
	1986	20	0.36	0.04	10.88	41	0.36	0.06	15.87
	1985	70	0.36	0.06	17.38	43	0.36	0.05	13.11
Wing	1991	29	0.12	0.005	4.31	56	0.12	0.005	4.04
	1990	64	0.14	0.01	7.53	74	0.16	0.03	20.75
	1989	22	0.13	0.01	4.85	30	0.13	0.01	7.37
	1988	74	0.13	0.01	9.72	69	0.14	0.01	10.02
	1987	44	0.13	0.01	10.04	56	0.13	0.01	9.40
	1986	21	0.15	0.04	28.60	40	0.14	0.01	10.75
	1985	102	0.15	0.02	14.03	66	0.15	0.02	12.58

* The numbers in this table are from completely reanalyzed data and may not agree with figures in earlier annual reports.

Table 40. Tree swallow inflection points derived from fitted growth curves. Data are from test (Piriot Road) and control (Tachycineta Meadows) sites for 1985 through 1991. N = number of nestlings^b.

Variable	Year	TEST				CONTROL			
		N	$\bar{X}$	SD	CV%	N	$\bar{X}$	SD	CV%
Weight	1991	31	5.47	0.55	10.03	56	4.92	0.37	7.60
	1990	60	5.94	1.01	17.02	60	6.20	1.03	16.53
	1989	21	5.81	0.70	12.10	30	6.65	1.00	15.02
	1988	69	5.47	0.74	13.57	60	5.49	0.74	13.44
	1987	42	5.93	1.09	18.42	61	5.50	0.94	17.00
	1986	21	6.53	1.16	17.72	42	6.51	0.89	13.66
	1985	102	5.50	0.92	16.74	61	6.45	1.07	16.58
Tarsus	1991	31	1.64	0.47	28.86	56	1.37	0.36	26.59
	1990	64	2.23	0.68	30.38	70	2.14	0.42	19.64
	1989	22	2.55	0.51	19.95	31	3.66	0.89	24.37
	1988	75	1.96	0.59	30.08	69	1.80	0.61	34.13
	1987	44	2.16	1.20	55.53	67	2.33	0.74	32.00
	1986	21	1.80	0.64	35.65	42	2.22	0.76	33.99
	1985	98	2.05	0.56	27.51	66	2.55	0.87	34.29
Ulna	1991	29	4.98	0.49	9.76	56	4.46	0.38	8.54
	1990	64	5.45	0.98	17.92	69	5.48	0.88	16.11
	1989	22	5.51	0.75	13.70	30	6.49	1.04	15.98
	1988	74	4.98	0.86	17.17	68	4.89	0.65	13.32
	1987	44	5.39	1.08	20.03	59	4.95	0.88	17.79
	1986	20	5.67	0.72	12.62	41	5.98	0.75	12.60
	1985	70	5.63	1.08	19.10	43	6.15	0.87	14.22

Wing ^a

^a Inflection point not applicable to curves for wing growth.

^b The numbers in this table are from completely reanalyzed data and may not agree with figures in earlier annual reports.

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Table 41. The means of the slope of linear regression of growth measures on nestling age. Data are from test and control sites for 1985 through 1991.

Variable	Year	TEST					CONTROL				
		N	$\bar{X}$	SD	SE	CV%	N	$\bar{X}$	SD	SE	CV%
Weight	1991	33	2.32	0.247	0.043	10.7	51	2.33	0.277	0.039	11.9
	1990	64	2.17	0.314	0.039	14.5	66	2.11	0.363	0.045	17.2
	1989	26	1.99	0.284	0.056	14.3	31	2.27	0.521	0.094	22.9
	1988	62	2.12	0.313	0.040	14.8	64	2.05	0.347	0.043	16.9
	1987	43	2.11	0.254	0.039	12.1	62	2.09	0.328	0.042	15.7
	1986	28	2.08	0.233	0.044	10.5	42	2.31	0.287	0.044	12.4
	1985	99	2.15	0.321	0.032	14.9	65	2.23	0.326	0.040	14.6
Tarsus	1991	9	0.79	0.147	0.049	18.5	14	0.79	0.187	0.050	23.6
	1990	53	0.85	0.126	0.017	14.9	55	0.83	0.157	0.021	18.8
	1989	25	0.82	0.179	0.036	21.9	27	0.81	0.192	0.037	23.8
	1988	25	0.74	0.202	0.040	27.3	28	0.67	0.157	0.030	23.6
	1987	17	0.89	0.190	0.046	21.5	30	0.89	0.142	0.026	15.9
	1986	27	0.78	0.136	0.026	17.5	41	0.76	0.153	0.024	20.1
	1985	72	0.77	0.144	0.017	18.7	53	0.76	0.161	0.022	21.3
Ulna	1991	32	2.24	0.154	0.027	6.8	55	2.23	0.265	0.036	11.9
	1990	64	2.15	0.189	0.024	8.8	68	2.23	0.377	0.046	16.9
	1989	29	1.85	0.356	0.066	19.3	34	1.94	0.540	0.093	27.8
	1988	69	2.07	0.242	0.029	11.7	65	2.04	0.243	0.030	11.9
	1987	42	2.32	0.259	0.040	11.2	62	2.26	0.302	0.038	13.4
	1986	25	2.34	0.177	0.035	7.6	33	2.47	0.164	0.029	6.6
	1985	90	2.14	0.350	0.037	16.4	52	1.95	0.414	0.057	21.3

Table 42. Means of maximum growth values attained by nestlings. Data are from test and control sites for 1985 through 1991.

Variable	Year	TEST				CONTROL			
		N	$\bar{X}$	SD	CV%	N	$\bar{X}$	SD	CV%
Weight	1990	54	22.59	1.882	8.3	34	22.52	1.935	8.6
	1989	24	21.87	1.525	7.0	30	22.77	1.456	6.4
	1988	73	21.93	1.833	8.4	58	22.65	1.945	8.6
	1987	39	22.24	1.884	8.5	57	22.24	1.761	8.1
	1986	17	23.60	1.051	4.5	41	22.88	1.563	6.8
	1985	78	22.41	1.782	8.0	59	22.55	2.748	12.2
Tarsus	1990	54	12.05	0.515	4.3	34	12.06	0.636	5.3
	1989	24	12.08	0.921	7.6	30	12.31	0.286	2.3
	1988	73	11.19	0.455	4.1	58	11.22	0.318	2.8
	1987	39	11.74	0.659	5.6	59	11.81	0.546	4.6
	1986	17	10.89	0.409	3.8	41	10.74	0.408	3.8
	1985	77	11.13	0.488	4.4	59	10.99	0.673	6.1
Ulna	1990	54	25.43	0.786	3.1	34	25.29	0.736	2.9
	1989	24	24.79	0.710	2.9	30	25.18	0.678	2.7
	1988	73	25.44	0.816	3.2	58	25.83	0.750	2.9
	1987	39	26.40	0.897	3.4	57	25.95	1.061	4.1
	1986	17	26.25	0.412	1.6	41	25.46	0.750	2.9
	1985	78	24.48	2.367	9.7	59	24.86	2.407	9.7

Table 43. The age at maximum growth values for growing nestling tree swallows. Data are from test and control sites for 1985 through 1991.

Variable	Year	TEST				CONTROL			
		N	$\bar{X}$	SD	CV%	N	$\bar{X}$	SD	CV%
Weight	1990	54	13.06	1.327	10.2	34	13.74	1.366	9.9
	1989	24	14.33	1.792	12.5	30	14.50	1.554	10.7
	1988	73	14.14	1.836	13.0	58	13.45	1.921	14.3
	1987	39	13.87	1.490	10.7	57	13.26	1.914	14.4
	1986	17	14.35	1.618	11.3	41	14.29	1.569	11.0
	1985	78	12.87	1.731	13.4	59	13.88	1.885	13.6
Tarsus	1990	54	12.61	2.545	20.2	34	14.03	2.269	16.9
	1989	24	14.50	1.700	11.7	30	14.83	1.768	11.9
	1988	73	13.95	2.460	17.6	58	13.96	2.551	18.7
	1987	39	13.62	2.642	19.1	57	13.86	2.642	19.1
	1986	17	11.06	2.794	25.3	41	14.68	2.423	16.5
	1985	78	13.46	2.208	16.4	59	13.51	2.322	17.2
Ulna	1990	54	14.24	1.627	11.4	34	13.85	1.769	12.8
	1989	24	15.17	1.381	9.1	30	15.97	1.655	10.4
	1988	73	14.49	1.488	10.0	58	15.14	1.034	6.8
	1987	39	14.74	1.681	11.4	57	14.46	1.833	12.7
	1986	17	14.12	1.576	11.2	41	14.54	1.567	10.8
	1985	78	13.69	1.995	14.6	59	14.56	1.794	12.4

Table 44. Minimum detectable differences of means for tree swallow growth constants and the minimum percent detectable change in the mean to reach 70% certainty (power) of test. * N = the number of nests per treatment for test or control. Detectable difference is in actual amount and percent of the grand mean.

Variable	Year	N	Actual Detectable Difference(%)	Actual Power	% Detectable Difference at 70% Power
Weight	1991	8	0.025(4.9)	<.30	0.136(26.7)
	1990	13	0.033(7.3)	<.30	0.125(27.8)
	1989	6	0.058(12.6)	<.30	0.155(33.7)
	1988	13	0.029(6.2)	<.30	0.105(22.3)
	1987	11	0.061(12.7)	<.30	0.118(24.6)
	1986	6	0.087(19.8)	<.30	0.232(52.7)
	1985	21	0.062(13.2)	<.30	0.100(21.3)
Tarsus	1991	8	0.034(7.2)	<.30	0.206(43.8)
	1990	13	0.035(9.5)	<.30	0.128(34.6)
	1989	6	0.125(39.1)	0.40	0.185(57.8)
	1988	13	0.068(14.8)	<.30	0.195(42.4)
	1987	12	0.067(17.2)	<.30	0.150(38.5)
	1986	6	0.072(20.0)	<.30	0.192(53.3)
	1985	21	0.053(13.3)	<.30	0.112(28.0)
Ulna	1991	8	0.045(11.5)	0.62	0.050(12.8)
	1990	13	0.042(12.4)	<.30	0.109(32.1)
	1989	6	0.020(6.1)	<.30	0.126(38.2)
	1988	13	0.038(10.3)	<.30	0.098(26.5)
	1987	11	0.037(9.5)	<.30	0.095(24.4)
	1986	6	0.060(16.7)	<.30	0.160(44.4)
	1985	16	0.052(8.1)	<.30	0.086(23.9)
Wing	1991	8	0.004(3.3)	<.30	0.010(8.3)
	1990	13	0.031(20.7)	.30	0.053(35.3)
	1989	6	0.026(20.0)	<.30	0.068(52.3)
	1988	13	0.008(6.2)	<.30	0.023(17.7)
	1987	11	0.004(3.1)	<.30	0.022(16.9)
	1986	6	0.021(15.0)	<.30	0.085(60.7)
	1985	21	0.006(4.0)	<.30	0.027(18.0)

* The data in this table have been reanalyzed using N = number of nests per treatment and do not agree with figures in earlier annual reports.

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Table 45. Minimum detectable differences in mean inflection points and the minimum percent detectable change in the mean to reach 70% certainty (power) of test. * N = the number of nests per treatment for test or control.

Variable	Year	N	Actual Detectable Difference(%)	Actual Power	% Detectable Difference at 70% Power
Weight	1991	8	1.109(21.7)	0.76	1.02(19.9)
	1990	13	0.656(10.8)	<.30	1.85(30.1)
	1989	6	1.520(24.1)	.40	2.20(34.9)
	1988	13	0.477(8.7)	<.30	1.23(22.4)
	1987	11	0.387(6.8)	<.30	1.95(34.3)
	1986	6	1.090(16.7)	<.30	2.90(44.5)
	1985	21	1.162(19.8)	.59	1.28(21.8)
Tarsus	1991	8	0.460(31.3)	0.30	0.86(58.5)
	1990	13	0.234(10.7)	<.30	0.95(43.6)
	1989	6	1.656(51.8)	.55	1.99(62.2)
	1988	13	0.218(11.6)	<.30	1.03(54.8)
	1987	12	0.619(27.4)	<.30	1.82(80.5)
	1986	6	0.606(31.7)	<.30	1.98(95.2)
	1985	21	0.505(22.4)	.30	0.86(38.2)
Ulna	1991	8	0.884(19.1)	0.65	0.98(21.1)
	1990	13	0.669(12.2)	<.30	1.75(32.0)
	1989	6	1.760(28.9)	.45	2.41(39.6)
	1988	13	0.524(10.6)	<.30	1.45(29.4)
	1987	11	0.447(8.7)	<.30	1.95(37.9)
	1986	6	0.569(9.7)	<.30	2.09(35.5)
	1985	16	0.209(3.6)	<.30	1.54(26.4)
Wing *					

* Inflection point not applicable to curves for wing growth.

^ The data in this table have been reanalyzed using N = number of nests per treatment and do not agree with figures in earlier annual reports.

Table 49. Analysis of Variance for the nestling exchange experiment done in 1990 and 1991. Tested are the effects of TREATMENT, YEAR and their interaction.

MAXIMUM WEIGHT

SOURCE	DF	SS	MS	F	P > F
TREATMENT	5	23.524	4.705	2.051	0.074
YEAR	1	21.962	21.962	9.519	0.002
TREATMENT*YEAR	5	7.521	1.504	0.656	0.657
ERROR	177	405.962	2.294		

MAXIMUM TARSUS

SOURCE	DF	SS	MS	F	P > F
TREATMENT	5	0.618	0.124	0.612	0.691
YEAR	1	12.502	12.502	61.891	0.0001
TREATMENT*YEAR	5	1.407	0.281	1.393	0.229
ERROR	177	35.755	0.202		

MAXIMUM ULNA

SOURCE	DF	SS	MS	F	P > F
TREATMENT	5	5.959	1.192	1.487	0.196
YEAR	1	7.099	7.099	8.861	0.003
TREATMENT*YEAR	5	9.143	1.829	2.282	0.048
ERROR	177	141.817	0.801		

Table 50. Least-squares means for nestling exchange experiment.

		TREATMENT- ELF EXPOSURE					
YEAR	VALUE	None& No swap	None& Swap	Egg& Swap	Nestling& Swap	Egg& Nestling No Swap	Egg& Nestling Swap
WEIGHT							
1990	$\bar{X}$	22.88	23.40	23.38	22.378	22.823	21.80
	SD	1.548	1.131	1.386	1.345	1.718	1.344
	N	31	12	10	9	24	5
1991	$\bar{X}$	22.59	22.25	22.08	21.14	22.083	21.583
	SD	1.363	1.610	1.822	1.409	1.688	0.791
	N	34	12	9	8	29	6
TARSUS							
1990	$\bar{X}$	12.05	12.16	12.10	11.99	12.18	12.334
	SD	0.514	0.637	0.476	0.483	0.507	0.648
	N	31	12	10	9	24	5
1991	$\bar{X}$	11.61	11.58	11.42	11.54	11.33	11.59
	SD	0.373	0.401	0.422	0.294	0.325	0.319
	N	343	12	9	8	29	6
ULNA							
1990	$\bar{X}$	25.26	25.78	25.33	25.98	25.53	25.81
	SD	0.758	0.886	1.100	1.130	0.725	0.919
	N	31	12	10	9	24	5
1991	$\bar{X}$	25.56	25.27	24.58	25.21	24.95	25.31
	SD	0.959	0.826	1.084	0.998	0.912	0.617
	N	34	12	9	8	29	6

Table 51. Statistics for growth rate of body mass for young deermice compared by year and plot. Growth rate is the slope of a linear model.

Year	Control					Test				
	N	$\bar{X}$	SD	SE	CV%	N	$\bar{X}$	SD	SE	CV%
1991	20	0.37	0.085	0.019	22.8	21	0.38	0.072	0.016	18.9
1990	58	0.34	0.046	0.006	13.5	27	0.30	0.048	0.009	16.0
1989	15	0.30	0.045	0.012	15.0	14	0.38	0.050	0.013	13.2
1988	32	0.33	0.062	0.011	18.8	35	0.37	0.064	0.011	17.3
1987	47	0.38	0.063	0.009	16.6	42	0.31	0.777	0.012	25.2
1986	42	0.25	0.091	0.014	36.4	50	0.28	0.085	0.012	30.4

Table 52. Analysis of Variance of deermice growth rates on test (Pirlot Road) and control (Michigamme) sites for years 1986 through 1991. Tested are the effects of PLOT (test vs. control), OPERATION (pre- and operational periods) and nested effects MOTHER(PLOT) and YEAR(OPERATION) and interaction terms for 1985 through 1991. See text for method used to determine the proper error mean square to test the main effects in the model.

Year	Source	SS	MS	F-Value	P	> F
	OPERATION	1	0.0219	0.0219	0.59	0.4838
	PLOT	1	0.0005	0.0005	0.008	0.25
	YEAR(OPERATION)	4	0.1472	0.0368	13.83	0.0001
	MOTHER(PLOT)	18	0.4736	0.0263	9.89	0.0001
	OPERATION*PLOT	1	0.0221	0.0221	8.30	0.0042
	PLOT*YEAR(OPERATION)	4	0.1824	0.0456	17.14	0.0001
	ERROR	367	0.9761	0.0027		

Table 53. Minimum detectable differences and power for deermice growth constants for years 1986 - 1991.

Year	N	Actual Detectable Difference(%)	Actual Power	% Detectable Difference at 70% Power
1991	3	0.154(41.0)	<.30	0.47(125.0)
1990	7	0.051(15.6)	<.30	0.15(45.8)
1989	2	0.212(62.4)	.33	0.34(100.0)
1988	5	0.040(11.4)	<.30	0.24(68.6)
1987	7	0.082(23.6)	<.30	0.22(63.4)
1986	7	0.103(38.1)	.30	0.19(68.5)

Table 54. Relevant statistics for age of eye-opening and incisor eruption for deermice reared in enclosures from 1985 through 1991.

Year	Plot	Eye Opening				Incisor Eruption			
		N	$\bar{X}$	SD	CV%	N	$\bar{X}$	SD	CV%
1991	Test	21	13.6	2.06	15.2	21	5.6	1.21	21.6
	Control	10	17.4	1.35	7.8	20	5.5	1.00	18.2
1990	Test	27	14.9	1.68	11.4	27	5.9	1.19	20.2
	Control	58	17.3	1.52	8.8	58	5.9	1.18	20.0
1989	Test	14	15.3	1.14	7.5	14	5.0	0.88	17.6
	Control	15	15.7	3.01	19.2	15	6.0	1.51	25.1
1988	Test	35	14.7	1.44	9.8	35	4.4	0.91	20.7
	Control	32	16.3	1.37	8.4	32	5.5	0.80	14.5
1987	Test	44	15.7	1.87	11.9	44	6.1	1.55	25.4
	Control	43	16.0	1.10	6.9	43	6.4	1.66	25.9
1986	Test	28	14.1	2.01	14.3	28	5.6	1.29	23.0
	Control	48	15.0	1.08	7.2	48	6.1	1.49	24.4

Table 55. Nested ANOVA of deermice age of eye opening on test (Pirlot Road) and control (Michigamme) sites for years 1985 through 1991. Tested are the effects of PLOT (test vs. control), OPERATION (pre- and operational periods) and nested effects MOTHER(PLOT) and YEAR(OPERATION) and interaction terms for 1985 through 1991. See text for method used to determine the proper error mean square to test the main effects in the model.

Source	DF	SS	MS	F-Value	P > F
OPERATION	1	19.6399	19.6399	1.64	0.27
PLOT	1	54.9552	54.9552	2.34	0.10
YEAR(OPERATION)	4	48.0197	12.0049	6.75	0.0001
MOTHER(PLOT)	18	332.1698	18.4539	10.38	0.0001
OPERATION*PLOT	1	99.0215	99.0215	55.69	0.0001
PLOT*YEAR(OPERATION)	4	27.3295	6.8324	3.84	0.0045
ERROR	345	613.4100	1.7780		

Table 56. Nested ANOVA of deermice incisor eruption on test (Pirlot Road) and control (Michigamme) sites for years 1986 through 1991. Tested are the effects of PLOT (test vs. control), OPERATION (pre- and operational periods) and nested effects MOTHER(PLOT) and YEAR(OPERATION) and interaction terms for 1985 through 1991. See text for method used to determine the proper error mean square to test the main effects in the model.

Source	DF	SS	MS	F-Value	P > F
OPERATION	1	1.7334	1.7334	0.12	0.7447
PLOT	1	0.0251	0.0251	0.004	0.50
YEAR(OPERATION)	4	56.9469	14.2367	9.74	0.0001
MOTHER(PLOT)	18	104.1552	5.7864	3.96	0.0001
OPERATION*PLOT	1	10.4833	10.4833	7.17	0.0078
PLOT*YEAR(OPERATION)	4	5.2819	1.3205	0.90	0.4623
ERROR	355	519.1465	1.4624		

Table 57. Minimum detectable differences and power for deermice maturation events for years 1986 through 1991.

Variable	Year	N	Actual Detectable Difference(%)	Actual Power	Detectable Difference at 70% Power(%)
Eye opening days (%)	1991	2	8.45(57.0)	<.30	14.3(96.0)
	1990	7	5.4 (32.7)	.74	5.2(31.5)
	1989	2	5.27(34.0)	<.30	16.8(108.4)
	1988	5	3.32(21.4)	.33	5.4(34.5)
	1987	7	1.58(10.0)	<.30	5.0(31.6)
	1986	6	1.00(6.8)	<.30	5.6(38.1)
Incisor eruption days (%)	1991	3	1.55(27.9)	<.30	4.6(82.9)
	1990	7	1.08(18.3)	<.30	2.9(49.2)
	1989	2	2.09(38.0)	<.30	9.2(167.3)
	1988	5	2.42(49.1)	.35	3.5(71.0)
	1987	7	1.54(24.9)	<.30	5.3(85.5)
	1986	6	1.61(27.4)	<.30	4.7(79.7)

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Table 58. Numbers of birds used in the tree swallow homing study and likelihood to return following displacement, 1986-1991. Returns are those birds which returned to the plot in less than 300 minutes. Likelihood to return was assessed using G-tests (Sokal and Rohlf 1981).

Year	Treatment	Return	Not Return	% Return		
1991	Test	34	1	97.1		
	Control	24	15	61.5	G = 15.690	P < 0.001
1990	Test	41	1	97.6		
	Control	30	9	76.9	G = 8.527	P < 0.005
1989	Test	14	0	100.0		
	Control	15	1	93.8	Not tested-	see text
1988	Test	37	4	90.2		
	Control	39	6	86.7	G = 0.256	P > 0.5
1987	Test	36	1	97.3		
	Control	25	13	65.8	G = 13.675	P < 0.001
1986	Test	26	3	89.7		
	Control	24	7	77.4	G = 1.577	P > 0.1

Table 59. Mean return speeds of tree swallows in kilometers per hour for 1986-1991 field seasons. Data for the two test sites during 1986-1990 were pooled after determining that there were no significant differences between them. Only one test site was used in 1991. See text.

Year	Treatment	N	$\bar{X}$	SD	CV%	Difference (km/hr)
1991	Test	34	14.7	6.01	40.9	
	Control	24	11.0	3.13	28.5	3.7
1990	Test	41	13.8	4.93	35.7	
	Control	30	11.4	3.50	30.7	2.4
1989	Test	14	17.1	5.28	30.9	
	Control	15	11.8	4.26	36.1	5.3
1988	Test	37	14.3	4.08	28.5	
	Control	39	10.3	3.17	30.8	3.0
1987	Test	36	12.6	3.74	29.7	
	Control	25	9.6	2.62	27.3	3.0
1986	Test	26	13.6	5.27	38.8	
	Control	22	12.3	6.42	52.2	1.3

Table 60. Nested ANOVA comparing tree swallow return speeds in kilometers per hour. Tested are the effects of PLOT (test and control), OPERATION (preoperational years 1986-1989 and operational years 1990 and 1991), YEAR (nested within operation), and the interactions of PLOT and OPERATION and PLOT and YEAR. To determine the F value for OPERATION the mean square for YEAR was used in the denominator.

Source	DF	TYPE III SS	MS	F	P
PLOT	1	798.678	798.678	40.32	0.0001
OPERATION	1	0.011	0.011	0.00	0.990
YEAR(OPERATION)	4	236.033	59.008	2.98	0.019
PLOT*OPERATION	1	2.565	2.565	0.13	0.719
PLOT*YEAR(OPERATION)	4	96.151	24.038	1.21	0.305
ERROR	331	6556.953	19.810		

Table 61. Data on tree swallow likelihood to return pooled over all years (1986-1991) for test and control plots.

Plot	Return	Not Return	
Test	154	9	G = 15.566 P < 0.001
Control	133	36	

Table 62. Detectable differences and power for tree swallow homing. return time for years 1986 - 1991. N = number of adults per treatment for test or control. Differences presented in minutes with % following.

Variable	N	Actual Detectable Difference(%)	Actual Power	Detectable Difference (%) at 70% Power
Return time minutes(%)	137	37.9 (23.9)	1.0	16 (10.1)

Table 63. Results of deermouse homing studies at Pirlot Road test plot and Michigamme control plot for all years of the study 1986-1991. Likelihood to return was tested for each year using a G-test (Sokal and Rohlf 1981).

Year	Plot	Return	Not Return	% Return	G statistic
1991	Test	28	10	73.7	G = 1.380
	Control	11	8	57.9	P > 0.1
1990	Test	20	23	46.5	G = 11.234
	Control	29	6	82.9	P < 0.001
1989	Test	13	8	61.9	G = 4.830
	Control	3	10	23.1	P < 0.05
1988	Test	17	24	41.5	G = 2.114
	Control	9	5	64.3	P > 0.1
1987	Test	16	7	69.9	G = 0.023
	Control	6	3	66.7	P > 0.5
1986	Test	5	1	83.3	G = 1.819
	Control	1	2	33.3	P > 0.1

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Table 64. Results of chipmunk homing studies at Pirlot Road test plot and Michigamme control plot for all years of the study 1986-1991. Likelihood to return was tested for each year using a G-test (Sokal and Rohlf 1981).

Year	Plot	Return	Not Return	% Return	G statistic
1991	Test	7	6	53.8	G = 0.141
	Control	5	3	62.5	P > 0.5
1990	Test	11	12	47.8	G = 2.477
	Control	15	6	71.4	P < 0.1
1989	Test	15	8	65.2	G = 0.306
	Control	9	7	56.3	P > 0.5
1988	Test	5	12	29.4	G = 0.172
	Control	2	3	40.0	P > 0.5
1987	Test	4	8	33.3	G = 0.304
	Control	2	2	50.0	P > 0.5
1986	Test	13	6	68.4	G = 3.161
	Control	20	2	90.9	P > 0.05

Table 65. Chi-square analysis of developmental abnormalities found in early tree swallow embryos collected from test and control sites in 1991.

Status	Test	Control	Total
Normal	67	67	134
Abnormal	9	10	19
Total	76	77	153

$X^2 = 0.05$

Contingency coefficient = 0.02

Table 66. Frequency of tree swallow abnormalities. First number is the number of embryos displaying abnormality. Second number (in parentheses) in the number of nests involved.

Plot	No Development	Spine Abnormal	Brain Abnormal	Other	Total
Test	2 (2)	1 (1)	4 (3)	2 (2)	9 (8)
Control	4 (3)	3 (2)	2 (2)	1 (1)	10 (7 [*])
Percent	3.9%	2.6%	3.9%	2.0%	12.4%

* Two embryos which showed a spinal abnormality came from the same nest as two which failed to develop.

Table 67. Analysis of Variance for egg weights. Tested are the effects of PLOT (test and control), OPERATION (preoperational years 1986-1989 and operational years 1990 and 1991), YEAR (nested within operation), and the interactions of PLOT and OPERATION and PLOT and YEAR. To determine the F value for OPERATION the mean square for YEAR was used in the denominator.

Source	DF	SS	MS	F Value	Pr > F
OPER	1	0.72366728	0.72366728	4.24	0.0946
PLOT	1	0.12203311	0.12203311	1.05	0.25
YEAR(OPER)	5	0.85379020	0.17075804	7.28	0.0001
NEST(PLOT)	35	2.75236326	0.07863895	3.35	0.0001
OPER*PLOT	1	0.00542369	0.00542369	0.23	0.6308
PLOT*YEAR(OPER)	5	0.30827131	0.06165426	2.63	0.0227
ERROR	991	23.24984230	0.02346099		

Table 68. Standard Statistics for egg weights.

OPERATION	YEAR	PLOT	N	Mean	Std Dev	Std Error	CV
B (Before)	1985	CONT	46	1.73	0.113	0.017	6.88
		TEST	58	1.66	0.174	0.023	10.57
	1986	CONT	55	1.82	0.151	0.020	8.50
		TEST	53	1.78	0.200	0.027	11.19
	1987	CONT	81	1.82	0.130	0.015	7.43
		TEST	110	1.79	0.133	0.013	7.58
	1988	CONT	78	1.86	0.130	0.015	7.45
		TEST	110	1.76	0.162	0.015	9.12
	1989	CONT	82	1.79	0.155	0.016	8.48
		TEST	80	1.80	0.130	0.015	7.70
A (After)	1990	CONT	81	1.72	0.135	0.015	7.84
		TEST	82	1.72	0.211	0.024	12.29
	1991	CONT	77	1.75	0.179	0.019	9.73
		TEST	84	1.71	0.187	0.020	10.54

Table 69. Analysis of Variance for measured egg volumes. Tested are the effects of PLOT (test and control), YEAR, and the interactions of PLOT and YEAR. To determine the F value for PLOT the mean square for NEST(PLOT) was used as the denominator.

SOURCE	DF	SS	MS	F-RATIO	P > F
YEAR	1	0.240	0.240	16.661	0.001
PLOT	1	0.010	0.010	0.144	0.707
NEST(PLOT)	30	1.807	0.067	4.642	0.0001
YEAR*PLOT	1	0.026	0.026	1.776	0.184
ERROR	246	3.546	0.014		

Table 70. Standard Statistics for egg volumes.

YEAR	PLOT	N	Mean	Std Dev	Std Error	CV
1990	CONTROL	72	1.63	0.134	0.016	8.30
	TEST	68	1.63	0.124	0.015	7.60
1991	CONTROL	70	1.70	0.166	0.020	9.70
	TEST	67	1.67	0.132	0.016	7.90

Table 71. Analysis of Variance for egg K const nt. Tested are the effects of PLOT (test and control), YEAR, and the interactions of PLOT and YEAR. To determine the F value for PLOT the mean square for NEST(PLOT) was used as the denominator.

SOURCE	DF	SS	MS	F-RATIO	P > F
YEAR	1	0.001	0.001	8.265	0.004
PLOT	1	0.0001	0.0001	0.518	0.477
NEST(PLOT)	30	0.012	0.0004	2.283	0.0001
YEAR*PLOT	1	0.001	0.001	7.287	0.007
ERROR	233	0.039	0.000167		

Table 72. Summary of peak metabolic rates measured on deermice and chickadees in the week following capture in 1991. All measured peaks, regardless of their quality rating, are included except for one value rejected as an outlier (see text).

Species and Plot	Number of Measures	Peak Metabolic Rate [ml O ₂ /(g X hr)]		Mean Body Weight (g)
		Mean	S.D.	
Deermice				
MGE (Control)	11	19.4	1.8	17.7
PRT (Test)	13	18.1	1.7	18.9
Chickadees				
MGE	9	23.3	1.7	11.4
PRT	15	22.6	1.8	11.4

Table 73. Summary of peak metabolic rates measured on deermice in the week following capture in 1986-7 and 1990-91. As discussed in the text, all measured peaks, regardless of their quality rating, are included.

Year and Plot	Number of Measures	Peak Metabolic Rate [ml O ₂ /(g X hr)]	
		Mean	S.D.
1986-87			
MGE (Control)	18	20.2	1.6
PRT (Test)	17	19.2	1.6
1990-91			
MGE	23	18.7	1.8
PRT	23	18.6	2.0

Table 74. Summary of peak metabolic rates measured on chickadees in the week following capture in 1986-7 and 1990-91. As discussed in the text, only peaks in quality classes 1-4 are included for 1986-7, whereas all measured peaks, regardless of quality rating, are included for 1990-1.

Year and Plot	Number of Measures	Peak Metabolic Rate [ml O ₂ /(g X hr)]	
		Mean	S.D.
1986-87			
MGE (Control)	20	25.2	1.8
PRT (Test)	15	24.4	2.1
1990-91			
MGE	22	23.9	1.8
PRT	26	23.3	2.0

Table 75. Summary of major findings by task for 1985-1991.

Task	Results	Year
SMALL MAMMAL COMMUNITIES*		
Species richness.	Test greater than Control. .	88,87
Species composition	No Plot effect	88,87,86,85
Species diversity	Test greater than Control. .	88
	Test less than Control . . .	87
	No Plot effect	86,85
Evenness.	Test greater than Control. .	88
	Test less than control . . .	87
	No Plot effect	86,85
TPN - chipmunk	Test less than Control . . .	88,87,86,85
TPN - deermouse.	Test greater than Control. .	88,87
	No Plot effect	86,85
TREE SWALLOW - FECUNDITY, GROWTH AND MATURATION STUDIES		
Fecundity		
Mean clutch size.	No Plot, Year or Operation effects	
Distrib. of clutch size. .	No Plot, Year or Operation effects	
Insect Covariate analysis.	No covariate response (1986-89)	
Likelihood to hatch	No Plot or Operation. Sign. Year effect	
Hatch rate.	No Plot or Operation. Sign. Year effect	
Likelihood to fledge. . . .	No Plot or Operation. Sign. Year effect	
Number fledged.	No Plot or Operation. Sign. Year effect	
Mortality		
Egg	Test greater than Control. .	87,90
	Test less than Control . . .	88,86
	No Plot effect	89,85,91
Nestling.	Test greater than Control. .	86,90
	Test less than Control . . .	85,88
	No Plot effect	89,87,91
Overall Nest.	Test greater than Control. .	88,87,90
	Test less than Control . . .	85
	No Plot effect	89,86,91
Incubation Phase/Nest . . .	Test greater than Control. .	87
	Test less than Control . . .	85
	No Plot effect	89,88,86,90,91
Nestling Phase/Nest	Test greater than Control. .	88
	No Plot effect	89,87,86,85,90,91
Landmark growth events		
Eye opening	Nest effect, no Plot or Operation effect	
Feather eruption.	Nest effect, no Plot or Operation effect	

(this table continued on following page)

Table 75. (Continued) Summary of major findings by task for 1985-1991.

Task	Results	Year
TREE SWALLOW - FECUNDITY, GROWTH AND MATURATION STUDIES (Continued)		
Tree Swallow Growth		
Weight increase ^b	.Nest, Year effect. No Plot or Operation effect	
Weight inflection pt.	.Nest, Year effect. No Plot or Operation effect	
Maximum weight.	.Nest, Year effect. No Plot or Operation effect	
Age at maximum wt	.Nest, Year effect. No Plot or Operation effect	
Tarsus growth ^b	.Nest, Year effect. No Plot or Operation effect	
Tarsus inflection pt.	.Nest, Year effect. No Plot or Operation effect	
Maximum tarsus.	.Nest, Year effect. No Plot or Operation effect	
Age at maximum tarsus	.Nest, Year effect. No Plot or Operation effect	
Ulna growth ^b	.Nest, Year effect. No Plot or Operation effect	
Ulna inflection pt.	.Nest, Year effect. No Plot or Operation effect	
Maximum Ulna.	.Nest, Year effect. No Plot or Operation effect	
Age at Maximum ulna	.Nest, Year effect. No Plot or Operation effect	
Wing growth	.Nest, Year effect. No Plot or Operation effect	
Analysis of Growth with Insect Biomass Covariate		
All variables	.Analysis not possible. Sign. interaction with covariate	
Nestling Exchange Experiment		
Maximum weight.	.No treatment effect, Year effect	
Maximum tarsus.	.No treatment effect, Year effect	
Maximum ulna.	.No treatment effect, Year effect	
Incubation ^a	.Nest effect. No Plot or Year effect	
	Ambient Temperature effect	88,87
DEERMOUSE - PARENTAL CARE, FECUNDITY, GROWTH AND MATURATION STUDIES		
Deermouse Growth		
Growth rate	.Mother effect, No Plot or Operation effect	
Eye opening	.Mother effect, No Plot or Operation effect	
Incisor eruption.	.Mother effect, No Plot or Operation effect	
TREE SWALLOW HOMING STUDIES (Pooled data for 1986-1991)		
Likelihood to Return.	.Test greater than Control.	90,87,91
	Test equal Control	89 ^a ,88,86
Mean Return Times	.Plot and Year effect, no interaction effect	
SMALL MAMMAL HOMING STUDIES		
Likelihood to Return		
Chipmunk.	.No Plot effect	all years
Deermouse	.No Plot effect	88,87,91
	Test less than Control	90,89

(This table continued on the following page.)

Table 75. (Continued) Summary of major findings by task for 1985-1991.

DEVELOPMENTAL STUDIES

Abnormality Frequency . . .No Plot effect all years
 Egg Volume. Nest and Year effect, no Plot effect
 Egg weight. Nest and Year effect, no Plot effect

MAXIMUM AEROBIC METABOLISM STUDIES

Peak Metabolic Rates

Deermouse No Plot, Operation effect. Sign. Year effect
 Chickadee No Plot^a, Operation effect. Sign. Year effect

- ^a Study element dropped in 1989 due to budget constraints. See text.
- ^b Includes fitted growth constant and linear growth rate statistics.
- ^c Not tested in 1989 due to small sample N caused by inclement weather. Pooled over years including 1989, test plots have greater return rates than control.
- ^d We report a significant Plot effect, but the Plot by Operation interaction indicates this is not due to the operation of the antenna.

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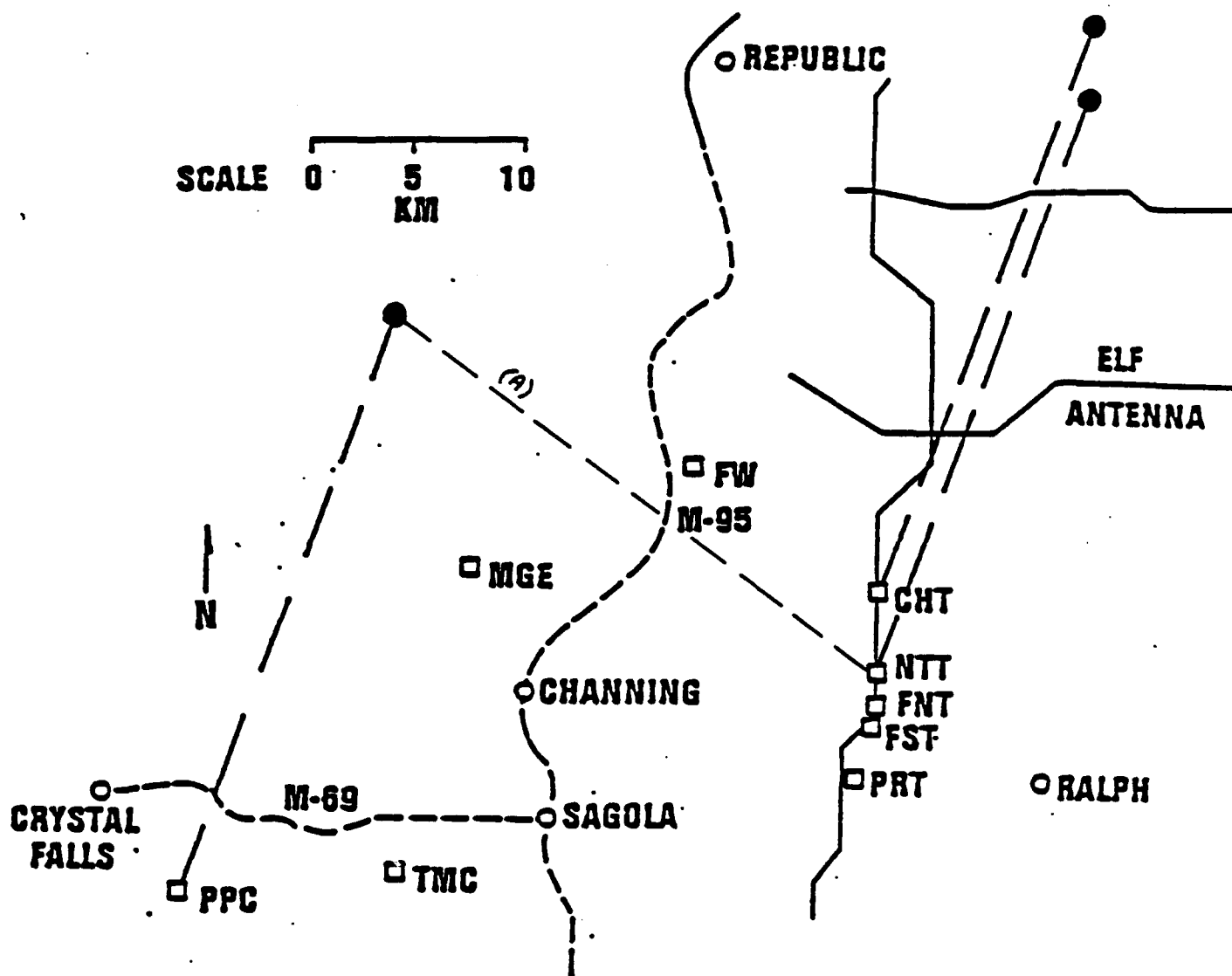


Figure 1. Location of Test and Control plots in relation to antenna system. Homing displacement routes and release sites are indicated. See Table 1 for translation of plot codes. Line (A) indicates new route for homing tree swallows to test plots in 1991.