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# ELF Communications System Ecological Monitoring Program: Soil Arthropods and Earthworms – Final Report

Richard J. Snider
Renate M. Snider

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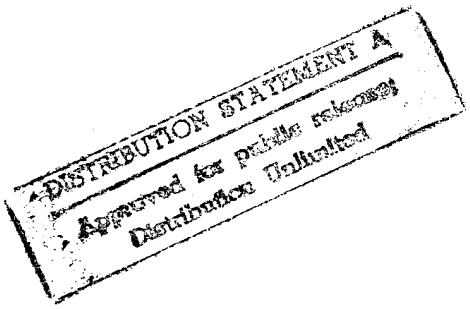


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The U.S. Navy has completed a program that monitored flora, fauna, and ecological relationships for possible effects from electromagnetic fields produced by its Extremely Low Frequency (ELF) Communications System. This report documents studies of soil arthropods and earthworms conducted near the Navy's transmitter in Michigan.

Researchers from Michigan State University (MSU) monitored soil invertebrates, litter inputs, and litter decomposition from 1982 through 1993. Monitoring studies were performed in areas near (treatment) and far (control) from the antenna. Study parameters included structural and functional characteristics of the invertebrate community found on the forest floor, in the litter, and in the soil of the study sites.

The research team used several statistical techniques; however, analysis of variance and "before and after control and impact" were most frequently used. Results were consistent with a small, short-term curtailment of earthworm reproduction in a single species. Notwithstanding, investigators conclude that the EM fields produced by the Naval Radio Transmitting Facility-Republic, Michigan had no adverse effects on soil mesobiota, soil macrobiota, nor community function.

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## FOREWORD

This report by researchers from Michigan State University (MSU) summarizes the results and conclusions of their study of soil arthropods and earthworms. In this effort, MSU monitored soil invertebrates exposed to electromagnetic fields produced by the U.S. Navy's ELF Communications System in Michigan. The Space and Naval Warfare Systems Command (SPAWAR) funded this MSU study through contracts N00039-81-C-0357, N00039-84-C-0070, N00039-88-C-0065, and N00039-93-C-0001 to IIT Research Institute (IITRI). IITRI, a not-for-profit organization, provided engineering support to MSU and managed their study through subcontract agreements.

MSU initiated their studies in late 1982. Their early efforts focused on selecting study sites, validating assumptions made in proposals, and characterizing critical study aspects. As these tasks were accomplished in 1983 and 1984, MSU then emphasized accumulating a data base for statistical analysis. The MSU research team and IITRI evaluated each study variable for continued funding before contract renewals in 1984, 1988, and 1993. As a result, several originally proposed study elements were either expanded or discontinued in subsequent periods of performance.

Since its inception, scientific peers have reviewed the technical quality of this study on an annual basis. In similar fashion, a draft of this report has been reviewed by peers with experience in soil ecology, statistics, and electromagnetics. MSU authors have considered, and addressed, peer critiques prior to submitting a revised manuscript to IITRI. Except for added prefatory and title pages, MSU's manuscript is here issued by IITRI on behalf of SPAWAR without further changes or editing by IITRI or SPAWAR.

Respectfully submitted,
IIT RESEARCH INSTITUTE

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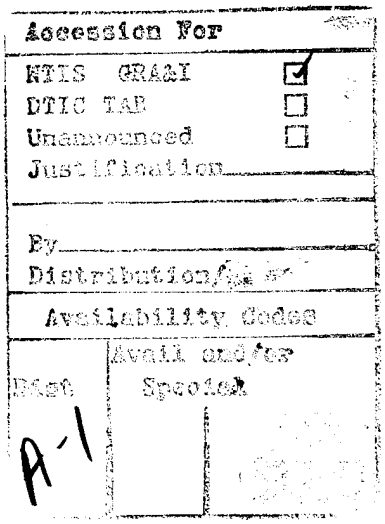

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## Arthropoda and Earthworms

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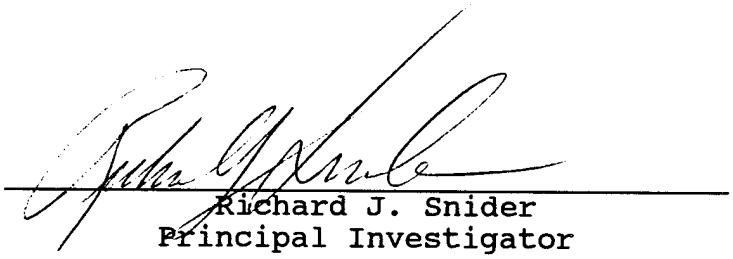

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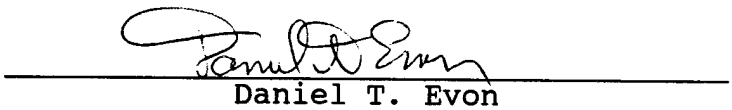

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## GLOSSARY

A horizon - uppermost zone of soils, in which organic matter accumulates and most biological activity is concentrated.

AFDW - Ash-Free Dry Weight, an estimate of dry weight of litter samples after subtraction of the weight of contaminating soil.

ANOVA - analysis of variance; statistical procedure for comparing treatment means by partitioning a total sum of squares into components associated with sources of variation.

B horizon - zone of soil underlying the A horizon; in our sites, it is sandy and contains relatively little organic matter and few animals.

BACI - statistical analysis (Before and After Control and Impact), used here to comparing differences between sites (means and variances) before and after antenna activation.

Biomass - total weight of all individuals of a given species or other taxon, usually estimated per unit area of one square meter.

Chaetotaxy - use of external characteristics (particularly the number and location of hairs) for identifying species or developmental stages of species.

Clitellate - possessing a clitellum - adult earthworms showing a glandular swelling which secretes material to form the cocoon; i.e., fully reproductive adults.

Cocoon - lemon-shaped structure produced by clitellate adult earthworms; contains one or more eggs and, later, one or more developing young worms.

Cohort - a group of animals of one species which have emerged or hatched at approximately the same time; loosely equivalent to "generation".

Correlation - statistical method for quantifying the amount of association between two variables, without assuming a causative relationship between them.

Density - number of individuals of a species or other taxon, estimated from numbers per sample and extrapolated to area units of one square meter.

Deutonymph - here, refers to the third developmental stage of Acari or mites (the first = larva, the second = protonymph).

Diel - refers to the 24-hour cycle of day and night (cf. diurnal, nocturnal).

Diurnal - refers to daytime; e.g., diurnal activity = activity during daylight hours.

Diversity - a measure of the relative abundance of the species within a community as related to the total number of species and individuals in the community; we use the Shannon-Wiener diversity index, H'.

Dominance - relative numerical abundance of a single species in the entire array of species present in a community.

Edaphic - refers to the soil; e.g., edaphic factors are conditions or characteristics of the soil which influence organisms.

ELF - Extremely Low Frequency electromagnetic radiation, produced by local power lines as well as by the U.S. Navy's ELF antenna.

Endogeic - (=endogean) - living in the soil; refers specifically to earthworms living and feeding in the A horizon or below it.

Epedaphic - living on or above the soil surface.

Epigeic - (= epigean) - living at or above the soil surface; refers specifically to earthworms which feed on and live in the litter layer unless conditions get dry; they have poor burrowing capabilities.

Equitability - a measure of of the degree of "evenness" with which the individuals of a community are apportioned among the component species of that community; we use the Lloyd and Ghelardi index, S'/S.

Euedaphic - strictly tied to or living in the soil.

Gravimetric - based on weight measurements; here used in reference to soil and litter moisture determinations based on the difference between wet and dry weight of samples.

Hatchling - young animal after it has emerged from the egg (in arthropods) or from the cocoon (in earthworms).

Hemiedaphic - living on or above the soil surface as well as in the soil itself; e.g., some Collembola which are capable of vertical migration and exploit leaf litter as well as soil resources.

Hibernation - dormancy during the winter; a state of reduced activity or complete inactivity.

Instar - general term for developmental stages of Collembola; instar I (= hatchling) refers to young after emergence from the egg, but prior to the first molt.

Larva - the first delopmental stage of certain arthropods; here, used in conjunction with mites and beetles.

Multivoltine - a type of life cycle in which two or more generations of young are produced per year.

Nocturnal - refers to nighttime; e.g. nocturnal activity = activity during nights.

Operational period - includes all years from 1989 onward, ending year variable depending on the specific work element.

Ovigerous - carrying developing or developed eggs in ovaries (of beetles, for instance).

Oviposition - deposition of eggs.

Pre-ELF period - includes all years through 1988, with beginning year variable depending on the specific work element.

Recruitment - addition of young (recruits) to a population of animals.

Regression - statistical method for expressing changes in one (dependent) variable associated with changes in one or more (independent) variables.

T-test - statistical test of the difference between two means.

Taxon - any taxonomic category, e.g., species, genus, family.

Teneral - newly or recently emerged; in carabid beetles, refers to adults just after they have emerged from the pupa.

Turnover time (1/k) - in natural systems, refer to the time (years) needed for forest floor litter to return to its previous state, i.e., to the mass of litter present just prior to the preceding leaffall; here, applied to decomposition of confined litter (in litterbags), where k = the rate of decay.

Univoltine - a type of life cycle in which only one generation of young is produced per year.

## ABSTRACT

Based on analysis of years grouped by pre-ELF and operational periods, density fluctuations of arthropods (Collembola and mites) were, in some taxa, significantly different between sites; in others, differences between year groups were significant within either of the study sites. No consistent patterns were seen at the level of species or higher taxa. In some species, effects of the 1988 drought may have carried over into 1989, the first year of antenna operation.

Surface-active Collembola, velvet mites and carabid beetles did not alter their activity patterns following antenna activation (e.g., species predominantly spring-active remained spring-active). Although analyses routinely yielded significant differences with respect to total numbers captured in Test and Control, numbers alone were found to be unreliable estimators for disturbance, because a variety of potentially important factors other than EM fields were present. Weekly changes in relative numbers captured, however, showed that increases and decreases in activity were synchronous in the study sites. Carabid beetle activity, which is highly seasonal and governed mainly by reproductive processes, was not affected by EM fields.

Earthworm behavior (in terms of vertical distribution) did not change during operational years, being determined mainly by moisture conditions. Antenna activation did not affect the health of two abundant Test site species (as measured by mean weight of cocoons and adults). Regression models were used to compare pre-ELF reproductive activity in *Aporrectodea tuberculata* to activity from 1989 through 1993. Differences between the two 5-year periods were not significant for cocoon densities and for numbers of reproductive adults. However, when single operational years were tested, 1990 data were found to differ significantly from pre-ELF years.

These results indicated that reproductive activity was depressed briefly after antenna activation, and was then resumed at near-normal or normal levels.

Three series of *A. tuberculata* were reared in mesh bags in Test and Control sites, and were periodically retrieved, examined and weighed; cocoons were counted and weighed as well. Incubated worms which had originated from the Test site after 2 years exposure to full intensity ELF EM fields reproduced better when removed from EM influence. Worms collected in Test after 4 years exposure, when incubated in Control bags, showed no differences with respect to all reproductive parameters tested. However, worms collected in an EM-free site and incubated in Test produced more cocoons than those in Control. Although interpretation is complex when both experimental worms and natural populations are taken into account, the hypothesis that EM fields would induce subtle, short-term curtailment of reproduction was substantiated.

Litter inputs (maple, basswood and total leaf litter) and litter decomposition rates were unaffected by antenna operation. Litter decomposition rates were shown to be under the partial control of earthworm decomposer species, biomass of decomposers explaining over 70% of observed variation in litter decay rates.

## SUMMARY

**1. Soil and litter Arthropoda:** data available at bi-weekly intervals from early May to mid- or late October, 1984-92 (litter) and 1986-92 (soil). All collembolan taxa fluctuated greatly in terms of total abundance during most years, and in both sites. These variations could not be clearly linked to the time of antenna activation in 1989. Population structure of one isotomid species, abundant in both sites, showed obvious differences during operational years in the Control site, but seemed unaffected in Test (although data were not amenable to rigorous analysis).

**2. Surface-active Arthropoda:** data available at weekly intervals, 1985-91, from early May to late October. Analyses of numbers trapped routinely revealed significant differences between pre-ELF and operational periods when sites were compared. However, changes in catch size showed no consistent patterns between single taxa or within sites. We concluded that several factors other than EM fields provided underlying causes for numerical changes, in Collembola, carabid beetles, and, to a lesser degree, Acarina. Patterns of reproduction and maturation, which are driving forces for seasonal activity patterns, were unaffected by ELF antenna activation. BACI tests of date-to-date fluctuations in numbers (catch ratios) showed that relative increases and decreases in Test and Control were not altered during operational years, i.e., that effects of biotic and abiotic variables which determine activity were still in operation.

**3. Earthworms: field populations:** data available at biweekly intervals, 1984-93, early May through mid-October. Two species abundant in the Test site (and one species in Control, although comparisons were used cautiously) were investigated. For *Lumbricus rubellus*, which

is relatively impervious to climatic and edaphic conditions, we were unable to construct predictive models for testing reproductive parameters. *Aporrectodea tuberculata* exhibited a brief (1990) depression in reproductive activity, which returned to approximately normal levels during the 1991-93 period. Cocoon production rates were significantly increased during operational years, but a 5-year series of relatively moist years (compared to 2 drought years and one partial drought year among the 5 pre-ELF years) may provide an explanation equally valid as that of EM field effects. Mean weight of cocoons and adults did not differ between the two 5-year periods.

**4. Earthworm isolation experiments:** three "series" of experiments were performed using adult *A. tuberculata* incubated in fiberglass mesh bags: a) worms collected in the Test site in 1991, after they had been exposed to EM fields for two years; b) worms collected in Test in 1993, after four years of exposure; and c) worms collected in a site removed from EM influence, i.e., never exposed. All series were replicated in Test and Control sites, representing continued (or first) exposure in Test bags, and representing removal from exposure (or continued non-exposure) when incubated in Control bags. Results were somewhat ambiguous, but we concluded, in a comparison between field populations and experimentally isolated groups, that EM fields produced subtle and transient effects on reproductive activity, decreasing maturation of worms to the clitellate state and increasing cocoon production rates. Several possible mitigating circumstances contributed to lack of clarity in interpretations. They included: the developmental state (and body size) of individuals at the time of first exposure in field populations, and the duration of exposure prior to removal from EM field effects; and a possible dose-response relationship, since EM fields inside mesh bags were of less than ambient intensity.

**5. Litter inputs and decomposition:** Litter inputs (maple, basswood and total leaf inputs) over the 1984-1992 period were consistent with amounts reported for similar sites in north-temperate areas. No effects of antenna operation were detectable.

Litterbag experiments were conducted through the 1993 season. Decay rates varied between years in both sites, variation being attributable to a large degree to fluctuating populations of decomposer earthworm species (mean annual biomass of decomposer species was significantly related to turnover times for maple litter). The worm biomass parameter was unlikely to have been affected by antenna operation, and at any rate would have masked potential effects of EM fields on decomposition.

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# I. SITE DESCRIPTION AND EXPERIMENTAL DESIGN

## 1. Description of study sites:

In late summer of 1983, one Test and one Control site were established in Dickinson County (T44N. R29W. S25 and T43N. R30W. S11 respectively). The Test site was located next to the north-south leg of the antenna, the Control approx. 11.5 km distant from it. In both sites, *Acer saccharum* Marsh was dominant, *Tilia americana* L. subdominant. Soils were naturally well-drained podzols (Alfic Haplorthods, coarse-loamy, mixed, frigid). Soil texture (approximately 60% sand, 23% silt, and 17% clay) and pH (approximately 5.9) were essentially equal in Test and Control. Detailed site descriptions are available in Snider and Snider (1987). A map of site locations with respect to the ELF antenna is included in **Appendix 1.**

## 2. Electromagnetic fields:

To a large extent, selection of paired study sites was governed by actual or anticipated EM field ratios (Test/Control). ELF fields, centered at a frequency of 76 Hz, and 60 Hz fields produced by commercial power lines, were both considered. Initially, the following ratios were desired:

1. $T(76) / C(76) \geq 10$
2. $T(76) / C(60) \geq 10$
3. $T(76) / T(60) \geq 10$
4. $0.1 \leq T(60) / C(60) \leq 10$,

where: T(76) = Test site EM field level due to the ELF antenna system; T(60) = Test site EM field level due to power lines; etc...

In 1983 and 1984, actual measurements of ambient 60 Hz fields were obtained in Test and

Control sites, while 76 Hz values were estimated using projected data of antenna operating conditions, earth conductivity, and distance to antenna elements (Enk and Gauger 1985). Calculated field ratios met or exceeded the criteria specified above, assuring that ELF fields in Test should dominate its own ambient as well as Control EM fields by a factor of $\geq$ 10; and that ambient fields from power lines were matched to within a factor of $\leq$ 10.

After the ELF antenna became fully operational in May 1989 (at 150 A), continued annual measurements confirmed that Test and Control sites were well paired; in 1993, for instance, the earth electric field ratio for T(76) / C(76) was 125, and that for T(76) / T(60) was 300. During years of full antenna operation, actual 76 Hz earth electric field intensities in Test averaged approximately 57 mV/m; and 76 Hz magnetic flux densities averaged approximately 2.0 mG. Detailed data on measurement point locations and results are given in **Appendix 1.**

As the study progressed, additional 60 Hz EM field measurements became necessary. They included (details in **Appendix 1**):

a. the collection sites for earthworms never exposed to EM fields, to be used in Isolation Experiments ("Fire Tower" and "Merriman Road" series, see section VI); both sites were found acceptable with respect to exposure criteria;

b. the laboratory where live earthworms from Isolation Experiments were processed after retrieval from the field; with the exception of the top of an electronic scale (on which earthworms rested for very brief time periods), EM field intensities were found to be low in the general work area.

**3. Experimental design:**

The most homogeneous portion of each site was divided into 10 x 10 m quadrats separated by walkways. Twenty quadrats per site were made available for faunal sampling, the remainder were used for environmental monitoring or litter decomposition studies. Maps showing the configuration of each site are included in **Appendix 1.**

Each quadrat contained one pittrap and one leaf litter trap, both permanently installed. Litter and soil samples were taken from randomly selected locations (the same in all quadrats sampled at a given time) along x/y coordinates (**Fig. 1**). In principle, the following cluster of samples were obtained on each occasion, in the sequence listed here: leaf litter and soil for arthropod extraction; soil cores (2 depths) for moisture determination; leaf litter for moisture determination; and finally, leaf litter and A and B horizon samples for earthworm and cocoon extraction (**Fig. 2**). Details regarding numbers of samples, sampling frequency, and/or changes in protocol or methodology, will be given in the pertinent sections of this report.

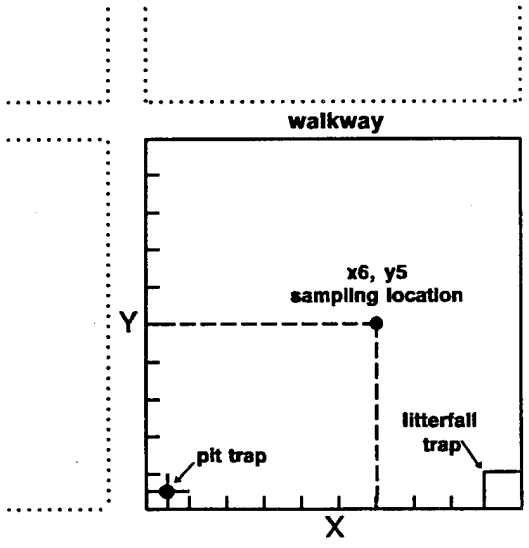


Fig. 1. General outlay of a sampling quadrat (10 x 10 m), with an example of a randomly chosen sampling location at coordinates X6, Y5.

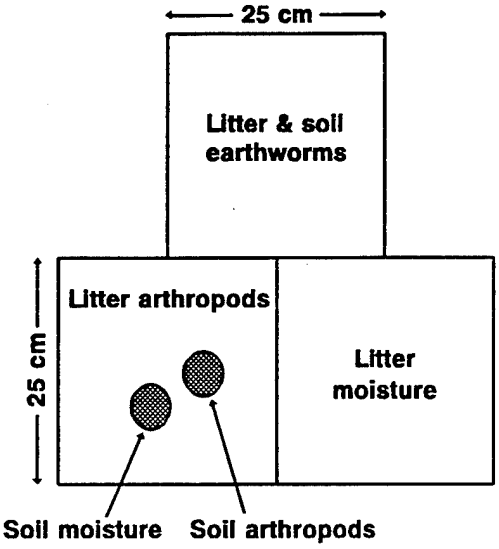


Fig. 2. General scheme for taking contiguous samples of earthworms (five vertical subsamples), arthropods, and litter and soil samples for moisture determination.

## 4. Statistical analyses:

Generally, data were divided into pre-ELF (through 1988, beginning year variable with work element) and operational (beginning in 1989, ending year variable) periods. All data sets were tested initially for homogeneity of variances (Bartlett's test), additivity (Tukey's test), and normality (Kolmogorow-Smirnov). Where appropriate, transformations were used (e.g., log transforms).

Those sets of data amenable to analysis were subjected to t-tests or Lohrding's q-test, or to ANOVA. In many cases BACI tests (Before and After Control and Impact) (Stewart-Oaten *et al.* 1986) proved the most meaningful for arriving at conclusions. In the case of earthworms, multiple regression procedures were used to test several response variables dealing with reproductive activity.

Due to the large number of results reported herein, we will not elaborate at this point, but include brief discussion of the statistical methods used in each of the major sections of this report. Data sets which could not be analysed, yet are important for understanding the subject matter, are included in descriptive form.

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## II. ENVIRONMENTAL MONITORING

### 1. Precipitation:

**Methods:** In an open area near each study site, rain gauges were mounted on poles, and were read and emptied at least once a week. Each year, they were brought out of winter storage and installed in the last days of April, and and records were obtained through the third or fourth week of October. To aid interpretation of results, 30-year means were obtained from the Crystal Falls Weather Station (Iron County, approx. 20 km distant) for comparison with site-specific data.

**Results:** General conclusions regarding rainfall are made possible by comparing overall season totals: precipitation through October, as well as through September only (because raingauges were dismantled at different times in October of each year) are listed in **Table 1.** The appropriate 30-year means (May through October and May through September) are included in **Table 1.** Years in which rainfall deficiencies occurred are easily recognizable (1986 in particular).

However, seasonal distribution patterns of rainfall yield a better appreciation of between-year differences (**Fig. 3**). In 1986, for instance, significant rains did not occur until late August and September, just as 1988 was characterized by subnormal rains in May, June and July. In 1985, rains were very unevenly distributed, being most ample in August and September. In contrast, rains were most ample in early- and mid-summer in 1987. Indeed, 1987 and 1990 were the two years in which monthly rainfall patterns came closest to the relatively evenly distributed 30-year averages (**Fig. 3**).

Although we do not show detailed Test and Control for each year individually, it was evident that major rainfall events were well synchronized between sites. Differences with respect to small localized rainfall events did occur occasionally, and contributed to differences in seasonal totals (**Table 1**).

**Table 1.** Precipitation totals (in mm) for May through October and May through September in Test (**T**) and Control (**C**) sites, 1984 through 1993, and 30-year average (**A**) totals for the same periods in the area at large (Crystal Falls Weather Station).

| | | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Total May thru Oct: | **T** | 457 | 524 | 362 | 535 | 457 | 434 | 477 | 475 | 400 | 487 |
| | **C** | 438 | 578 | 382 | 530 | 459 | 362 | 476 | 494 | 385 | 462 |
| | **A** | 514 | 514 | 514 | 514 | 514 | 514 | 514 | 514 | 514 | 514 |
| Total, May thru Sep: | **T** | 443 | 445 | 282 | 474 | 388 | 398 | 401 | 381 | 375 | 451 |
| | **C** | 417 | 500 | 304 | 465 | 377 | 330 | 399 | 415 | 356 | 419 |
| | **A** | 461 | 461 | 461 | 461 | 461 | 461 | 461 | 461 | 461 | 461 |

## 2. Temperature:

**Methods**: In a centrally located quadrat in each site, remote sensors and dataloggers were installed to record air and soil (soil surface, 5 cm and 15 cm depth) temperature at 1 or 2 hr intervals (one sensor per level). Because of repeated equipment malfunction, back-up data were obtained by periodic measurements with YSI telethermometers, and with chart-type

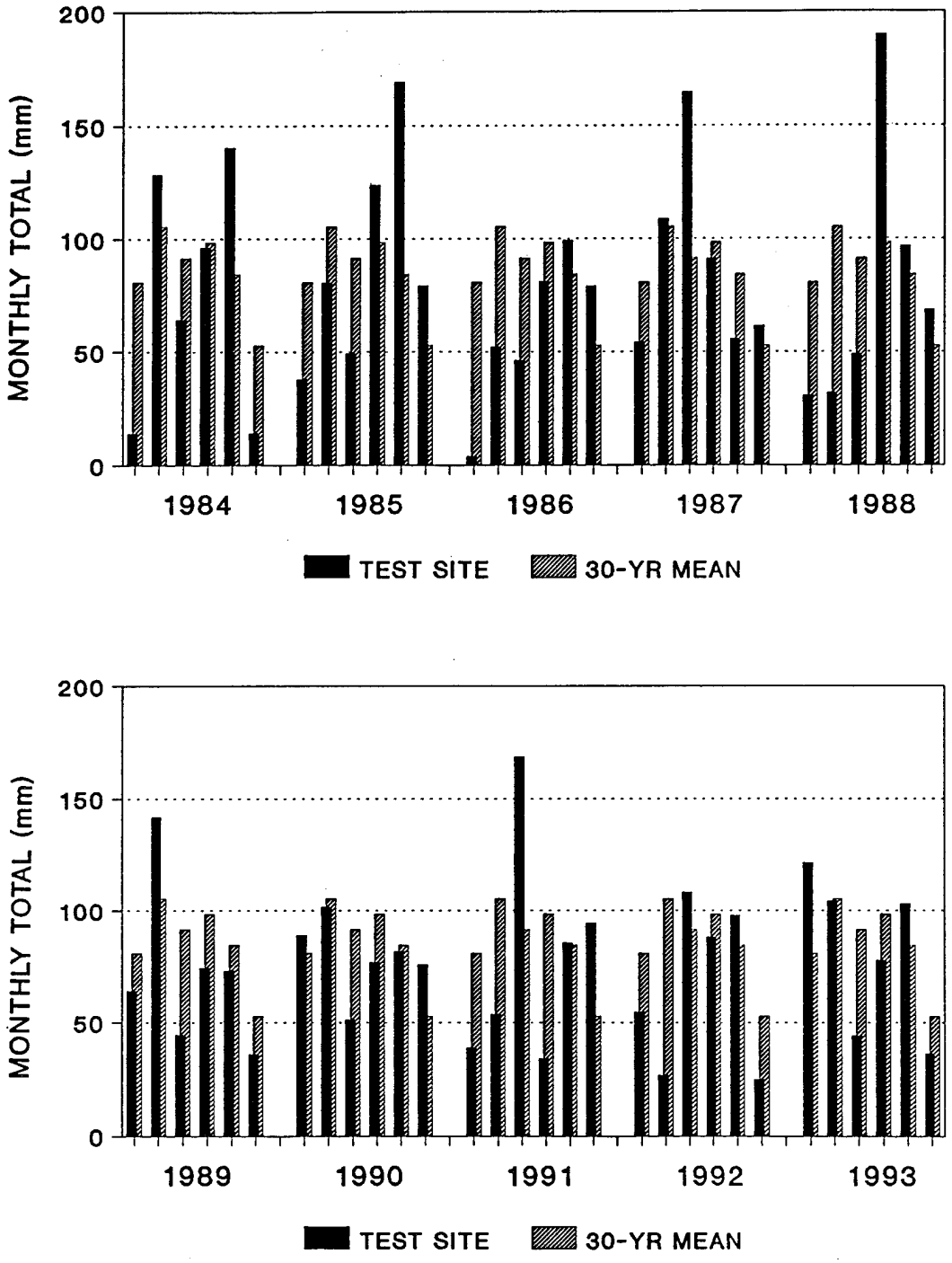


Fig. 3. Total monthly (May through October) precipitation in the Test site, and monthly 30-year means for the area at large (Crystal Falls Weather Station), 1984 through 1993.

hygrothermographs housed in equipment shelters. Finally, the systems were replaced in spring of 1993 with new sensors and multichannel recorders. In the A horizon (5 cm depth), three replicate sensors were buried in each site, so that accurate mean temperatures could be obtained.

**Results:** All available information indicated that temperatures in Test and Control were essentially identical. As examples, mean weekly temperatures at 5 cm depth in 1993 are illustrated in **Fig. 4**, and mean air temperatures for 1992 are shown in **Fig. 5**. Correlation coefficients between sites were invariably high ($R^2 \geq 0.94$). Therefore, a single set of temperature data, from either site if proven reliable, were used in analyses of faunal data whenever temperature effects were needed for interpretation of results.

Among the 10 years of study, 1992 stood out as one of the coolest: compared to 1991 for instance, weekly air and A horizon temperatures were frequently $>5\ ^{o}C$ lower (**Figs. 6-7**). The specific form of temperature data used in analyses (e.g., daily, weekly or bi-weekly means) will be described in the pertinent subsequent sections of this report. A year-specific summary of weekly temperature means at 5 cm depth is provided in **Appendix 2.**

**3. Litter and soil moisture:**

**Methods:** Samples of A and B horizon soil (approx. 150 ml) were taken at the time of faunal sampling (20 samples /date /site, at intervals of 2 weeks from early May to October), weighed, air-dried, and re-weighed. Root masses and gravel were removed before enclosing these samples in screw-top jars in the field. Litter samples (N = 20) were taken from a 1/16 $m^2$ area of the forest floor, woody debris being eliminated at the time of sampling. They were weighed, oven-dried at 60 $^{o}C$, and re-weighed. Moisture was calculated as percent of dry weight.

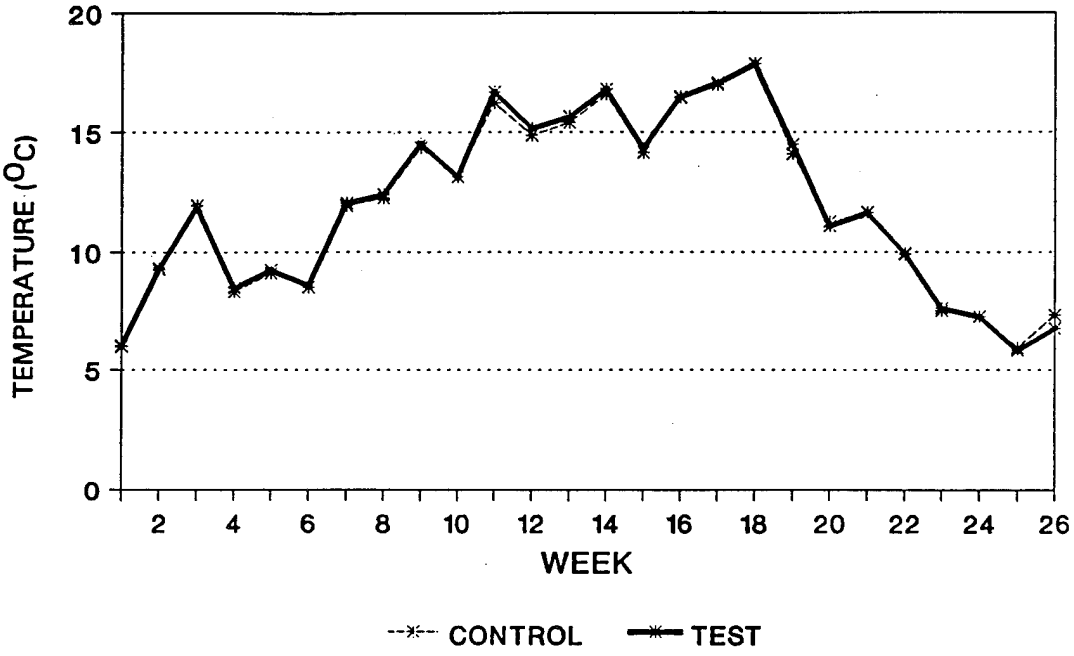


Fig. 4. Mean weekly soil temperature (5 cm depth) in Test and Control, 1993 (week 1 beginning on May 1; data derived from three replicate sensors per site).

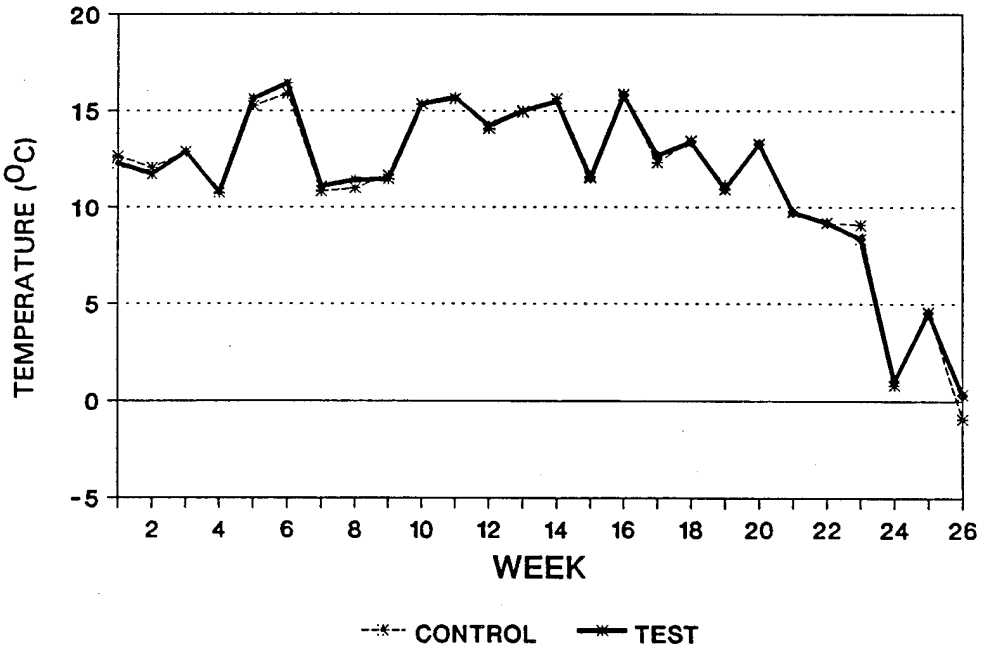


Fig. 5. Mean weekly air temperatures in Test and Control, 1992 (week 1 beginning on May 1).

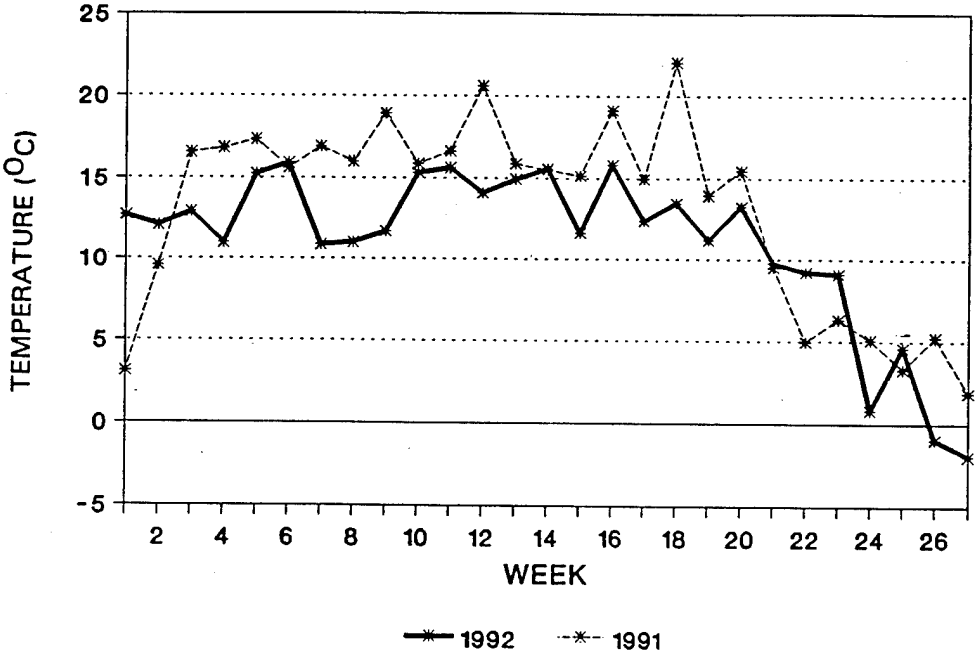


Fig. 6. Average weekly air temperatures in Control, 1991 vs. 1992 (week 1 beginning on May 1 of each year).

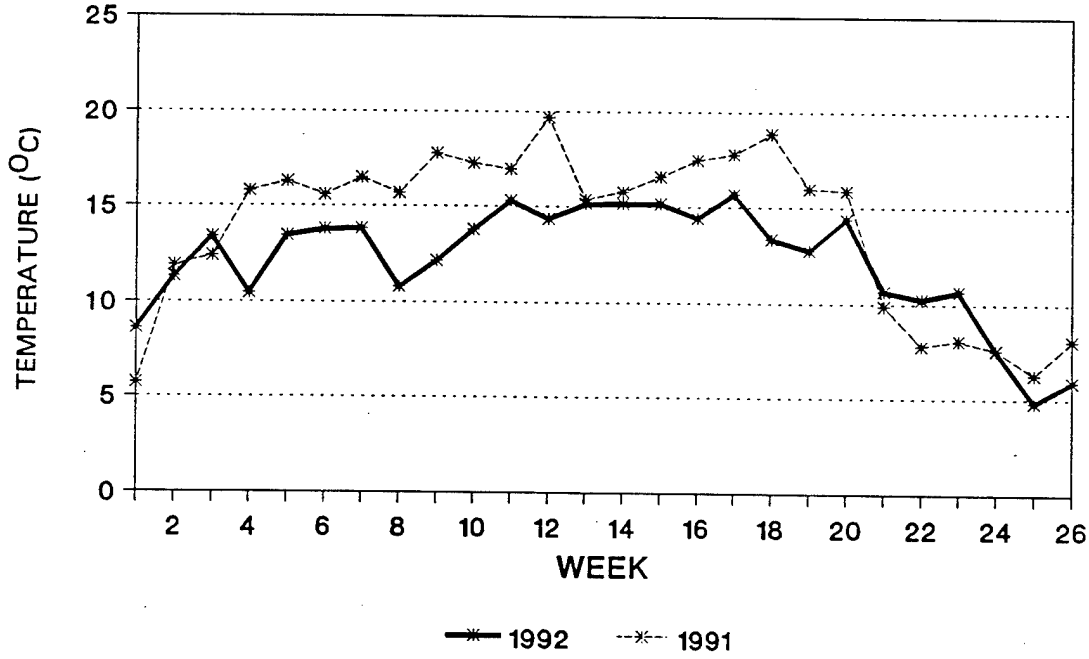


Fig. 7. Average weekly temperature of the A horizon at 5 cm depth in the Test site, 1991 vs. 1992 (week 1 beginning on May 1 of each year).

**Results:** Moisture estimates for litter, A and B horizons are illustrated for all years in **Appendix 3.** As an example of between-site comparisons, 1993 data are shown in **Fig. 8.** Much as in other years, moisture fluctuations were well correlated between sites, soil moisture was depressed in mid-season, and A horizon moisture tended to be somewhat higher in Control than in Test.

Between-year variations are illustrated by means of 1987, 1988 and 1990 data (**Fig. 9**). Both 1987 and 1990 were "moist" years, while 1988 was a drought year during which A horizon moisture repeatedly fell to « 20%.

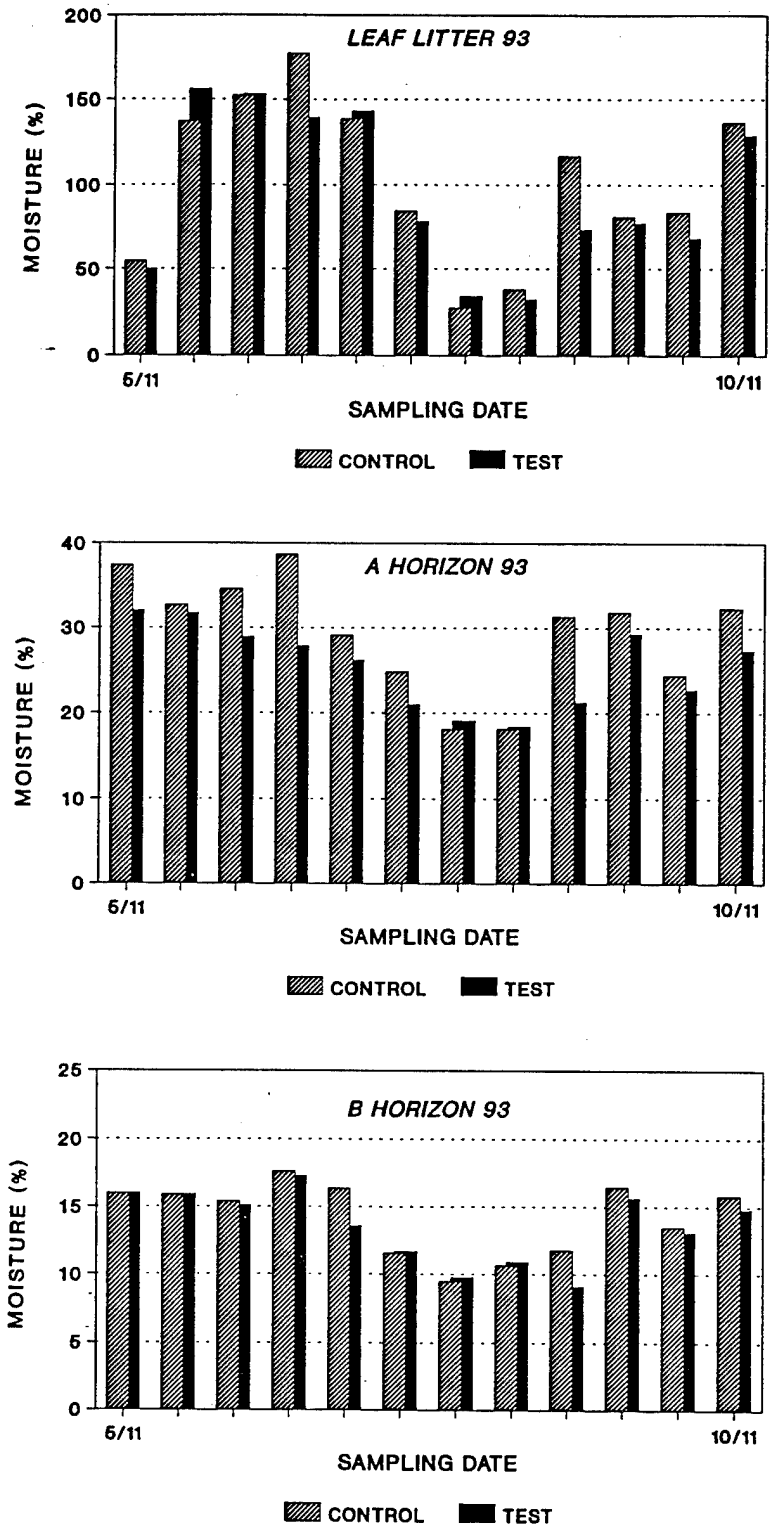


Fig. 8. Mean litter and soil moisture in Test and Control sites at biweekly intervals, 1993.

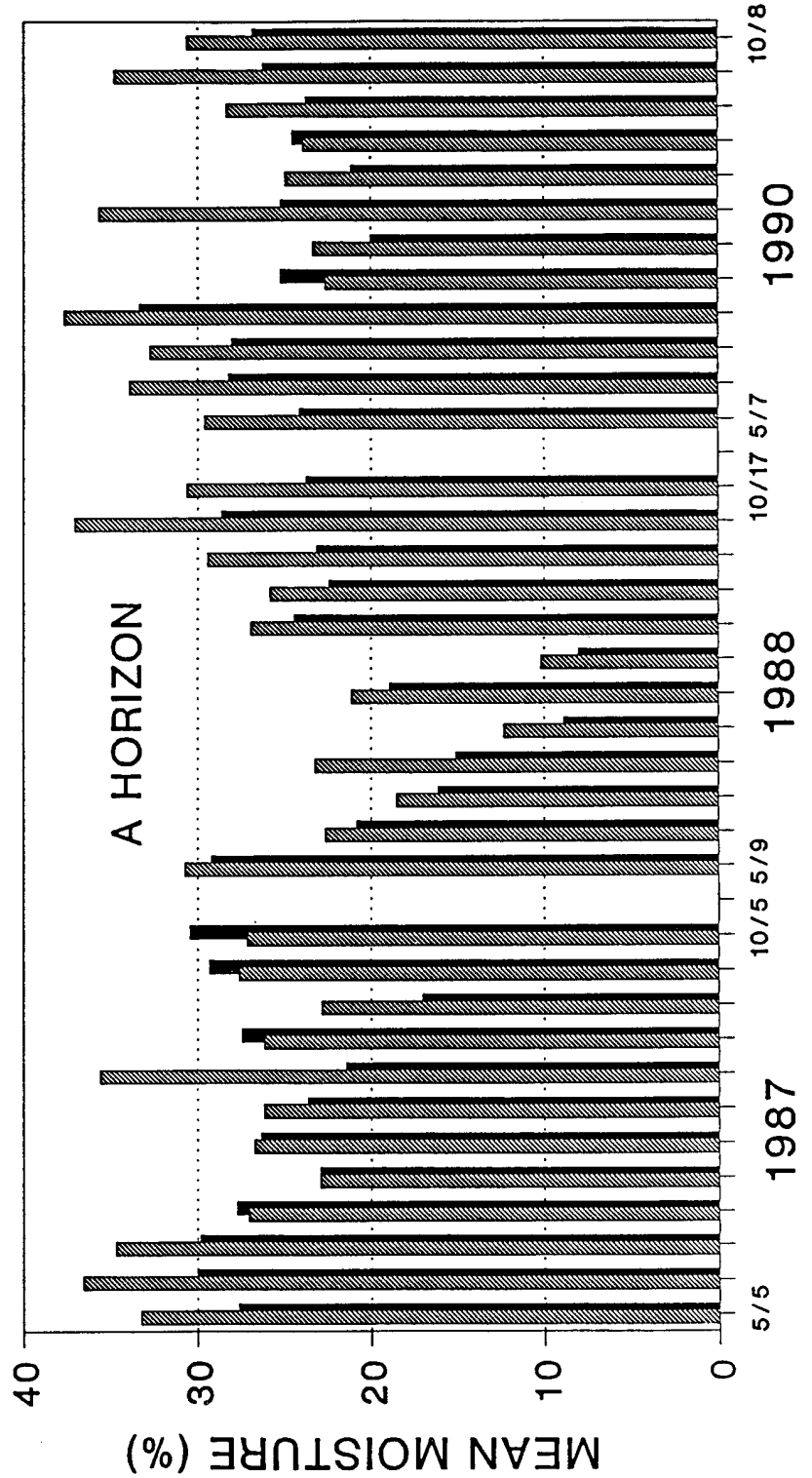


Fig. 9. Mean moisture of the A horizon on each biweekly sampling date in 1987, 1988 and 1990, in Test and Control sites.

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## III. SOIL AND LITTER ARTHROPODA

### A. METHODS

Soil samples were taken with a corer, 5 cm diameter, to a depth of 15 cm. Litter samples were cut with a sharp knife along the inside periphery of a 25 x 25 cm metal frame. All samples were transported in coolers, and animals were extracted in Tullgren funnels and collected in 95% alcohol. Ten samples /date /site (all stemming from even-numbered quadrats) were thus obtained. Sampling dates /year numbered either 12 or 13, depending on weather conditions late in the season.

In 1984 and 1985, soil samples received no further treatment. Beginning in 1986, soil samples were taken off the funnels after heat-extraction, and were individually floated in saturated sugar solution. The procedure was repeated twice, all supernatant being scooped off and rinsed and preserved in 95% alcohol. For many (though not all) taxa, data are only reliable from 1986 onward, when specimens obtained by sugar floatation could be added to those obtained by heat extraction.

It was necessary to limit taxonomic identification and data analyses to those for which expertise was available and/or those which occurred fairly frequently in both study sites: in the case of Collembola, all were identified to species level; in the case of Acarina, a few taxa were selected which were readily identifiable (including their immature stages), even if the species had not yet been described and named.

One species of Collembola, *Isotoma notabilis*, was selected for analysis of population structure. Body length of specimens obtained by heat extraction of soil and litter samples was

recorded, allowing division of the populations into developmental classes (first instars, other juveniles, and adults). Class limits were established by rearing the species in the laboratory. In questionable specimens, size measurements were supplemented by chaetotaxy observations, e.g., presence or absence of a genital plate to distinguish between large juveniles and adults.

## B. RESULTS

### 1. Efficiency of heat extraction of soil cores:

For a few of the major soil-inhabiting taxa, extraction efficiency is summarized in **Table 2.** Some taxa were always poorly extracted by heat (e.g., Onychiuridae in general and the mesostigmatid sp. A), others were consistently obtained with relatively high efficiency (e.g., *Nanorchestes* sp. A).

In almost all cases, data for 1984 and 1985 were excluded from analyses. Correction factors (based on 1986-1992 data) would have had to be applied to single sample data. However, not only did efficiencies vary between dates (**Table 3**), but they also varied greatly between single samples (an example is given in **Table 4**). A posteriori "correction" was liable to introduce a large amount of artificial error.

### 2. Collembolan populations

#### 2.1. Annual fluctuations

A checklist of all species obtained during the project period is given in **Appendix 4.** Estimated mean annual densities per $m^2$, for all taxa inhabiting litter and soil, are listed in **Appendix 5.** In virtually all species, as well as at the family level, major density fluctuations were observed

in both sites. Between-year differences were often attributable to numbers of one or a few species within a given family: e.g., *Willemia* spp. and *Anurida furcifera* among Control Hypogastruridae; or *Orchesella hexfasciata* and *Pseudosinella violenta* among Test Entomobryidae (**Appendix 5**). Onychiuridae (with *Tullbergia mala* and *T. granulata* its most abundant members) strongly dominated both communities. In general, total collembolan abundance in the Control site tended to be at least twice that in the Test site.

**Table 2.** Mean annual efficiency of heat extraction of soil cores for selected arthropods : values are given as percent [(N individuals obtained by heat extraction) / (N total obtained by heat and floatation)] x 100. T = Test, C = Control.

| | | PERCENT EXTRACTED BY HEAT | | | | | | |
|---|---|---|---|---|---|---|---|---|
| YEAR | | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 |
| ACARINA | | | | | | | | |
| *Nanorchestes* sp. A | T | 100 | 80.1 | 92.3 | 91.5 | 94.2 | 87.2 | 100 |
| | C | 94.9 | 84.4 | 97.8 | 98.4 | 94.1 | 98.7 | 100 |
| Mesostigmata sp. A | T | 36.9 | 23.9 | 38.9 | 27.5 | 42.1 | 20.9 | 18.9 |
| | C | 25.6 | 32.4 | 40.3 | 40.6 | 34.8 | 27.7 | 14.4 |
| COLLEMBOLA | | | | | | | | |
| *Tullbergia mala* | T | 27.8 | 25.2 | 15.1 | 11.1 | 27.2 | 12.2 | 9.1 |
| | C | 23.4 | 11.9 | 7.3 | 10.1 | 9.1 | 8.6 | 7.7 |
| *T. granulata* | T | 29.2 | 19.8 | 20.4 | 11.1 | 19.5 | 16.2 | 4.8 |
| | C | 28.5 | 12.1 | 7.5 | 19.7 | 12.8 | 13.9 | 7.8 |
| *Isotoma notabilis* | T | 92.4 | 90.4 | 90.7 | 84.5 | 94.6 | 78.1 | 72.7 |
| | C | 94.2 | 87.5 | 90.2 | 90.1 | 91.6 | 93.9 | 71.1 |
| *Isotomiella minor* | T | 43.8 | 44.3 | 30.3 | 34.3 | 29.7 | 15.7 | 2.1 |
| | C | 50.7 | 28.6 | 22.9 | 48.3 | 33.3 | 29.3 | 19.6 |
| Total Onychiuridae | T | 31.6 | 24.1 | 18.1 | 12.8 | 20.3 | 16.5 | 6.6 |
| | C | 24.5 | 12.1 | 7.3 | 12.6 | 13.1 | 13.1 | 4.4 |
| Total Isotomidae | T | 77.1 | 78.3 | 80.3 | 70.1 | 78.7 | 56.8 | 51.4 |
| | C | 84.8 | 71.2 | 68.9 | 74.1 | 64.6 | 66.1 | 48.9 |

**Table 3.** Example of date-specific heat extraction efficiencies: *Tullbergia mala* in Control, dates 1 through 13 (early May to late October), 1986. N Heat = number of individuals extracted by heat; N Float = number obtained by sugar floatation; % Effic = percent of total number extracted by heat.

TOTAL NUMBER OF INDIVIDUALS /DATE

| DATE | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N Heat | 78 | 173 | 75 | 212 | 97 | 83 | 35 | 38 | 22 | 138 | 50 | 67 | 23 |
| N Float | 254 | 209 | 382 | 336 | 281 | 130 | 410 | 203 | 196 | 241 | 322 | 260 | 331 |
| % Effic | 23.5 | 45.3 | 16.4 | 38.7 | 25.7 | 39.0 | 7.9 | 15.8 | 10.1 | 36.4 | 13.4 | 20.5 | 6.5 |

**Table 4.** Examples of sample-specific heat extraction efficiencies: *Tullbergia mala* from the Control site, May 5 and 19, 1986. Abbreviations as in Table 3.

TOTAL NUMBER OF INDIVIDUALS /SAMPLE

| SAMPLE NO. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| May 5, 86: | | | | | | | | | | | |
| N Heat | 9 | 0 | 0 | 0 | 7 | 8 | 0 | 1 | 3 | 50 | 78 |
| N Float | 15 | 10 | 3 | 6 | 17 | 28 | 16 | 12 | 90 | 57 | 254 |
| % Effic | 37.5 | 0.0 | 0.0 | 0.0 | 29.2 | 22.2 | 0.0 | 7.7 | 3.2 | 46.7 | 23.5 |
| May 19, 86: | | | | | | | | | | | |
| N Heat | 9 | 4 | 34 | 18 | 37 | 19 | 3 | 1 | 34 | 14 | 173 |
| N Float | 2 | 0 | 5 | 20 | 3 | 11 | 7 | 5 | 147 | 9 | 209 |
| % Effic | 81.8 | 100 | 87.2 | 47.4 | 92.5 | 63.3 | 30.0 | 16.7 | 18.8 | 60.9 | 45.3 |

Examples of year-to-year numerical fluctuations are illustrated below for some of the common collembolan taxa.

The dominant litter-dwelling family, Isotomidae, was consistently more prevalent in Control than in Test, although Test populations experienced considerable increases in 1989 and 1990 (**Fig. 10**). Annual fluctuations were determined entirely by the single dominant, *Isotoma notabilis*, to the extent that family means precisely reflected *I. notabilis* means (**Fig. 11**).

Sminthuridae were also more abundant in Control than in Test during all pre-ELF years (**Fig. 12**). In 1989 and 1990, essentially equal numbers were obtained in both sites, followed by a return to pre-ELF Test/Control relationships. In 1992, abundance was somewhat reduced in both sites. To a large extent, annual fluctuations at the family level were determined by fluctuating numbers of the single dominant, *Sminthurinus henshawi* (**Fig. 13**).

Litter-dwelling Entomobryidae (**Fig. 14**) showed a striking pattern reversal in 1988. Much more abundant in Test through 1987, family means in 1988-1990 were higher in Control. Although this pattern reversal appeared to be similar to that of *Orchesella hexfasciata* (**Fig. 15**), other species contributed significantly to it. In 1988, for instance, high numbers of entomobryids in Control were due mainly to unprecedented numbers of *Entomobrya comparata*, which contributed 80% to the family total (a trend which persisted, to a lesser extent, through 1990). On the other hand, reduced total numbers in Test (**Fig. 14**) were attributable to decreases in two species: *O. hexfasciata* (**Fig. 15**) and *E. comparata* (decreases which persisted, in variable degrees, through 1992).

The only non-onychiurid collembolan regularly extracted from soil samples was the hemiedaphic *Isotoma notabilis* (**Fig. 16**). Populations were intitially higher in Control, and

declined drastically in both sites in 1988 (a severe drought year). From 1990 to 1992, however, numbers in Test exceeded those in Control. Mean annual density of the species, based on summed densities in litter and soil (**Appendix 5**) also shows that overall abundance in Control was below that in Test during 1990-92, unlike any of the preceding years.

The strictly euedaphic Onychiuridae were found to fluctuate considerably between years, particularly in Control (**Fig. 17**). The most abundant component species, *Tullbergia mala* and *T. granulata* (**Figs. 18-19**) contributed significantly to family fluctuations, particularly *T. mala* in Control (**Fig. 18**).

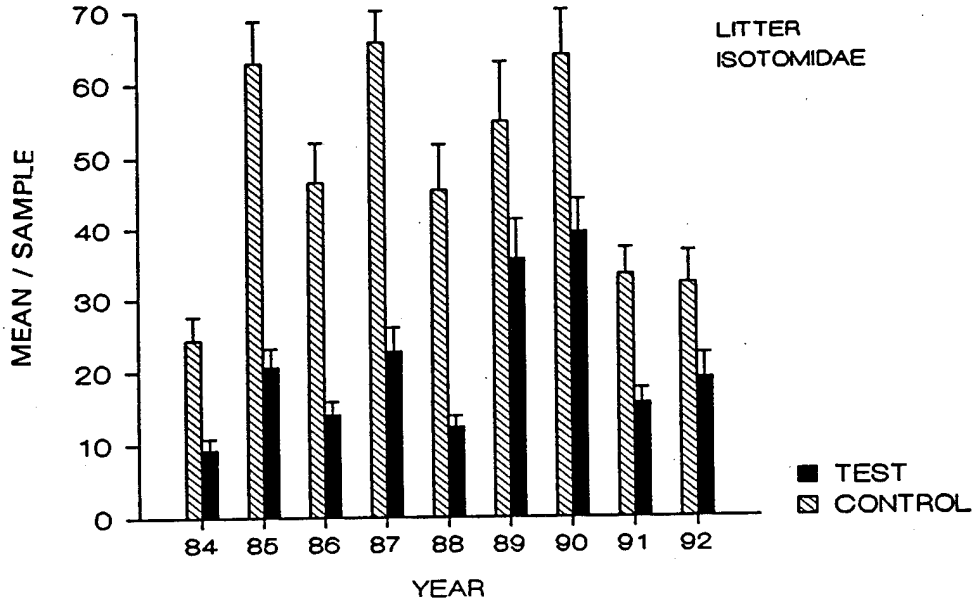


Fig. 10. Mean annual number of Isotomidae extracted from leaf litter samples (means /sample ± SE, N = 120 or 130 samples per year) in Test and Control sites.

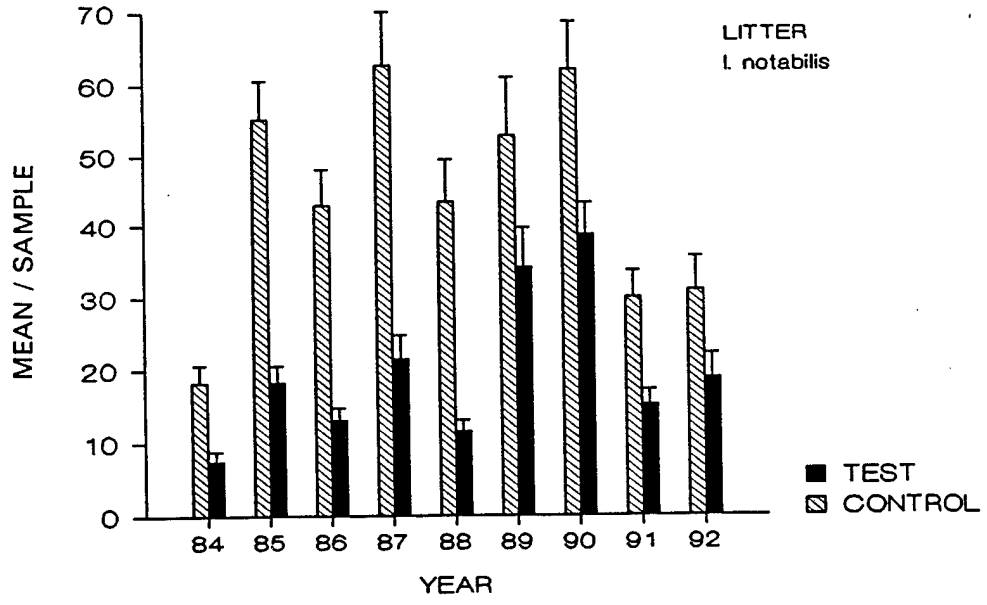


Fig. 11. Mean annual number of *Isotoma notabilis* extracted from leaf litter samples (means /sample ± SE, N = 120 or 130 samples per year) in Test and Control sites.

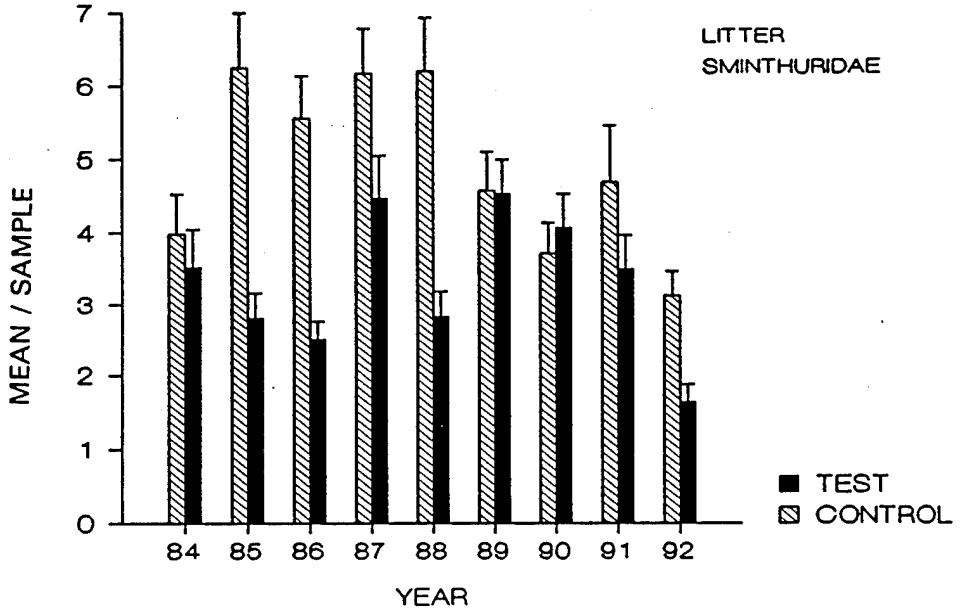


Fig. 12. Mean annual number of Sminthuridae extracted from leaf litter in Test and Control (means /sample ± SE, N = 120 or 130 samples per year).

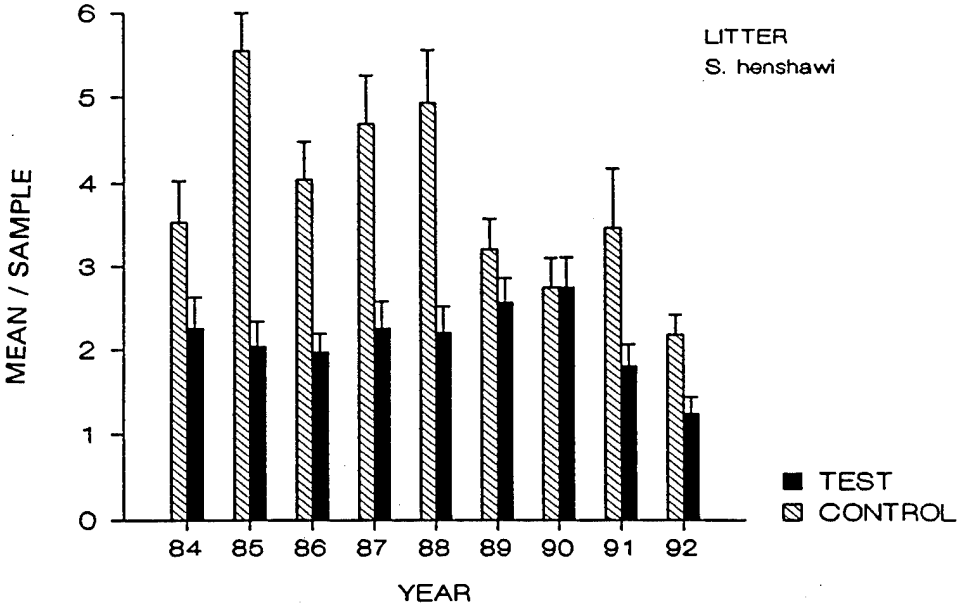


Fig. 13. Mean annual number of *Sminthurinus henshawi* extracted from leaf litter in Test and Control (means /sample ± SE, N = 120 or 130 samples per year).

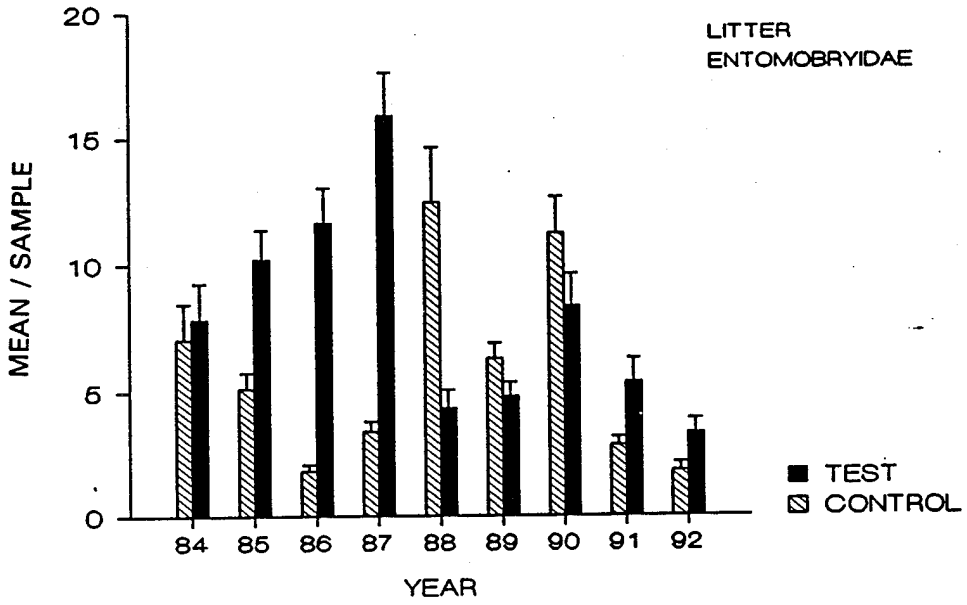


Fig. 14. Mean annual number of Entomobryidae extracted from leaf litter samples in Test and Control (means /sample ± SE, N = 120 or 130 samples per year).

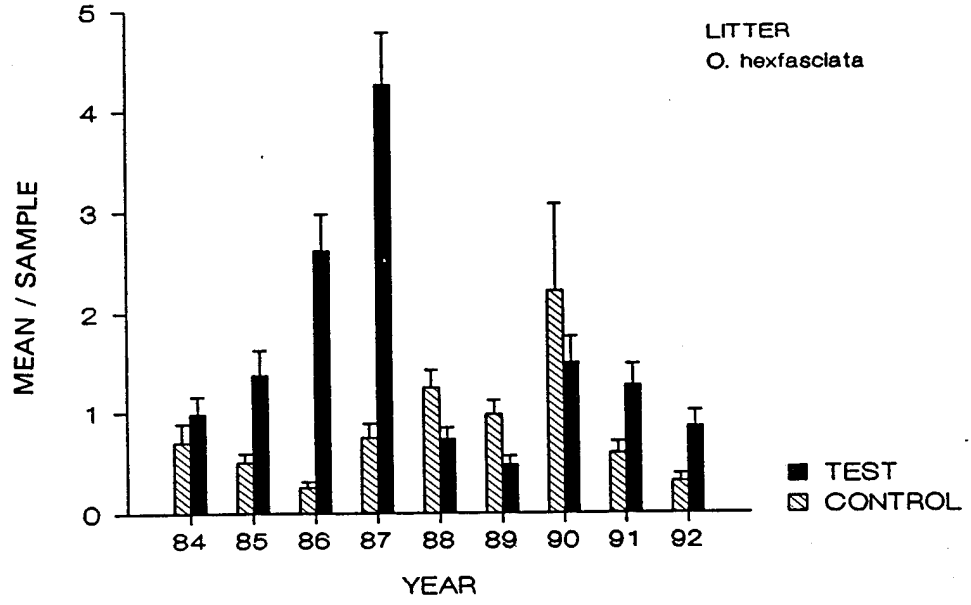


Fig. 15. Mean annual number of *Orchesella hexfasciata* extracted from leaf litter in Test and Control (means /sample ± SE, N = 120 or 130 samples per year).

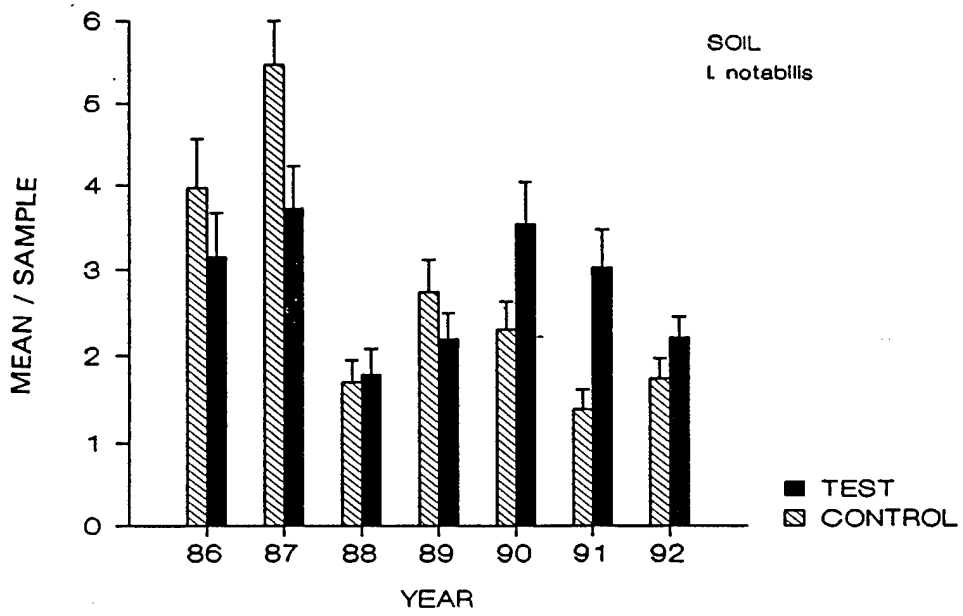


Fig. 16. Mean annual number of *Isotoma notabilis* obtained from Test and Control soil samples (means /sample ± SE, N = 120 or 130 per year).

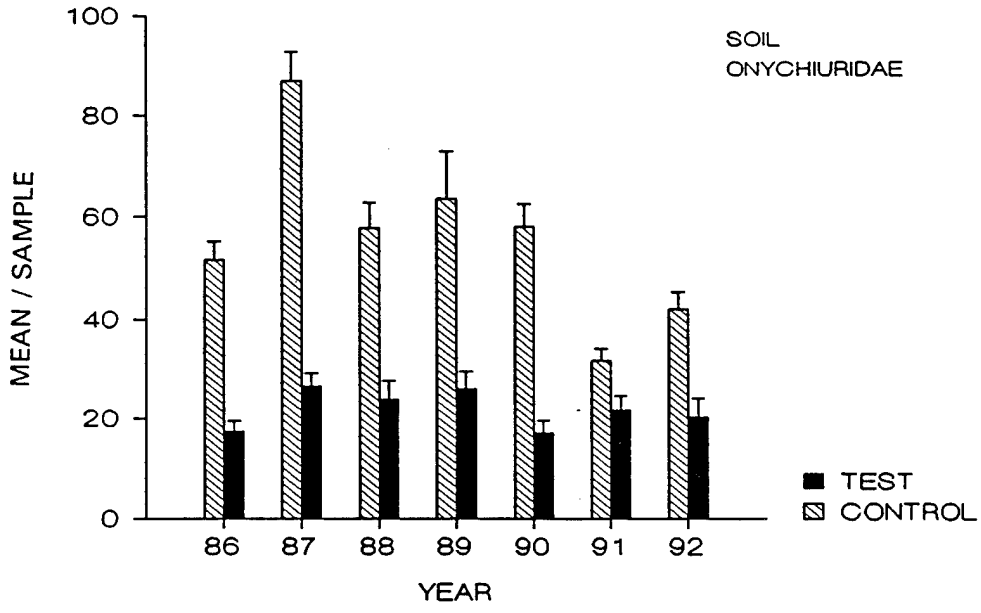


Fig. 17. Mean annual number of Onychiuridae extracted from Test and Control soil samples (means /sample ± SE, N = 120 or 130 per year).

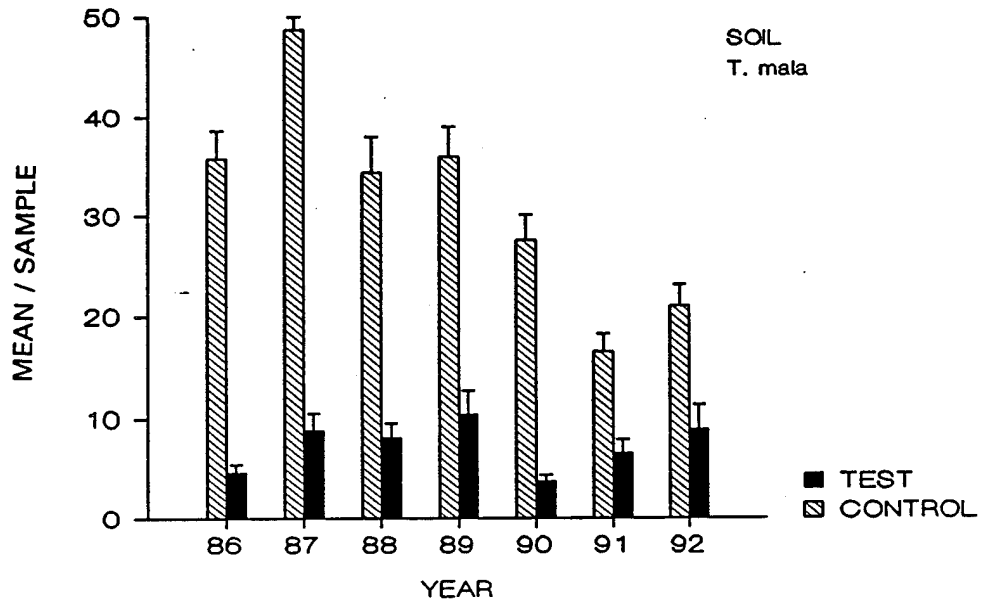


Fig. 18. Mean annual number of *Tullbergia mala* extracted from Test and Control soil samples (means /sample ± SE, N = 120 or 130 per year).

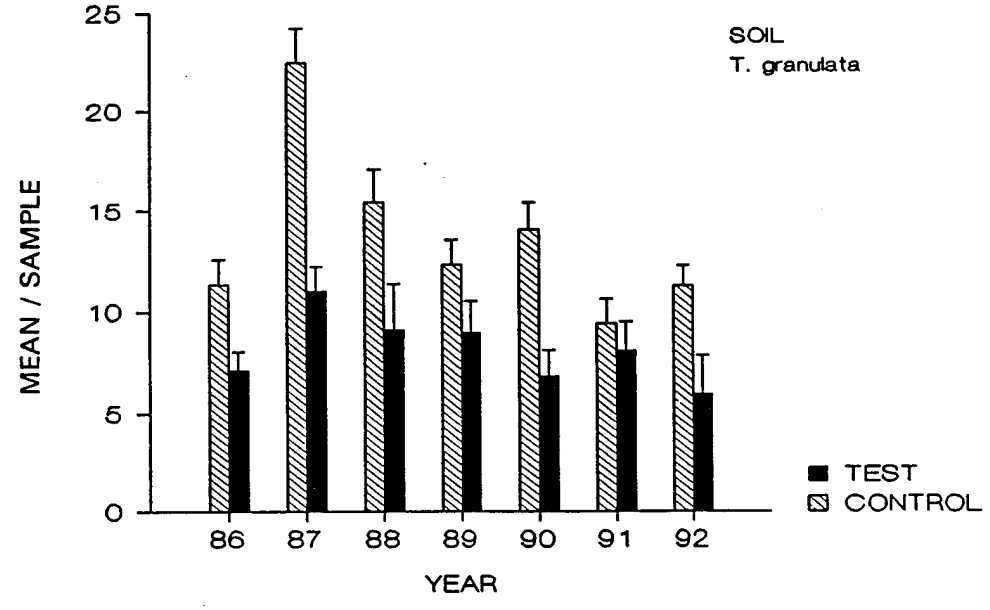


Fig. 19. Mean annual number of *Tullbergia granulata* extracted from Test and Control soil samples (means /sample ± SE, N = 120 or 130 per year).

## 2.2. Seasonal fluctuations

Biweekly numbers of total Collembola present in leaf litter (**Fig. 20**) were well correlated between Test and Control, mainly because synchronous litter moisture fluctuations (**Fig. 8** and **Appendix 3**), was a major determinant of abundance of litter-dwelling Collembola.

Entomobryidae were selected as an example of seasonal variation at the family level, allowing us to point out potential difficulties in comparing sites at taxonomic levels above that of species. Total entomobryids in Control exceeded those in Test in 1988, 1989 and 1990 (**Fig. 21**). Biweekly numerical changes in Control were mainly due to one species, *Entomobrya comparata* (**Fig. 22**), which dominated the family during those three years (**Appendix 5**). In Test, several species contributed to seasonal and yearly fluctuations: *E. comparata* to a small extent, *Orchesella hexfasciata* to an appreciable degree in 1986 and 1987 (**Fig. 23**), and *Pseudosinella violenta*, dominant in Test, but very rare in Control (**Appendix 5**).

At the species level, it was obvious that large fluctuations over time were the rule. *Entomobrya comparata* (**Fig. 22**) and *O. hexfasciata* have already been mentioned above. Data for *I. notabilis* and *S. henshawi* indicated that biweekly abundance estimates were well synchronized between sites (**Figs. 24-25**). *Tomocerus flavescens*, obtained mainly from the Test site (**Fig. 26**) was least abundant in 1988, 1989 and 1992.

Fluctuations in numbers of Collembola obtained from soil samples were not as well synchronized as those from leaf litter. Total Collembola (**Fig. 27**), as expected, were strongly influenced by numbers of Onychiuridae (**Fig. 28**), which in turn were determined mainly by seasonal abundance of *Tullbergia mala* (**Fig. 29**). *Tullbergia granulata* (**Fig. 30**) and to a lesser degree Isotomidae (**Fig. 31**) also influenced soil collembolan fluctuations.

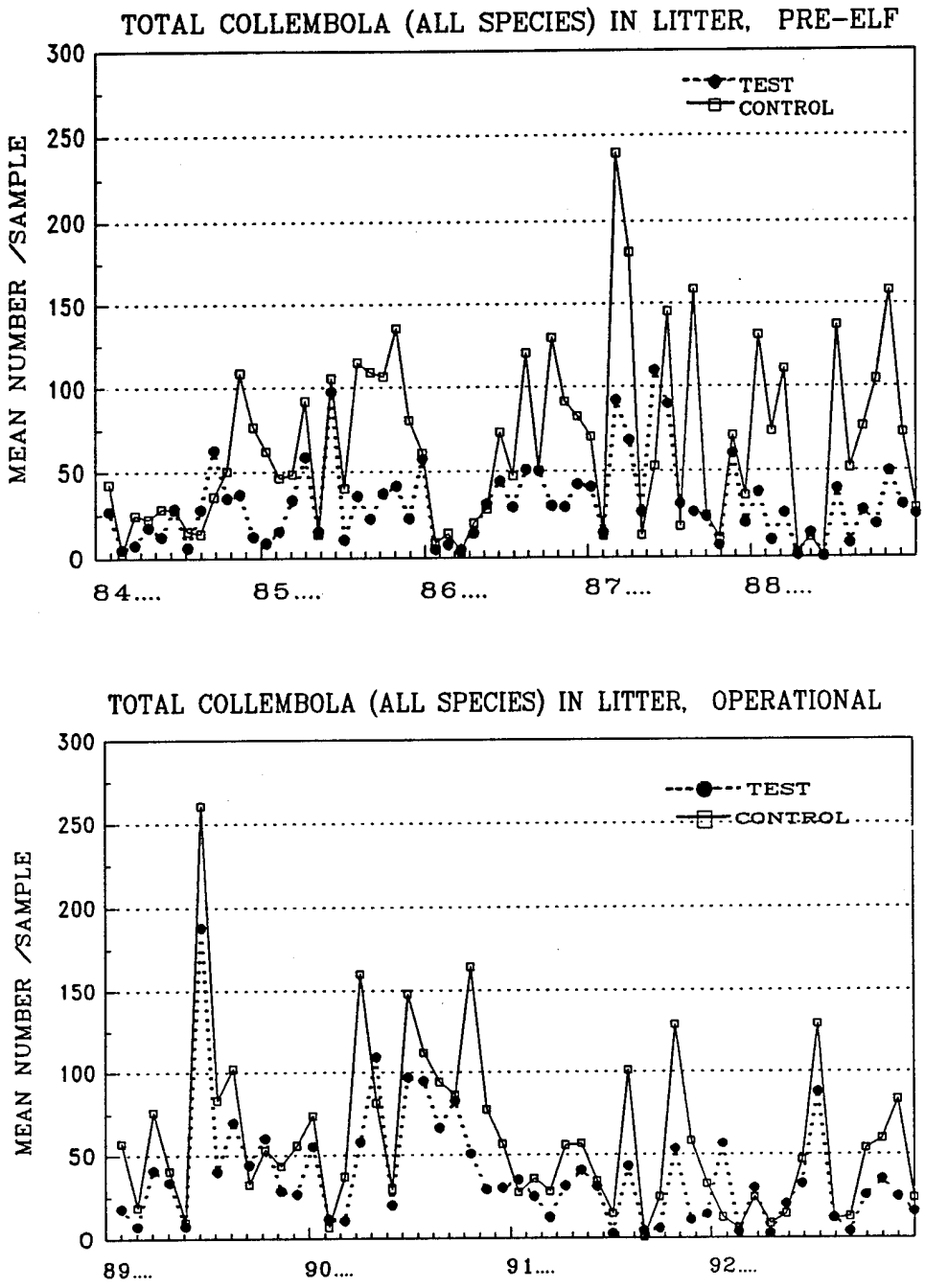


Fig. 20. Mean number of Collembola (all species combined) extracted from leaf litter samples (N=10 samples /site /date) during pre-ELF and operational years.

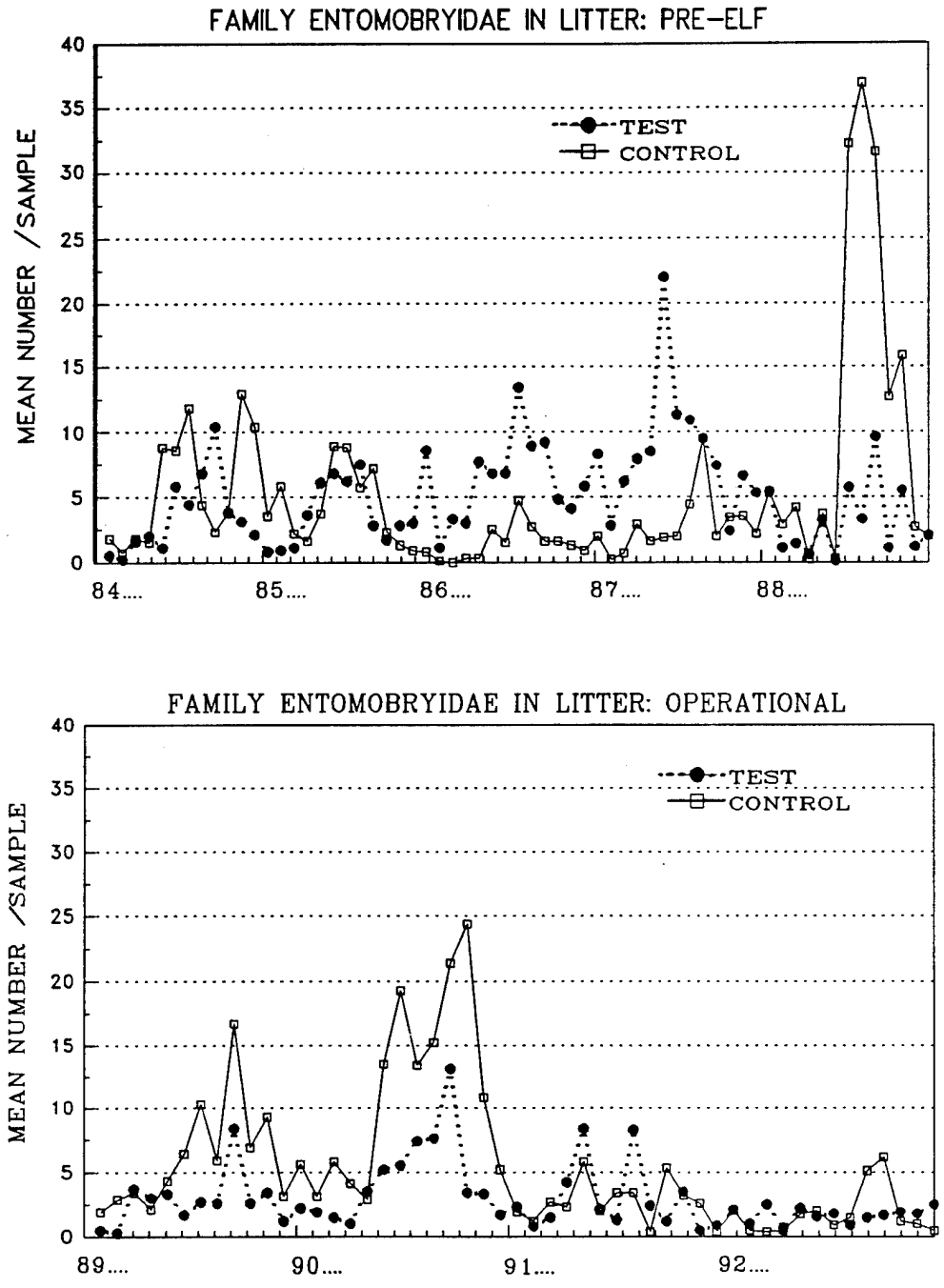


Fig. 21. Mean number of Entomobryidae extracted from leaf litter samples (N=10 samples /site /date) during pre-ELF and operational years.

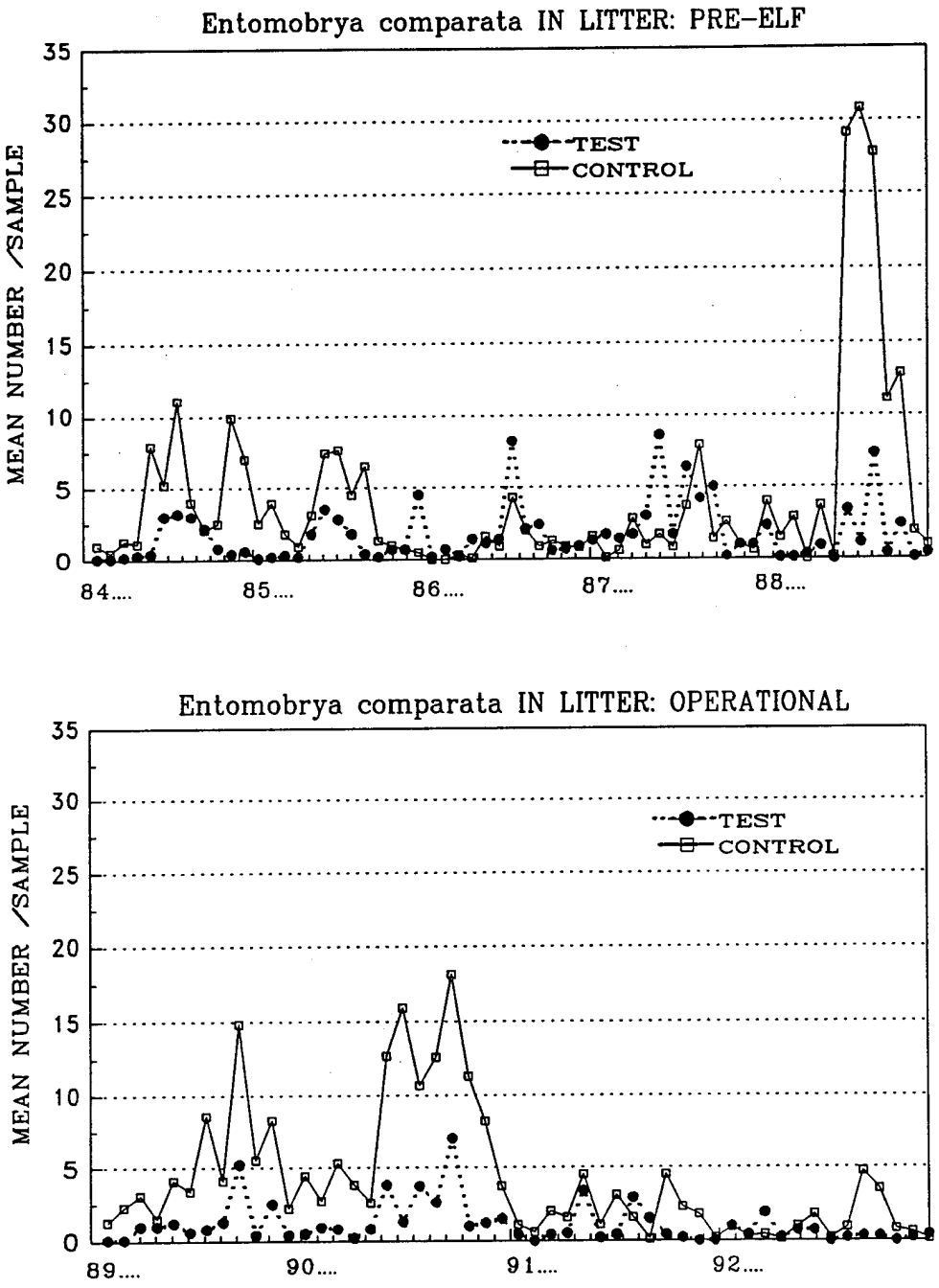


Fig. 22. Mean number of *Entomobrya comparata* in leaf litter (N=10 samples /site /date) during pre-ELF and operational years.

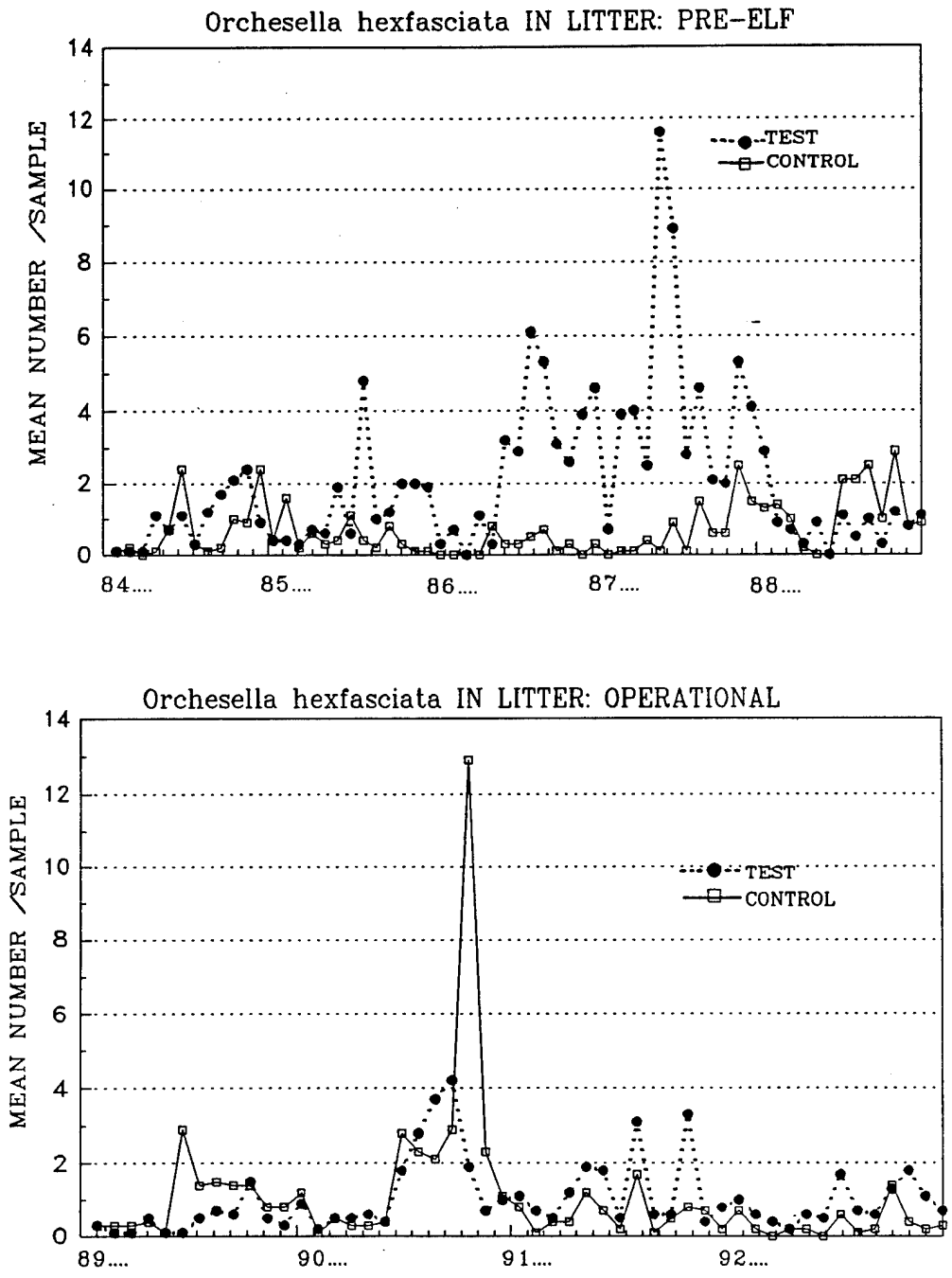


Fig. 23. Mean number of *Orchesella hexfasciata* in leaf litter (N=10 samples /site /date) during pre-ELF and operational years.

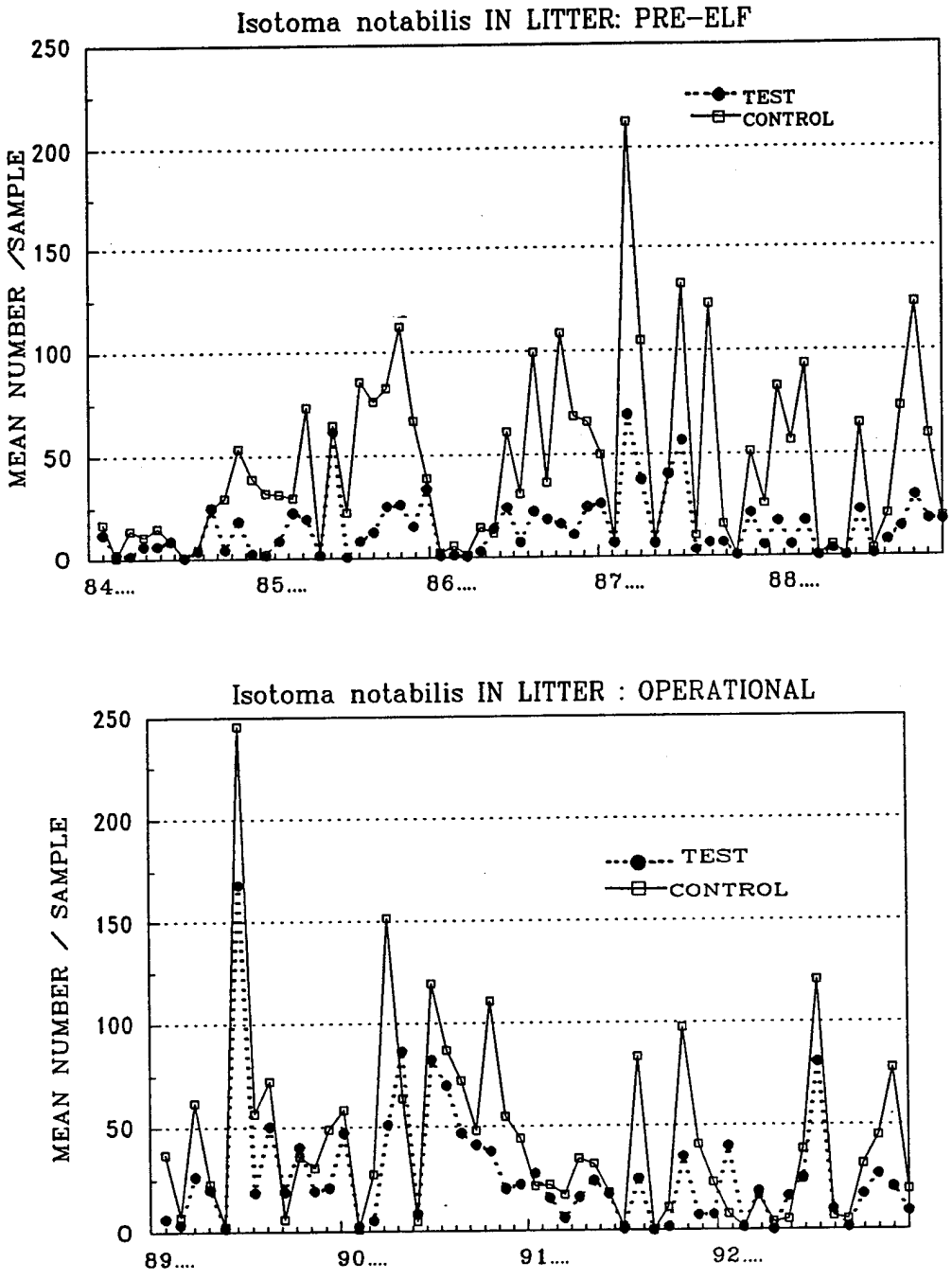


Fig. 24. Mean number of *Isotoma notabilis* in leaf litter (N=10 samples /site /date) during pre-ELF and operational years.

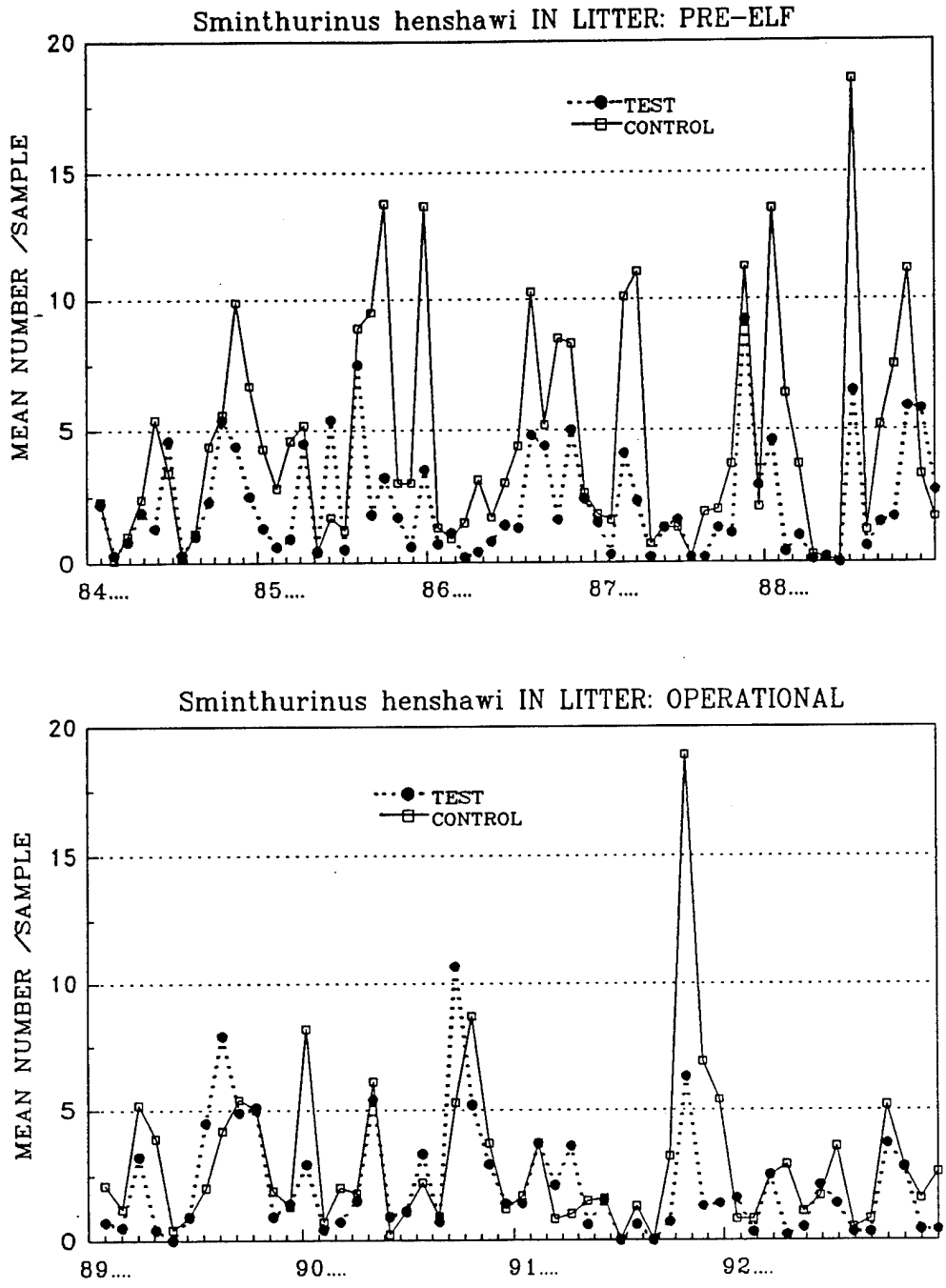


Fig. 25. Mean number of *Sminthurinus henshawi* in leaf litter (N=10 samples /site /date) during pre-ELF and operational years.

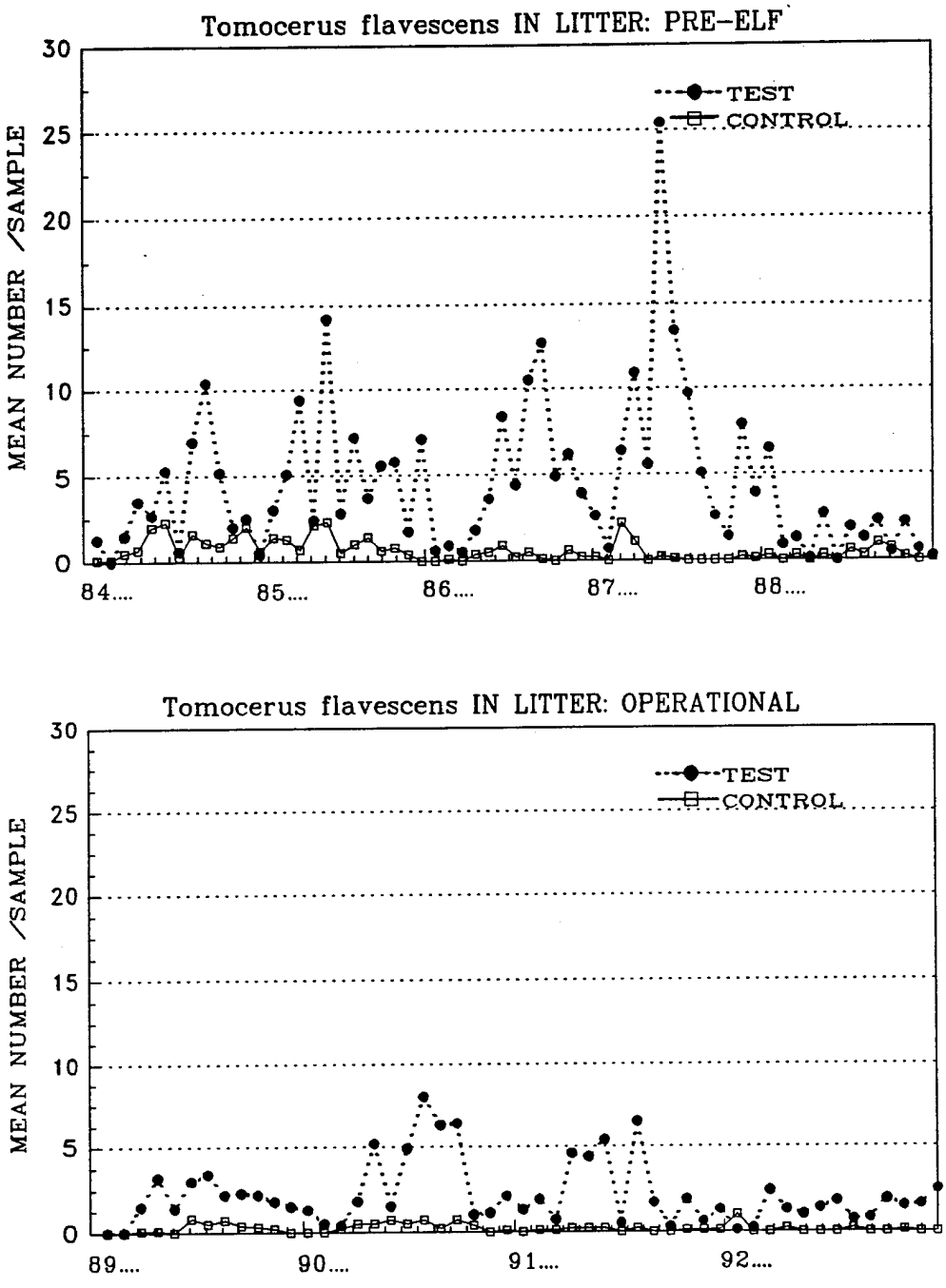


Fig. 26. Mean number of *Tomocerus flavescens* in leaf litter (N=10 samples /site /date) during pre-ELF and operational years.

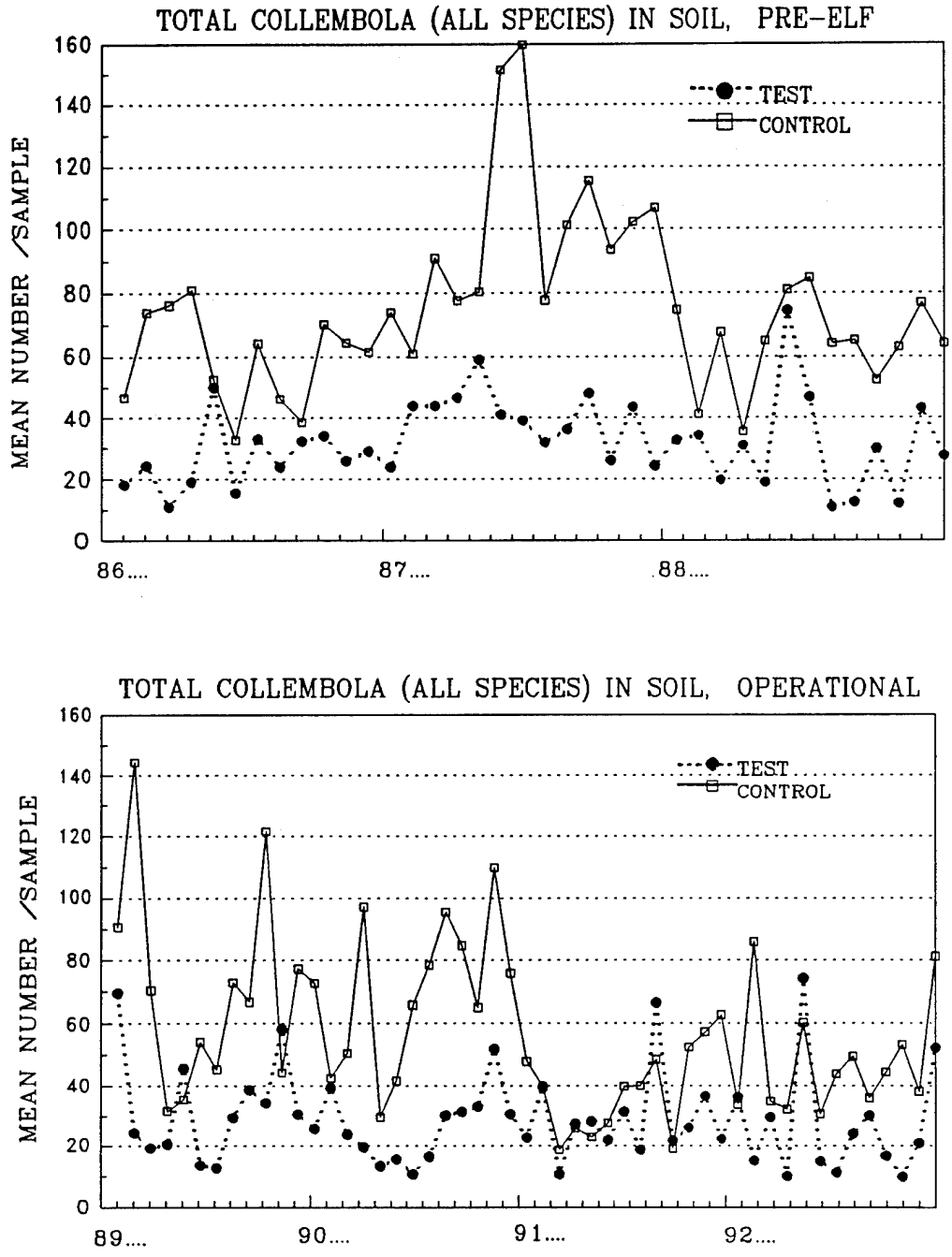


Fig. 27. Mean number of Collembola (all species combined) extracted from soil cores (N= 10 samples / site /date) during pre-ELF and operational years.

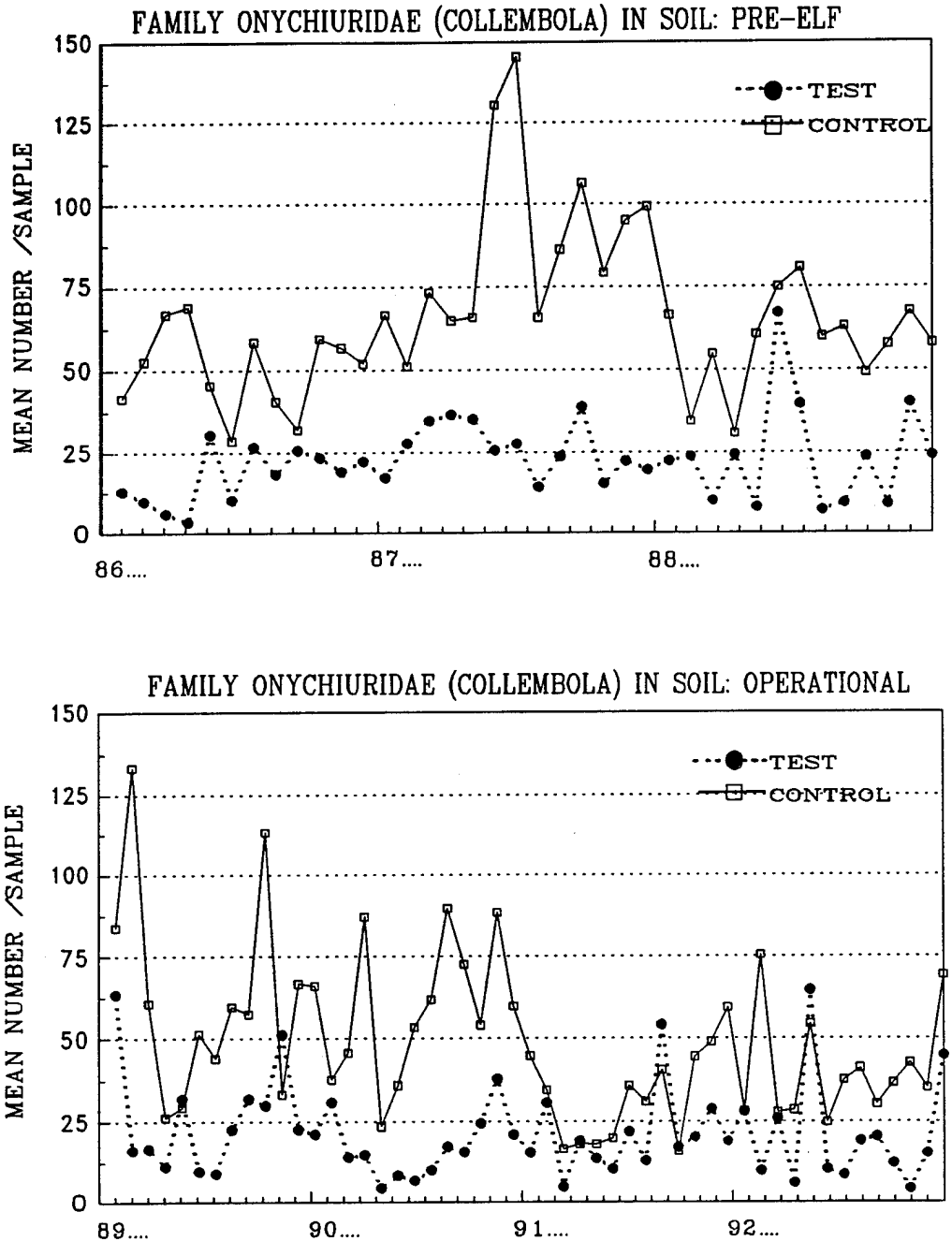


Fig. 28. Mean number of Onychiuridae extracted from soil cores (N= 10 samples /site /date) during pre-ELF and operational years.

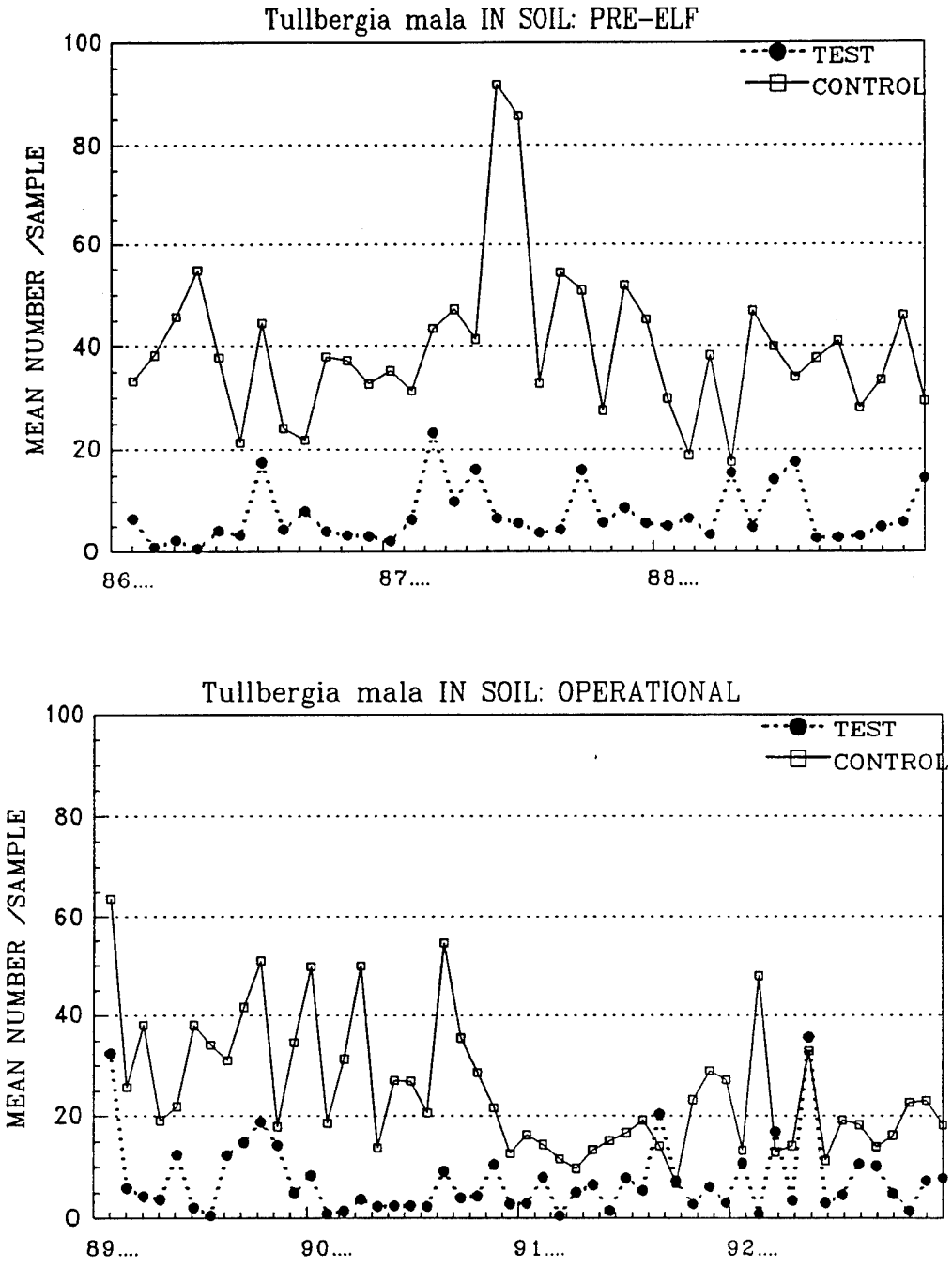


Fig. 29. Mean number of *Tullbergia mala* extracted from soil cores (N= 10 samples /site /date) during pre-ELF and operational years.

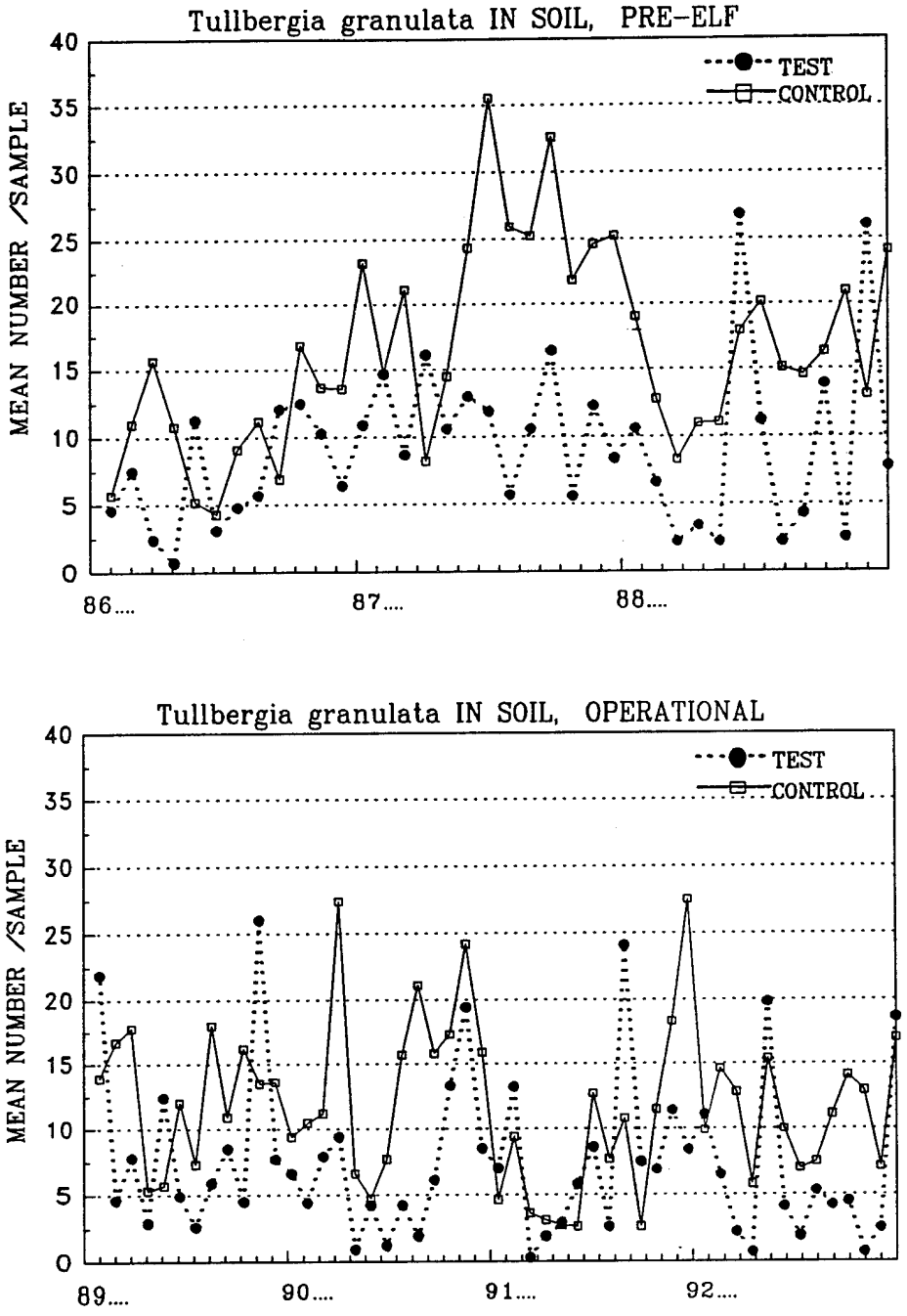


Fig. 30. Mean number of *Tullbergia granulata* extracted from soil cores (N=10 samples /site /date) during pre-ELF and operational years.

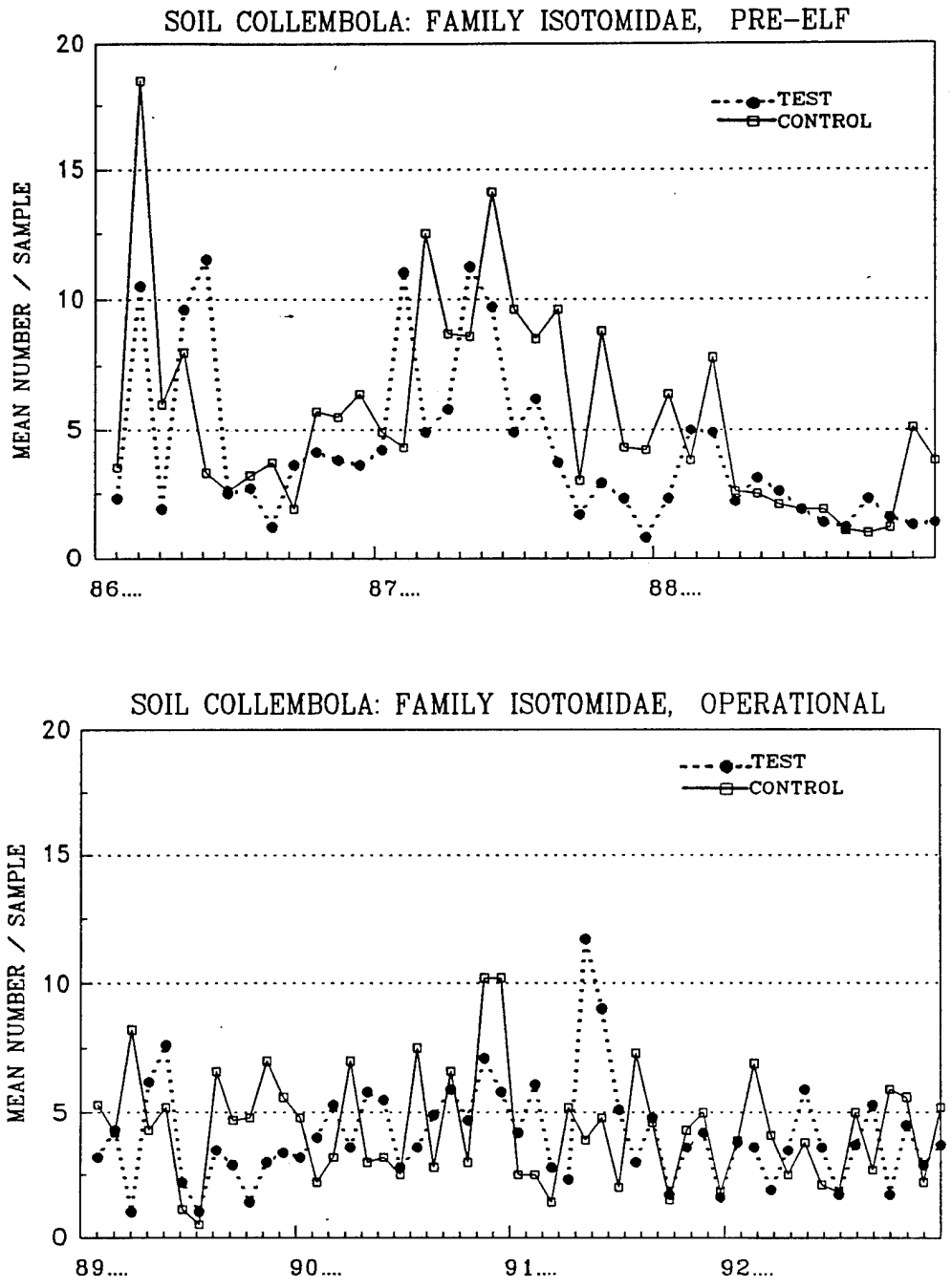


Fig. 31. Mean number of Isotomidae extracted from soil cores (N = 10 samples /site /date) during pre-ELF and operational years.

## 2.3. Community structure

Diversity as well as equitability indices (**Fig. 32**) were consistently lower in Control, where the collembolan community was heavily dominated by Onychiuridae. Summarized over pre-ELF and operational periods (**Table 5**), both indices were found to be stable in Test, but increased significantly in Control. BACI tests of date-specific differences (Control-Test) during pre-ELF vs. operational periods reflected the shift toward higher indices in Control, mean differences between sites being reduced in 1989-92 (**Table 6**).

**Table 5.** Mean diversity and equitability indices of Test and Control collembolan communities, based on densities /$m^2$ (soil and litter estimates summed); P values obtained by t tests.

| | DIVERSITY (H') | | | EQUITABILITY (S'/S) | | |
|---|---|---|---|---|---|---|
| SITE | 86-88 | 89-92 | P | 86-88 | 89-92 | P |
| TEST | | | | | | |
| MEAN | 2.144 | 2.047 | 0.10 | 0.217 | 0.210 | 0.40 |
| SD | 0.276 | 0.234 | | 0.042 | 0.036 | |
| N | 38 | 51 | | 38 | 51 | |
| CONTROL | | | | | | |
| MEAN | 1.550 | 1.647 | 0.05 | 0.140 | 0.163 | 0.001 |
| SD | 0.187 | 0.244 | | 0.027 | 0.031 | |
| N | 38 | 51 | | 38 | 51 | |

**Table 6.** Results of BACI tests of [Control-Test] differences in date-specific diversity and equitability indices of collembolan communities, based on densities /$m^2$ (litter + soil).

| INDEX/PERIOD | | N | MEAN DIFF. | SD | P |
|---|---|---|---|---|---|
| DIVERSITY | 86-88 | 38 | -0.6018 | 0.3191 | |
| | 89-92 | 51 | -0.3994 | 0.3381 | 0.005 |
| EQUITABILITY | 86-88 | 38 | -0.0786 | 0.0498 | |
| | 89-92 | 51 | -0.0471 | 0.0438 | 0.003 |

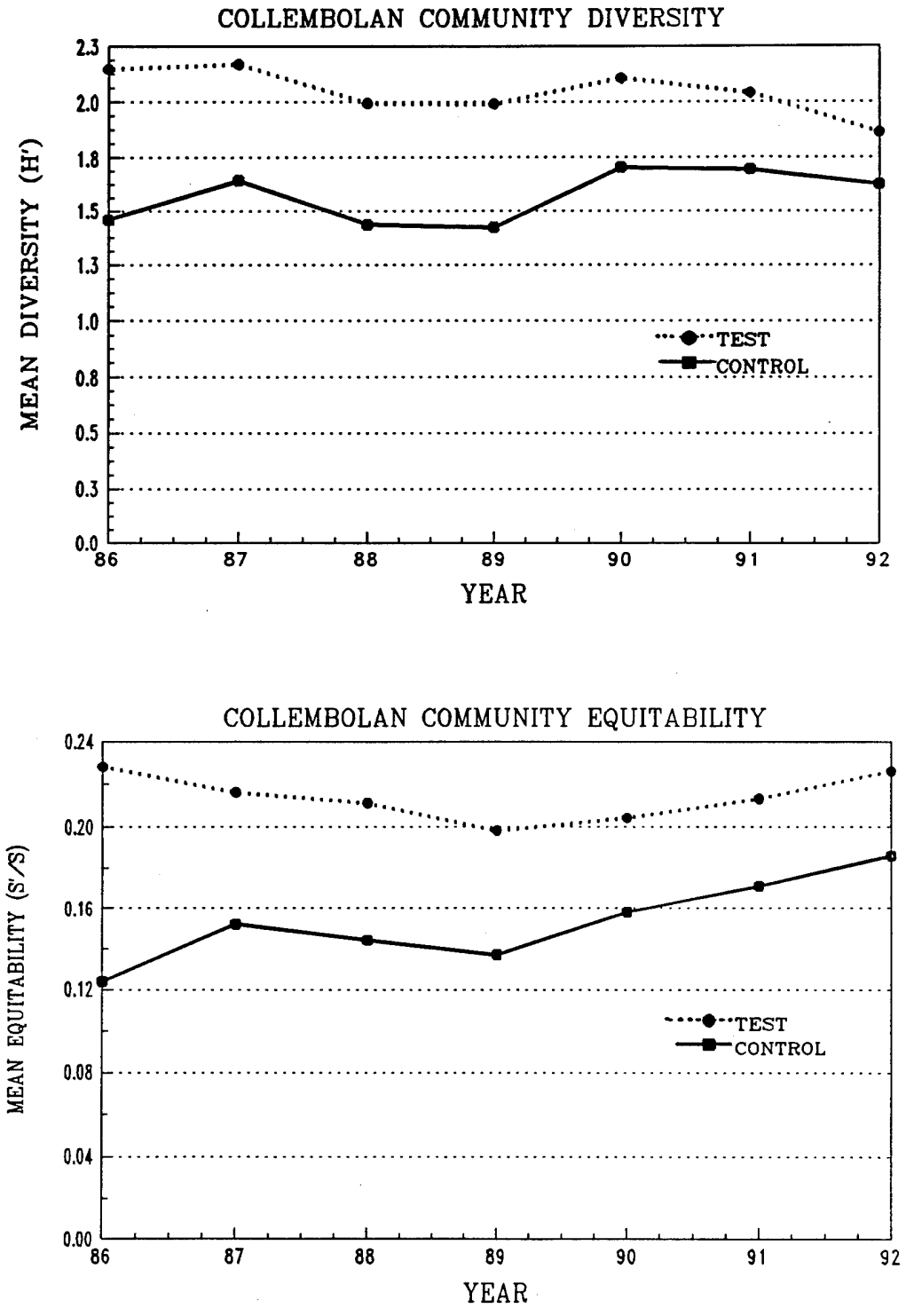


Fig. 32. Mean annual diversity and equitability indices for the collembolan communities in Test and Control sites, based on date-specific indices (N= 12 or 13 dates /year).

**2.4. Statistical analyses: population densities**

BACI tests of date-specific differences (Control-Test) between sites were performed on all collembolan taxa in which data could be made to meet the required assumptions (i.e., soil collembolan data were transformed by ln (x+1)).

Results pertaining to soil Collembola are summarized in **Table 7**. Tests of **site-specific** means showed that reduced numbers of *Tullbergia mala* and *T. granulata* entailed significantly lower numbers of Onychiuridae. Lower numbers of Onychiuridae, enhanced by reduced *I. notabilis* populations, resulted in significantly reduced numbers of total Collembola in Control during operational years. In the Test site, Entomobryidae and Tomoceridae underwent significant reductions. BACI tests of mean differences reflected some of these changes, i.e., in Entomobryidae, Tomoceridae, and *T. mala*.

Among litter-dwelling Collembola (**Table 8**), Tomoceridae and its single dominant member *T. flavescens* experienced simultaneous decreases in both sites, such that differences between Test and Control were not significant. Where BACI test results were significant, they fell into three categories:

a. decreased differences between sites due to increased populations in Test only: Isotomidae and its dominant constituent species *I. notabilis*, and Hypogastruridae;

b. reduced populations in Test only: Entomobryidae and two of its major component species, *O. hexfasciata* and *E. comparata*;

c. reduced populations in Control only: *S. henshawi*; at the sminthurid family level, effects of *S. henshawi* decreases were not significant (P = 0.07) (**Table 8**).

**Table 7.** Soil collembolan abundance (total of all species, major families and dominant species): results of t-tests (P values) of pre-ELF *vs.* operational period means within each site, and of mean differences between sites (Control - Test BACI tests); data transformed by ln (x+1). N = 38 for pre-ELF years (1986-1988); N = 51 for operational years (1989-1992).

| TAXON | SITE-SPECIFIC TESTS (1986-88) *vs.* (1989-92) | | (CONTROL-TEST) DIFFERENCES (BACI TESTS) | | |
|---|---|---|---|---|---|
| | CONTROL | TEST | P | 1986-88 MEAN ± SD | 1989-92 MEAN ± SD |
| Total Collembola | 0.000 | 0.190 | 0.104 | 0.870 ± 0.475 | 0.687 ± 0.577 |
| Onychiuridae | 0.000 | 0.480 | 0.069 | 1.127 ± 0.619 | 0.877 ± 0.654 |
| Entomobryidae | 0.351 | 0.000 | 0.000 | -0.755 ± 0.357 | -0.294 ± 0.383 |
| Tomoceridae | 0.074 | 0.000 | 0.000 | -0.555 ± 0.445 | -0.252 ± 0.217 |
| Hypogastruridae | 0.942 | 0.570 | 0.730 | 0.265 ± 0.467 | 0.226 ± 0.609 |
| *I. notabilis* | 0.004 | 0.880 | 0.001 | 0.165 ± 0.446 | -0.198 ± 0.573 |
| *T. mala* | 0.000 | 0.670 | 0.012 | 1.745 ± 0.735 | 1.314 ± 0.845 |
| *T. granulata* | 0.000 | 0.100 | 0.516 | 0.632 ± 0.664 | 0.538 ± 0.694 |

**Table 8.** Litter collembolan abundance (total of all species, major families and dominant species): results of t-tests (P values) of pre-ELF *vs.* operational period means within each site, and of mean differences between sites (Control - Test BACI tests). N = 63 for pre-ELF years (1984-88); N = 51 for operational years (1989-92).

| TAXON | SITE-SPECIFIC TESTS (1984-88) *vs.* (1989-92) | | (CONTROL-TEST) DIFFERENCES (BACI TESTS) | | |
|---|---|---|---|---|---|
| | CONTROL | TEST | P | 1986-88 MEAN ± SD | 1989-92 MEAN ± SD |
| Total Collembola | 0.823 | 0.370 | 0.108 | 0.633 ± 0.693 | 0.436 ± 0.605 |
| Isotomidae | 0.963 | 0.028 | 0.001 | 1.006 ± 0.789 | 0.521 ± 0.695 |
| Entomobryidae | 0.421 | 0.001 | 0.002 | -0.178 ± 0.987 | 0.317 ± 0.631 |
| Tomoceridae | 0.000 | 0.001 | 0.159 | -1.096 ± 0.752 | -0.924 ± 0.542 |
| Sminthuridae | 0.161 | 0.866 | 0.070 | 0.299 ± 0.628 | 0.094 ± 0.563 |
| Neelidae | 0.330 | 0.505 | 0.460 | 0.673 ± 0.759 | 0.782 ± 0.798 |
| Hypogastruridae | 0.157 | 0.089 | 0.019 | 0.181 ± 0.618 | -0.071 ± 0.510 |
| *I. notabilis* | 0.869 | 0.012 | 0.000 | 0.961 ± 0.795 | 0.445 ± 0.698 |
| *O. hexfasciata* | 0.182 | 0.002 | 0.000 | -0.483 ± 0.691 | -0.072 ± 0.435 |
| *E. comparata* | 0.508 | 0.058 | 0.031 | 0.415 ± 0.847 | 0.715 ± 0.619 |
| *T. flavescens* | 0.000 | 0.001 | 0.100 | -1.035 ± 0.738 | -0.842 ± 0.499 |
| *S. henshawi* | 0.029 | 0.838 | 0.006 | 0.485 ± 0.496 | 0.223 ± 0.490 |

**2.5. Population structure: *Isotoma notabilis***

Summary data for densities and proportions of developmental stages are presented below and in **Appendix 6.**

As discussed previously, soil-dwelling *I. notabilis* populations underwent major reductions in the Control site during operational years, while Test populations experienced moderate increases (**Fig. 33**). Broken down to developmental stages, these changes were clearly consistent in Test, all stage densities increasing by approximately equal increments from pre-ELF to operational periods (**Fig. 34**). In Control, adults and juveniles (but not instars I) decreased significantly during operational years ($P = 0.000$) (**Fig. 33**). BACI tests of (Control - Test) differences simply confirmed decreased Control densities in 1989-92 for adults and juveniles (**Table 9**).

Data on proportions in each stage were not amenable to parametric analysis due to severe heterogeneity of variances. However, there was little noticeable difference, visually, either between sites or between ELF periods within sites (**Fig. 34**). Population structure after antenna activation was thus not detectably distorted in any way.

Biweekly fluctuations in adult and hatchling proportions were quite extreme and not always well correlated between sites (**Figs. 35-36**). Hatchlings, however, tended to be well represented at the very beginning of each season, with a second peak following approximately 2-3 months later (**Fig. 35**).

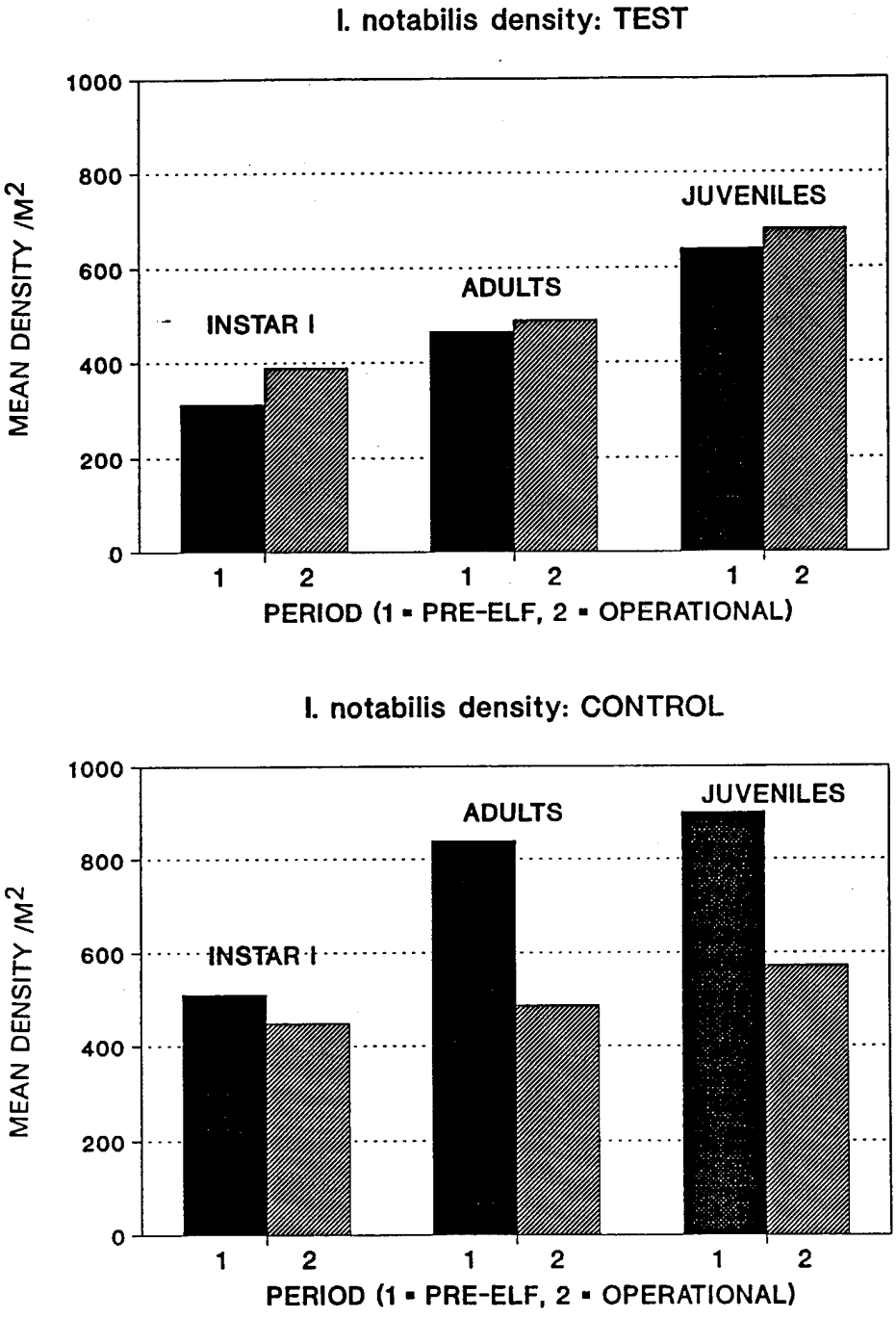


Fig. 33. *Isotoma notabilis*: mean density during pre-ELF and operational years of instars I, adults and juveniles other than instars I, in Test and Control sites (densities in litter and soil summed). Period 1 encompasses 1984-1988; Period 2 encompasses 1989-1992.

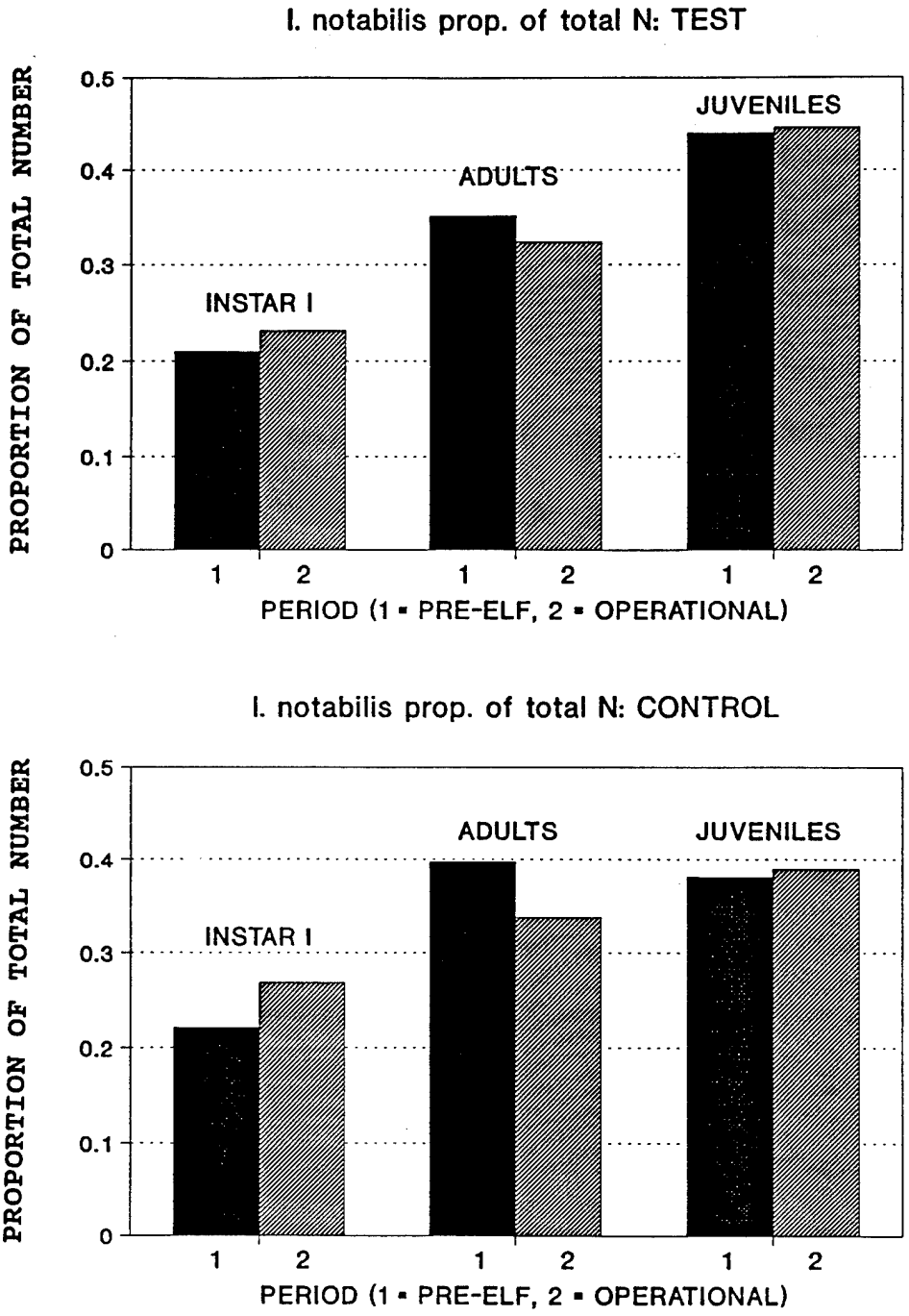


Fig. 34. Mean proportion of the total *Isotoma notabilis* population in instar I (hatchling), adult and juvenile stages in Test and Control, during pre-ELF and operational years.
Period 1 = 1984-1988; Period 2 = 1989-1992.

**Table 9.** Results of BACI tests of (Control - Test) differences in density of *I. notabilis* developmental stages during pre-ELF and operational periods.

| DEVELOPM.STAGE / PERIOD | N | MEAN DIFF. | SD | P |
|---|---|---|---|---|
| INSTAR I | | | | |
| 1984-1988 | 63 | 197.06 | 419.73 | |
| 1989-1992 | 51 | 59.42 | 418.61 | 0.084 |
| JUVENILES | | | | |
| 1984-1988 | 63 | 261.55 | 700.43 | |
| 1989-1992 | 51 | -107.58 | 476.99 | 0.002 |
| ADULTS | | | | |
| 1984-1988 | 63 | 377.03 | 519.10 | |
| 1989-1992 | 51 | -0.61 | 398.29 | 0.000 |

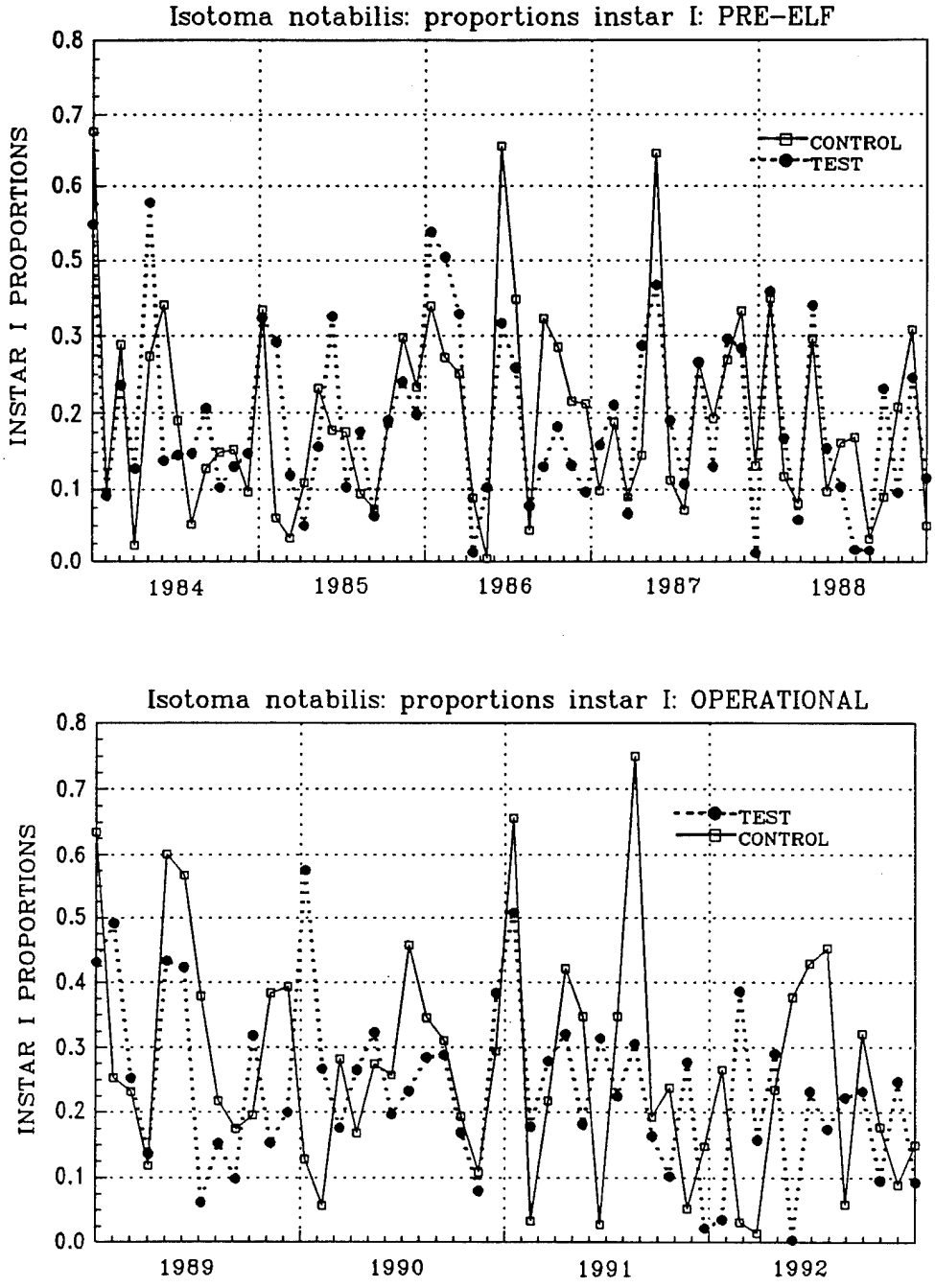


Fig. 35. Proportion of *I. notabilis* populations in the instar I (hatchling) stage, at biweekly intervals during pre-ELF and operational years in Test and Control.

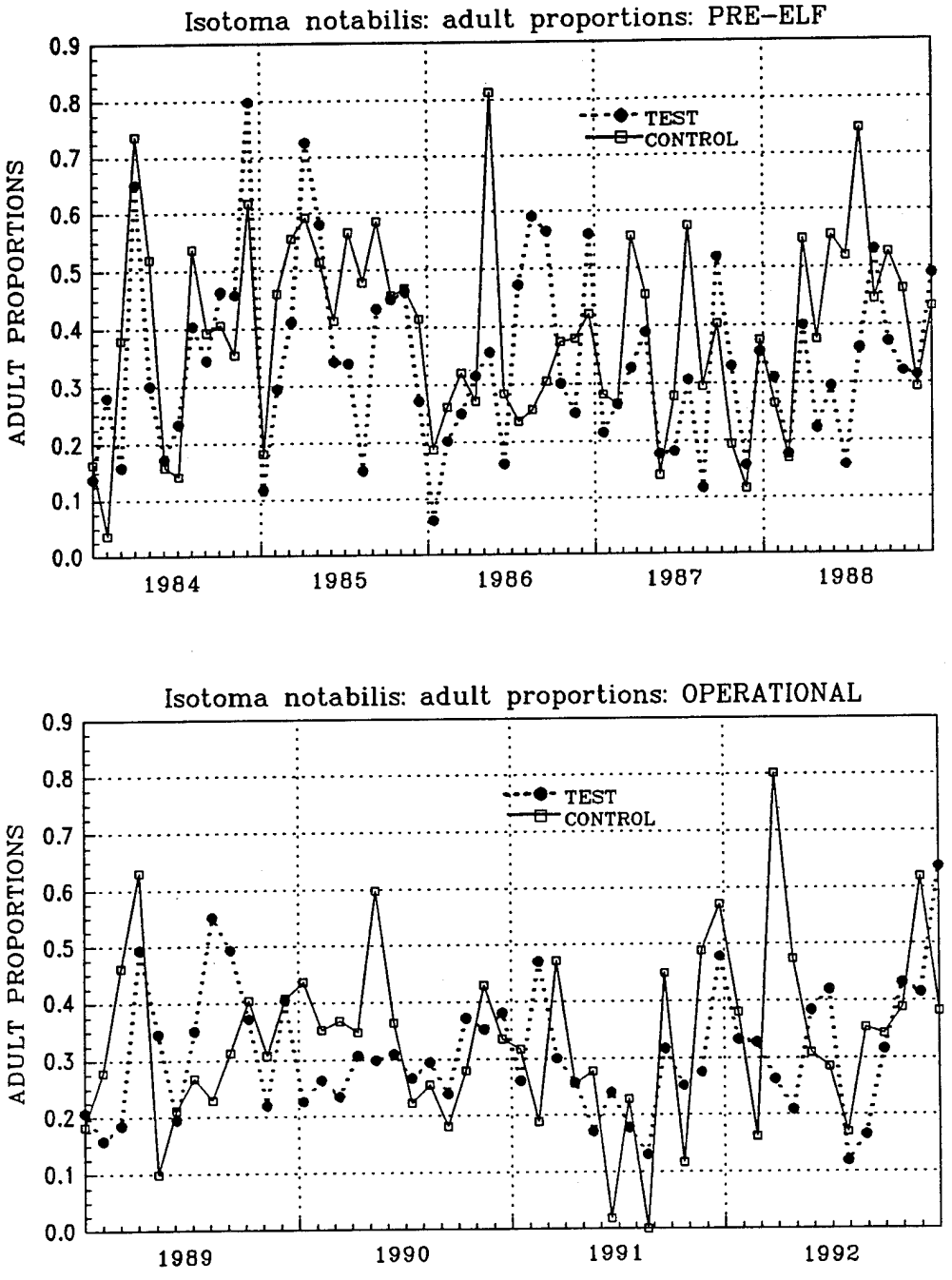


Fig. 36. Proportions of *I. notabilis* populations in the adult stage at biweekly intervals during pre-ELF and operational years in Test and Control.

**3. Acarina**

Among three species routinely obtained from litter and soil samples, *Asca aphidioides* (L.) had been previously described. The second belonged in the genus *Nanorchestes*, was morphologically distinct from other *Nanorchestes* spp. found in our samples, and is here designated as *Nanorchestes* "sp. A". The third was a mesostigmatid of unknown generic or specific assignation (Dr. A. Welbourn, pers. comm.), and is herein called "mesostigmatid sp. A".

*Asca aphidioides* was almost exclusively litter-dwelling; *Nanorchestes* sp. A frequented both soil and litter, while the mesostigmatid sp. A was exclusively soil-dwelling. Mean annual densities for the three species are listed in **Table 10**. Error measures were typically very high, reflecting strong aggregation tendencies (SD for *Nanorchestes* density estimates in litter or soil, not shown in **Table 10**, always exceeded the means by a factor of 2 to 3). With the exception of the mesostigmatid sp. A, correlations between Test and Control abundances were high, indicating synchronicity in between-year variations.

Examples of biweekly numerical fluctuations are shown in **Fig. 37** for litter-dwelling *Nanorchestes* subpopulations, and in **Fig. 38** for *A. aphidioides*. The latter experienced drastic population declines after 1985, and never recovered during the study period. In the mesostigmatid sp. A, fluctuations showed only a general synchronicity between sites, be it with respect to the total population (**Fig. 39**) or with respect to a given developmental stage (**Fig. 40** illustrates adult numbers as example).

Data for *Nanorchestes* sp. A could not be made to meet required assumptions for parametric statistics, either in terms of additivity or homogeneity of variances. However, numerical

fluctuations were well correlated between sites ($R^2$ for 1984 through 1988 = 0.85). Edaphic factors potentially causing these fluctuations were apparently not overriden by EM field effects once the antenna was activated ($R^2$ for 1989-1992 = 0.90).

In *A. aphidioides*, only data for adults could be analyzed (after ln-transform). Results showed that numerical reductions were significant during 1989-1992 in Control (P = 0.02), but not in Test (P = 0.47) (**Table 11**). Despite severe population decreases in both sites (**Table 10**), relatively more drastic reductions in Control caused significant BACI differences, i.e., a significant reduction in the magnitude of [Control-Test] differences (**Table 11**).

Data for the mesostigmatid sp. A met all required assumptions. BACI tests of [Control-Test] differences showed that site relationships were not significantly altered by antenna activation. Site-specific tests of [1986 to 1988] *vs.* [1989 to 1992] indicated that numerical increases in adults and in total populations occurred in both sites during operational years (**Table 11**).

**Table 10.** Mean annual density (± SD) of three mite species in Test and Control sites, 1984-1992. *Nanorchestes* estimates are summed densities from litter and soil samples (SD cannot be calculated); N /year variable, either 120 or 130 samples /year.

| | YEAR (N SAMPLES) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| TAXON/ SITE | 84 (120) | 85 (130) | 86 (130) | 87 (130) | 88 (120) | 89 (130) | 90 (130) | 91 (130) | 92 (120) |
| Mesotigmatid sp. A | | | | | | | | | |
| TEST | 1121 ± 2758 | 581 ± 1402 | 1469 ± 2496 | 2169 ± 2640 | 1521 ± 2394 | 3092 ± 3624 | 2600 ± 3615 | 2900 ± 3399 | 1437 ± 2002 |
| CONTROL | 2062 ± 4198 | 465 ± 940 | 1685 ± 2202 | 3227 ± 4381 | 1746 ± 2305 | 3988 ± 5493 | 3096 ± 3435 | 1996 ± 1947 | 3062 ± 3203 |
| *A. aphidioides* | | | | | | | | | |
| TEST | 127 ± 347 | 34 ± 121 | 12 ± 44 | 19 ± 67 | 18 ± 60 | 51 ± 159 | 32 ± 101 | 8 ± 23 | 6 ± 17 |
| CONTROL | 502 ± 976 | 176 ± 368 | 35 ± 79 | 22 ± 85 | 21 ± 56 | 72 ± 160 | 68 ± 265 | 37 ± 73 | 19 ± 53 |
| *Nanorchestes* sp. A | | | | | | | | | |
| TEST | 367 | 119 | 1163 | 401 | 344 | 327 | 980 | 437 | 396 |
| CONTROL | 328 | 266 | 771 | 186 | 227 | 282 | 734 | 346 | 159 |

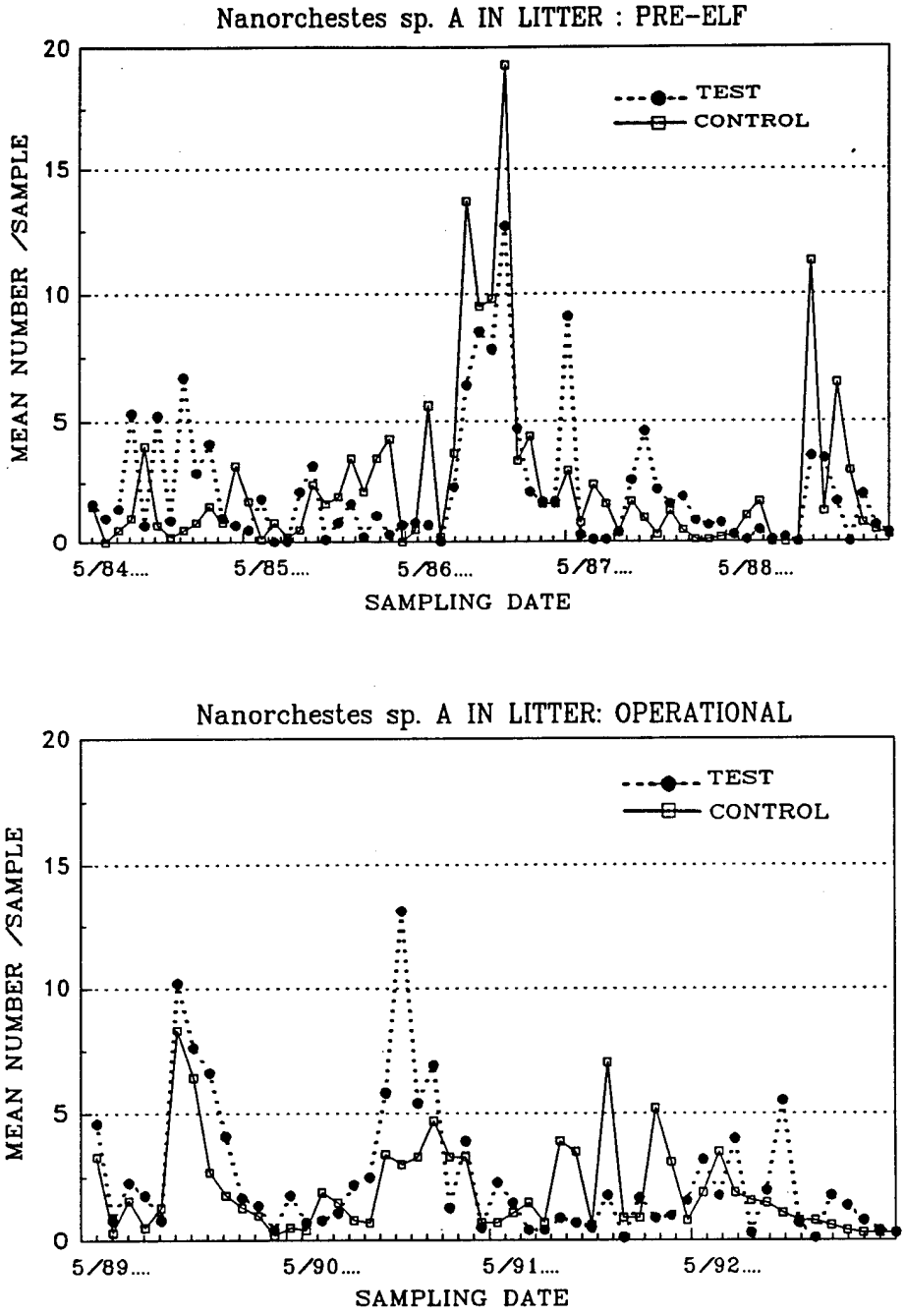


Fig. 37. Mean number /date (N = 10 samples /site /date) of *Nanorchestes* sp. A in leaf litter during pre-ELF and operational years (early May to October of each year).

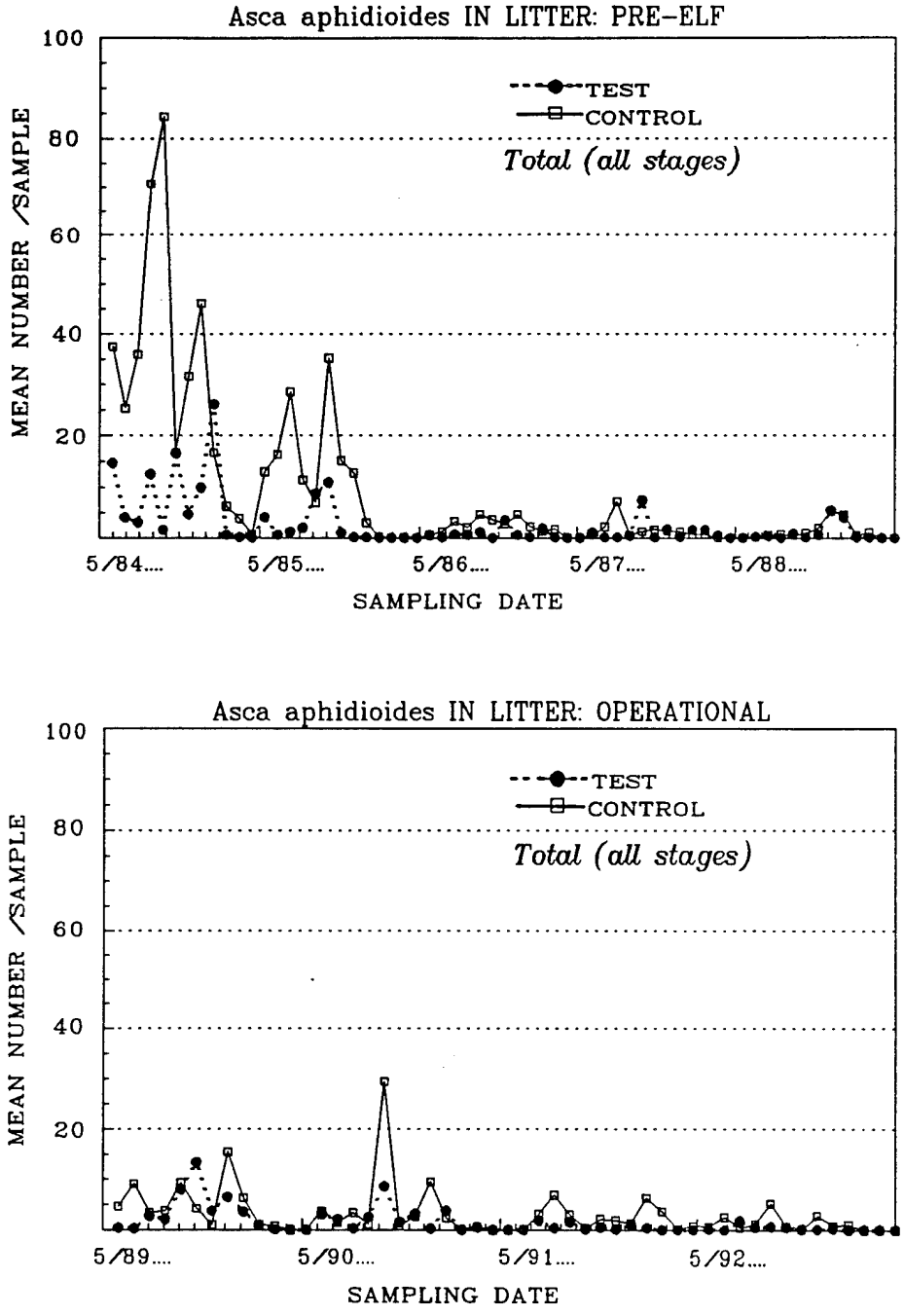


Fig. 38. Mean number /date (N = 10 samples /site /date) of *Asca aphidioides* in leaf litter during pre-ELF and operational years (early May to October of each year).

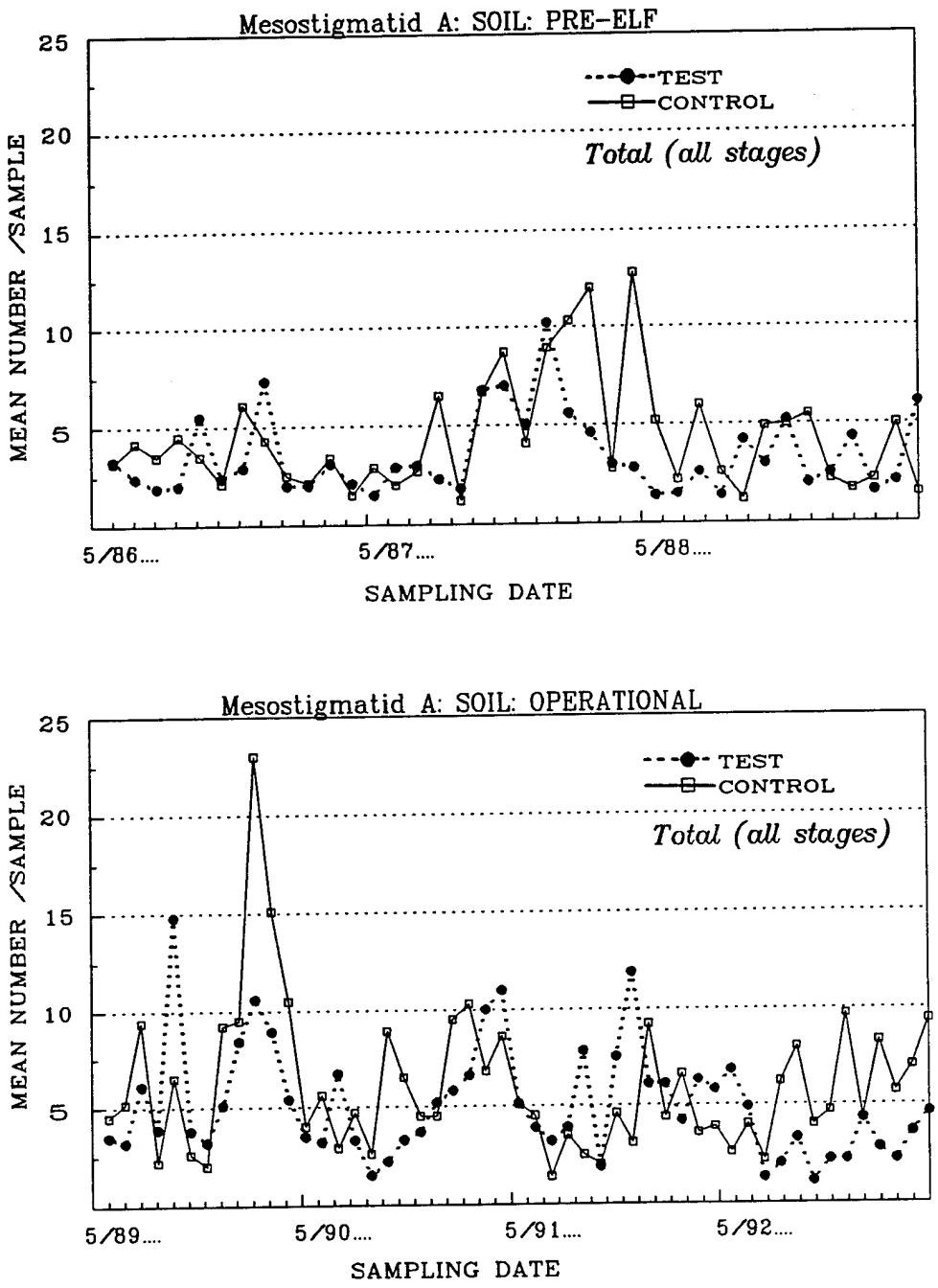


Fig. 39. Mean number /date (N = 10 samples /site /date) of mesostigmatid sp. A (all developmental stages summed) in soil during pre-ELF and operational years (early May to October of each year).

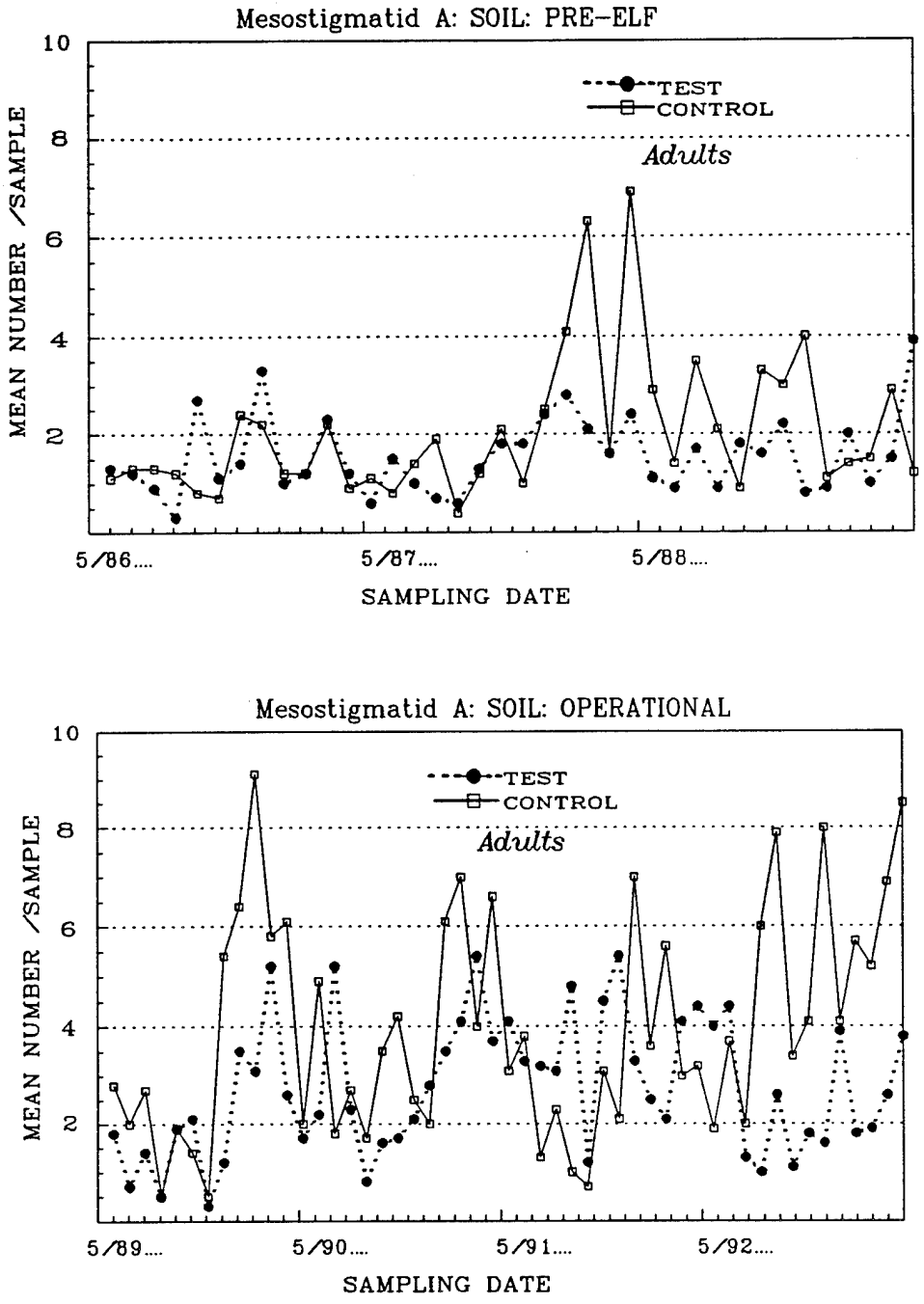


Fig. 40. Mean number /date (N = 10 samples /site /date) of mesostigmatid sp. A (adults only) in soil during pre-ELF and operational years (early May to October of each year).

**Table 11.** Results of t-tests (P values) of population sizes of *Asca aphidioides* in leaf litter and of Mesostigmatid sp. A in soil samples during pre-ELF and operational periods. For the litter-dwelling *A. aphidioides*, N = 61 for the pre-ELF years 1984-88, N = 48 for operational years 1989-92; for the soil-dwelling Mesostigmatid sp. A, N = 38 for the pre-ELF years 1986-88 (sugar floatations of samples began in 1986, ref. section III), and N = 48 for operational years 1989-92. "Site-specific tests" refer to pre-ELF *vs.* operational periods within each site.

| | SITE-SPECIFIC TESTS | | (CONTROL-TEST) DIFFERENCES (BACI TESTS) | | |
|---|---|---|---|---|---|
| TAXON / STAGE | CONTROL | TEST | P | PRE-ELF MEAN ±SD | OPER. MEAN ±SD |
| *A. aphidioides* : Adults | 0.018 | 0.468 | 0.026 | 0.635 ± 0.824 | 0.230 ± 0.703 |
| *Mesostigmatid sp. A:* Larvae | 0.230 | 0.281 | 0.779 | -0.150 ± 0.512 | -0.122 ± 0.439 |
| Protonymphs | 0.269 | 0.809 | 0.198 | 0.066 ± 0.651 | -0.186 ± 1.058 |
| Deutonymphs | 0.903 | 0.137 | 0.263 | 0.437 ± 1.053 | 0.114 ± 1.515 |
| Adults | 0.000 | 0.000 | 0.105 | 0.479 ± 1.412 | 1.208 ± 2.453 |
| Total populations | 0.021 | 0.009 | 0.807 | 0.832 ± 2.839 | 1.014 ± 3.877 |

## C. SUMMARY AND DISCUSSION

There is little information available in the literature on long-term density fluctuations of microarthropod populations. Judging by data on macroarthropods such as millipedes, centipedes, pseudoscorpions and dipteran larvae (Blandin *et al.* 1982), or on nematodes (Willard 1973, cited in Peterson and Luxton 1982), highly significant between-year fluctuations are the rule rather than the exception, and can be partly due to variations in climate.

Takeda (1987) obtained data on collembolan populations in a Japanese pine forest over a 15 year period. In eight dominant species, annual abundances varied by factors of 3.5 to 29, and up to 128 in one species. Years when maxima and minima occurred differed between species, and the most severe drought year had no clearly definable effect on any of them. In our study, densities of several abundant species fluctuated (generally by factors of $<2$ to approximately 3) in both sites, with no apparent synchronicity between Test and Control. Possible relationships with climatic patterns were discernible only in two epedaphic species, *T. flavescens* and *O. hexfasciata,* in the Test site (neither was abundant in Control): reduced numbers in 1988, a severe drought year, carried over into 1989, the year of antenna activation. In north temperate zones, entomobryids and tomocerids tend to have only one generation per year (Persson and Lohm 1977; Huhta and Mikkonen 1983; Peterson 1980), so that populations reduced by drought would not be able to recover as rapidly as multivoltine species. On the other hand, these same species also incurred reduction in the Test site in 1993 (**Appendix 5**), with no clear relation to edaphic conditions.

Based on analysis of years grouped by pre-ELF and operational periods, several species and higher taxa were found to have increased or decreased in Control as well as Test. Changes in

relationships (differences) between sites after 1988 were thus due to increases or decreases in either site (**Tables 7 and 8,** also ref. page 49). Since decreased population densities in Control in particular cannot be linked to ELF EM field effects, our data indicate that observed differences reflected:

a) species-specific responses to climatic and edaphic conditions, in interaction with site-specific factors: a given species may show variable population dynamics in two different sites, although causative agents are usually not identifiable (as is the case here) (Joosse 1969; Verhoef and van Selm 1978);

b) very long-term changes in population densities and community structure, which may be cyclic or may be related to maturation of the two forest stands. We found little substantiating evidence for these conjectures in the literature although, in a general sense, distinct soil faunal differences between successional communities (discussed in Usher 1985) may represent an analogy to slow, subtle changes over time in slowly maturing forest systems.

We conclude that "ELF effects" (referring strictly to differences between pre-ELF and operational years) were statistically detectable **in both sites,** and were not consistent between taxa. In some species, effects of the 1988 drought were carried over into 1989. Climatic effects thus happened to coincide with the year of antenna activation, and cannot be distinguished from potential ELF effects. In other species density variations were well correlated between sites over all years, indicating absence of ELF effects. For *Isotoma notabilis*, our data indicated two to three generations per year, in agreement with Bödvardsson (1973). Population structure was not visibly affected by antenna activation (**Fig. 34**), and numerical changes were drastic in the Control site only (**Fig. 33**).

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# IV. SURFACE-ACTIVE ARTHROPODA

## A. METHODS

Pittraps were placed in permanent locations in each quadrat (**Fig. 1**). At intervals of 1 week, they were activated at dusk and collected at dawn (= night catch), replaced and collected again the following evening (= day catch). Twenty traps were installed in each site.

Beginning in 1985, each trap was provided with four barriers analogous to the single barriers described by Reeves (1980): four 1 m lengths of plastic garden edging, protruding approx. 8 cm above ground and abutting to the trap, were positioned at $90^{o}$ angles to each other. Catches of some arthropods (particularly carabid beetles) were thereby increased significantly (Snider and Snider 1986).

Barrier-trapping was used from 1985 through 1991; 1984 data are disregarded in summaries and analyses below.

Classification of Collembola follows the system of Gisin (1960), that of mites follows Krantz (1978), and that of Carabidae follows Lindroth (1961-1969), with more recent corrections being taken into account where appropriate.

## B. RESULTS

### 1. Collembola

### 1.1. Annual and seasonal fluctuations

An overview of total numbers trapped per year is provided in **Table 13** for the most commonly encountered taxa in either Test or Control sites. (The entire array of species is included in the Collembola checklist in **Appendix 4**).

Large between-year fluctuations were observed in single species (e.g., *Orchesella hexfasciata*), species groups ( *Pseudachorutes* spp.) and total Collembola (**Table 12**). Although most of the 30-odd species captured were common to both sites, they were collected in differing proportions. For instance, *Lepidocyrtus paradoxus* and *Dicyrtoma aurata* were common in Control, but relatively rare in Test. Conversely, *Pseudosinella violenta* and *Entomobrya nivalis* were more common in Test than in Control (**Table 12**).

**Table 12.** Total annual catches of selected Collembola in Test and Control, 1985 through 1991. Night and day catches summed, T = Test, C = Control.

| | | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 |
|---|---|---|---|---|---|---|---|---|
| *S. henshawi* | T | 1637 | 1435 | 1992 | 2811 | 3065 | 3196 | 2364 |
| | C | 2606 | 2934 | 4123 | 5084 | 3675 | 2666 | 2475 |
| *S. lepus* | T | 669 | 236 | 1049 | 503 | 1438 | 1375 | 1335 |
| | C | 397 | 375 | 1019 | 824 | 724 | 505 | 1129 |
| *T. flavescens* | T | 4213 | 1965 | 2429 | 1684 | 641 | 1033 | 2198 |
| | C | 842 | 242 | 280 | 165 | 237 | 170 | 90 |
| *O. hexfasciata* | T | 3201 | 3402 | 4137 | 3426 | 738 | 1767 | 3434 |
| | C | 1099 | 421 | 1180 | 3549 | 1662 | 2976 | 1500 |
| *E. comparata* | T | 35 | 80 | 119 | 150 | 57 | 90 | 69 |
| | C | 287 | 87 | 157 | 1493 | 440 | 731 | 92 |
| *E. nivalis* | T | 531 | 1057 | 294 | 291 | 218 | 326 | 546 |
| | C | 4 | 14 | 34 | 77 | 104 | 243 | 172 |
| *L. paradoxus* | T | 22 | 6 | 37 | 123 | 22 | 229 | 1377 |
| | C | 1142 | 961 | 2701 | 2649 | 3783 | 4385 | 2717 |
| *P. violenta* | T | 166 | 381 | 606 | 916 | 327 | 132 | 330 |
| | C | 1 | 1 | 47 | 0 | 2 | 4 | 4 |
| *D. aurata* | T | 5 | 0 | 4 | 1 | 0 | 22 | 1 |
| | C | 468 | 976 | 2198 | 448 | 403 | 233 | 145 |
| *Pseudachorutes* spp. | T | 13 | 0 | 5 | 0 | 187 | 131 | 174 |
| | C | 1925 | 198 | 348 | 379 | 659 | 860 | 483 |
| **TOTAL COLLEMBOLA** | T | 11518 | 9550 | 12010 | 11072 | 7987 | 9301 | 13101 |
| | C | 9946 | 6815 | 13120 | 15521 | 12964 | 13467 | 10282 |

Weekly catches of total Collembola reflected low activity in early spring and late fall, and generally good correlation between sites with respect to the timing of major activity peaks (**Fig. 41**). In late 1987 and 1988, and throughout 1989 and 1990, Control catches were higher than Test catches, while numbers tended to be higher in Test in 1986 and 1991.

Between-site comparisons at taxonomic levels above that of species may, however, be relatively meaningless. We illustrate this point by means of the family Entomobryidae. In Control, *Lepidocyrtus paradoxus* contributed the bulk of entomobryids trapped and frequently determined the time and size of activity peaks at the family level (**Fig. 42**). In Test, *L. paradoxus* was virtually non-existent until 1991 (**Fig. 43**). Total numbers trapped (Entomobryidae including *L. paradoxus*) exhibited a startling change in pattern: much higher in Test during 1985 through early 1988, then higher in Control during 1989 and 1990, then again higher in Test in 1991 (**Fig. 44**). Excluding *L. paradoxus*, the family-level pattern still holds true during pre-ELF years; in 1989 and 1990, however, numbers trapped in Test were essentially equal to the low catches obtained in Control (**Fig. 45**).

It is obvious that the component species must be the primary subjects of analysis if trends observed in higher taxa are to be explained; e.g., was the reversal of the pre-ELF Test/Control proportionality seen in **Figs. 44-45** due to increased numbers in Control, or to decreased numbers in Test?

In addition to *L. paradoxus*, one other species greatly affected total numbers captured in this group. Activity patterns of *Orchesella hexfasciata* (**Fig. 46**) were mainly responsible for those observed in the family (**Fig. 44**), including the "reversal" of Test/Control proportionality between mid-1988 and late 1990 caused by simultaneous increases in Control and decreases in

Test.

The family Tomoceridae was represented almost exclusively by a single species, *Tomocerus flavescens* (**Fig. 47**), which showed a yearly pattern of reduction and increase strongly reminiscent of that in *O. hexfasciata*.

A third family consistently well represented in trap catches was Sminthuridae (**Fig. 48**), with *Sminthurinus henshawi* (**Fig. 49**) the single main determinant of total numbers and of the timing of activity peaks in both sites. *Sminthurides lepus* (**Fig. 50**), a secondary component of the family, exhibited relatively drastic overall between-year fluctuations in both sites (**Table 12**). Neither at the species nor at the family level were drastic numerical changes around the time of antenna activation recorded.

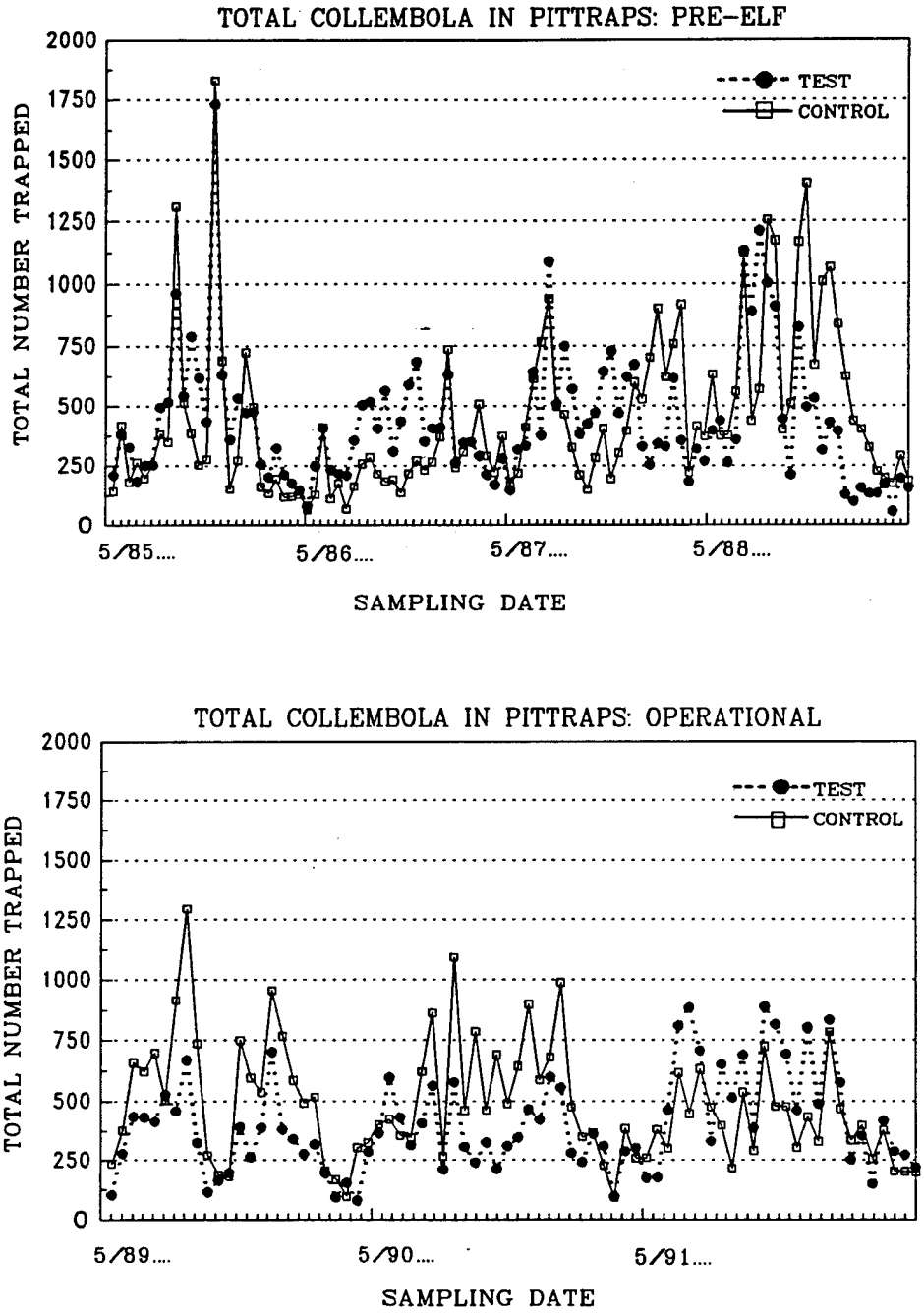



Fig. 41. Weekly catches of Collembola (all species summed) in Test and Control sites, early May to late October, 1985 through 1991.

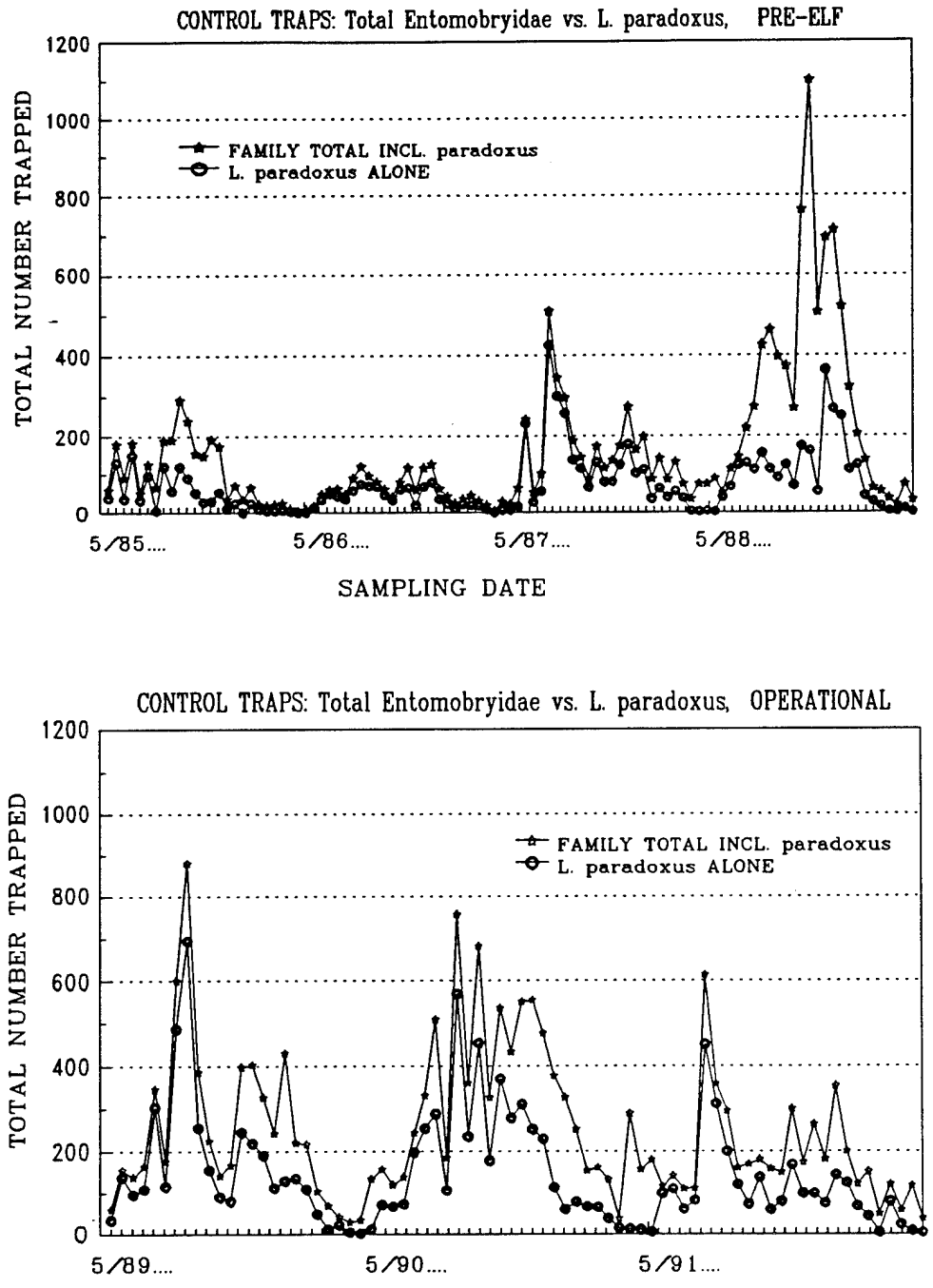



Fig. 42. Weekly catches of total Entomobryidae and of *Lepidocyrtus paradoxus* alone in the CONTROL site, from early May to late October of each year.

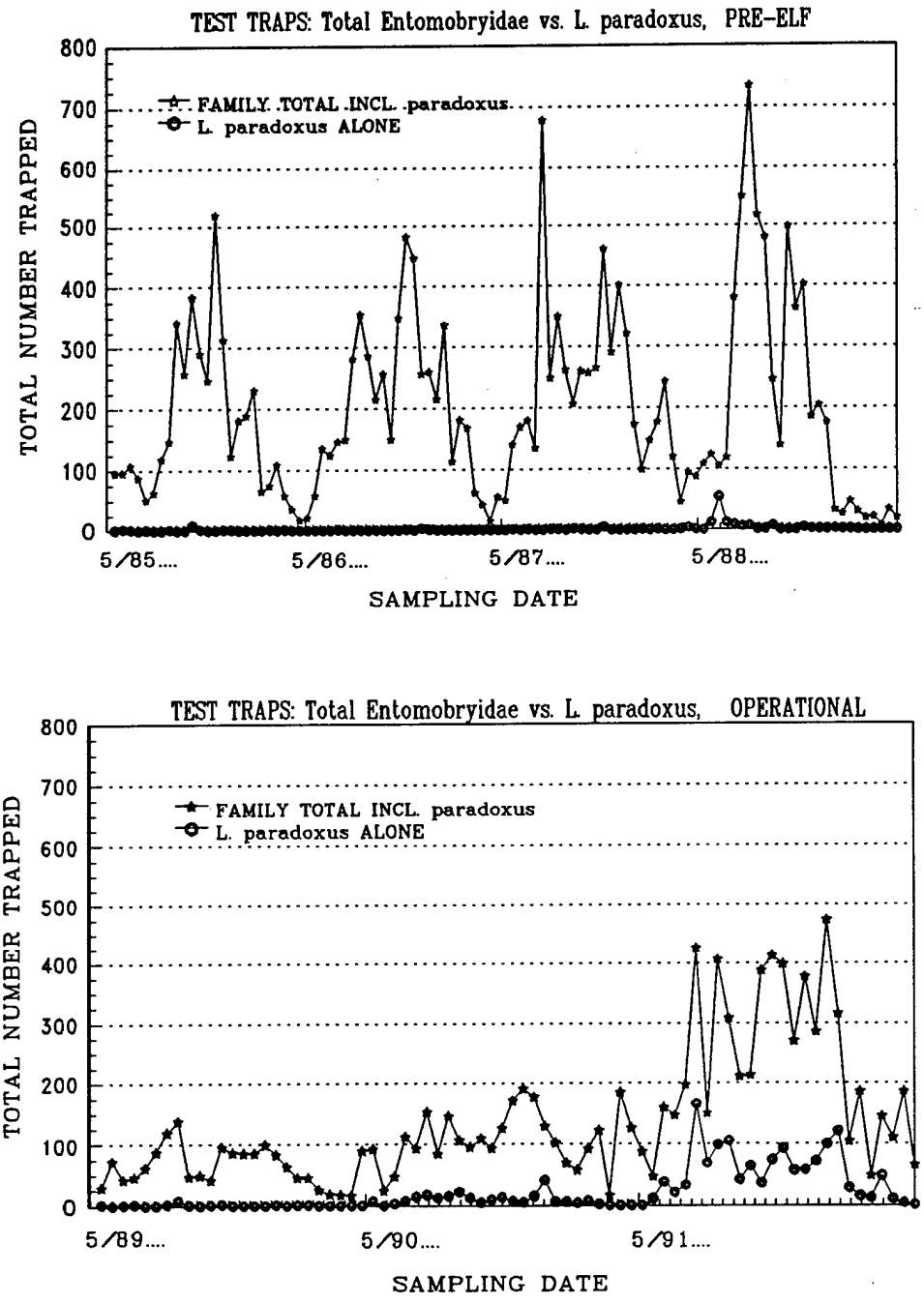



Fig. 43. Weekly catches of total Entomobryidae and of *Lepidocyrtus paradoxus* alone in the TEST site, from early May to late October of each year.

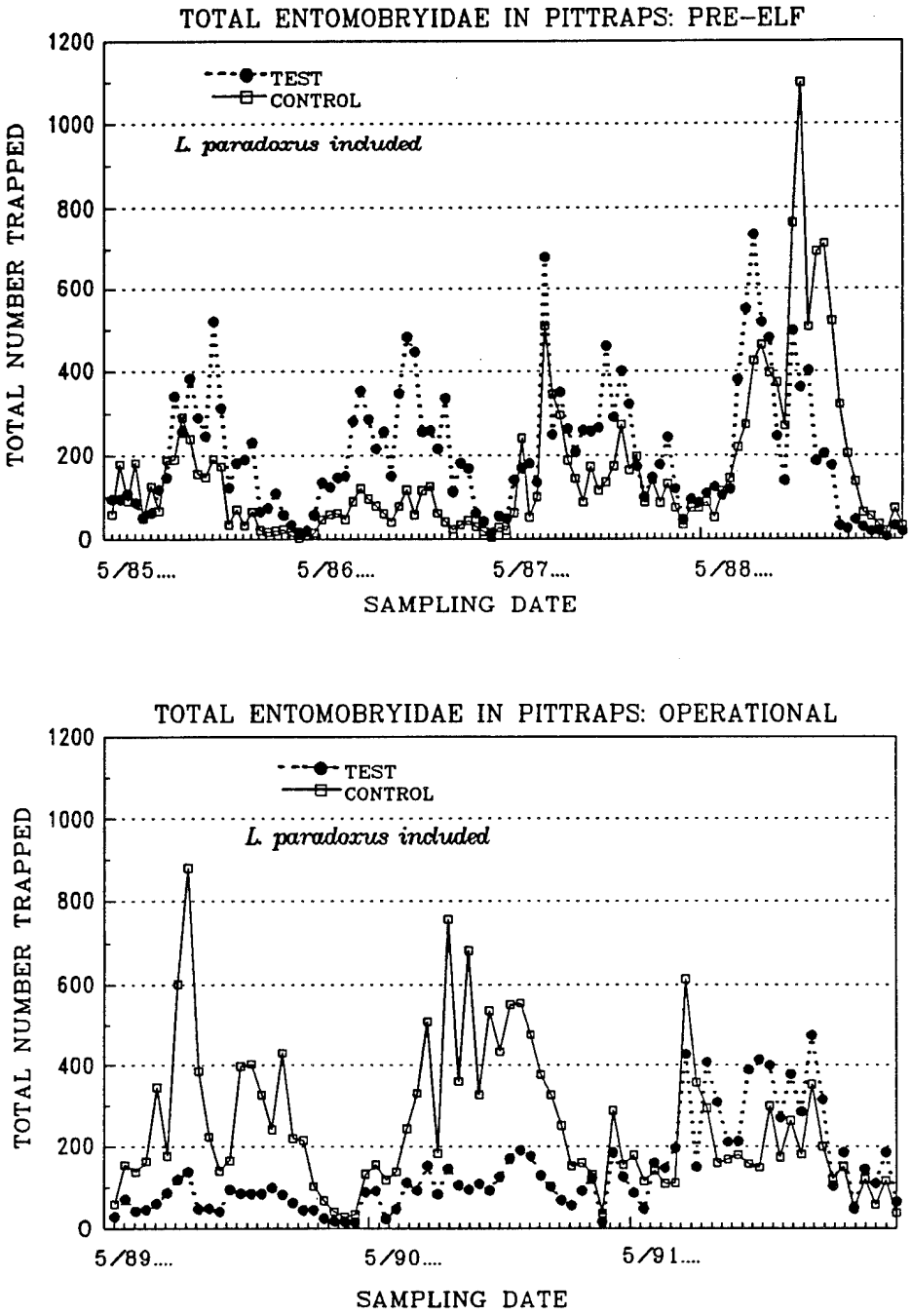



Fig. 44. Weekly catches of total Entomobryidae (*Lepidocyrtus paradoxus* included) in Test and Control sites, from early May to late October of each year.

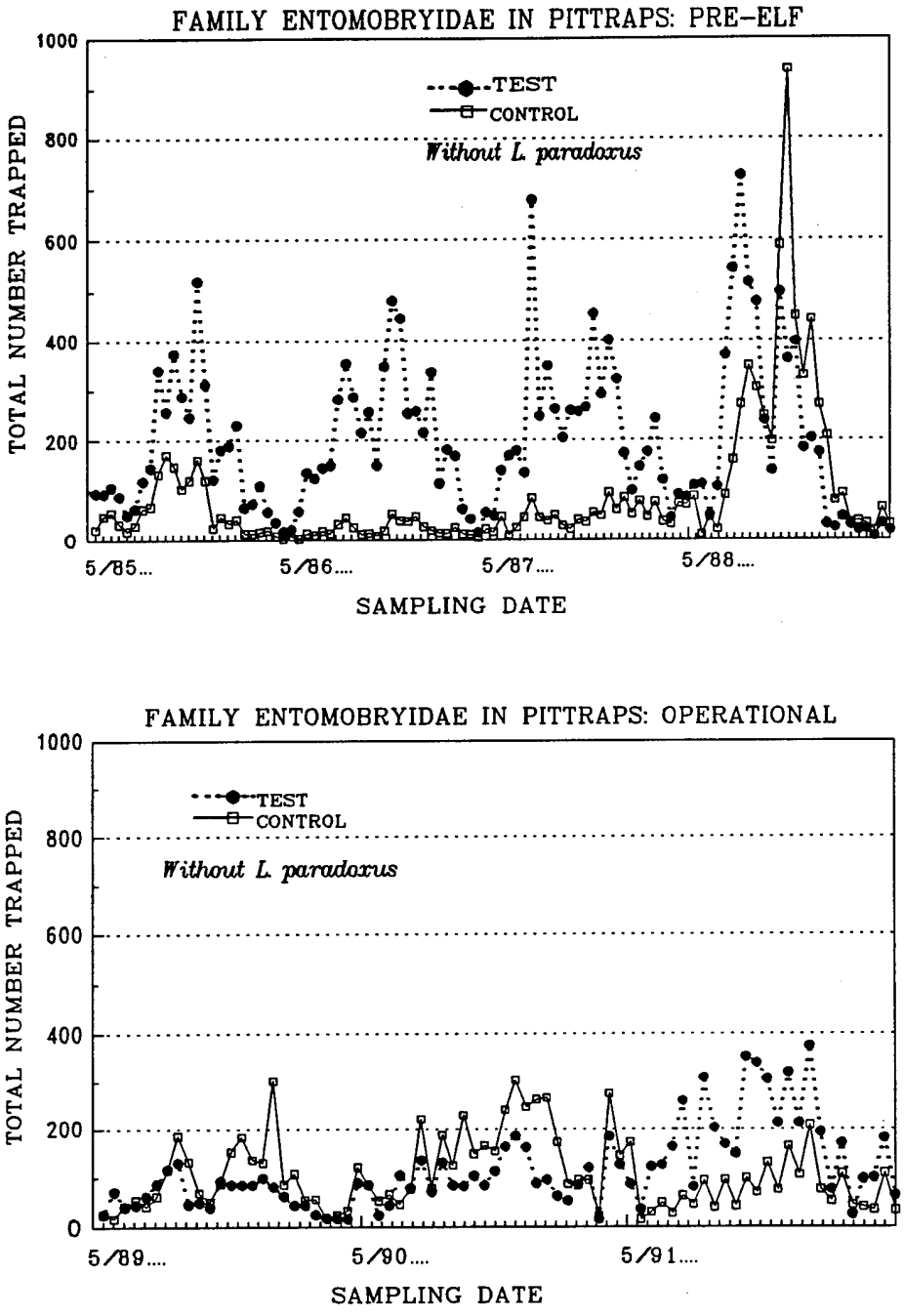



Fig. 45. Weekly catches of total Entomobryidae (*Lepidocyrtus paradoxus* excluded from family totals) in Test and Control, from early May to late October of each year.

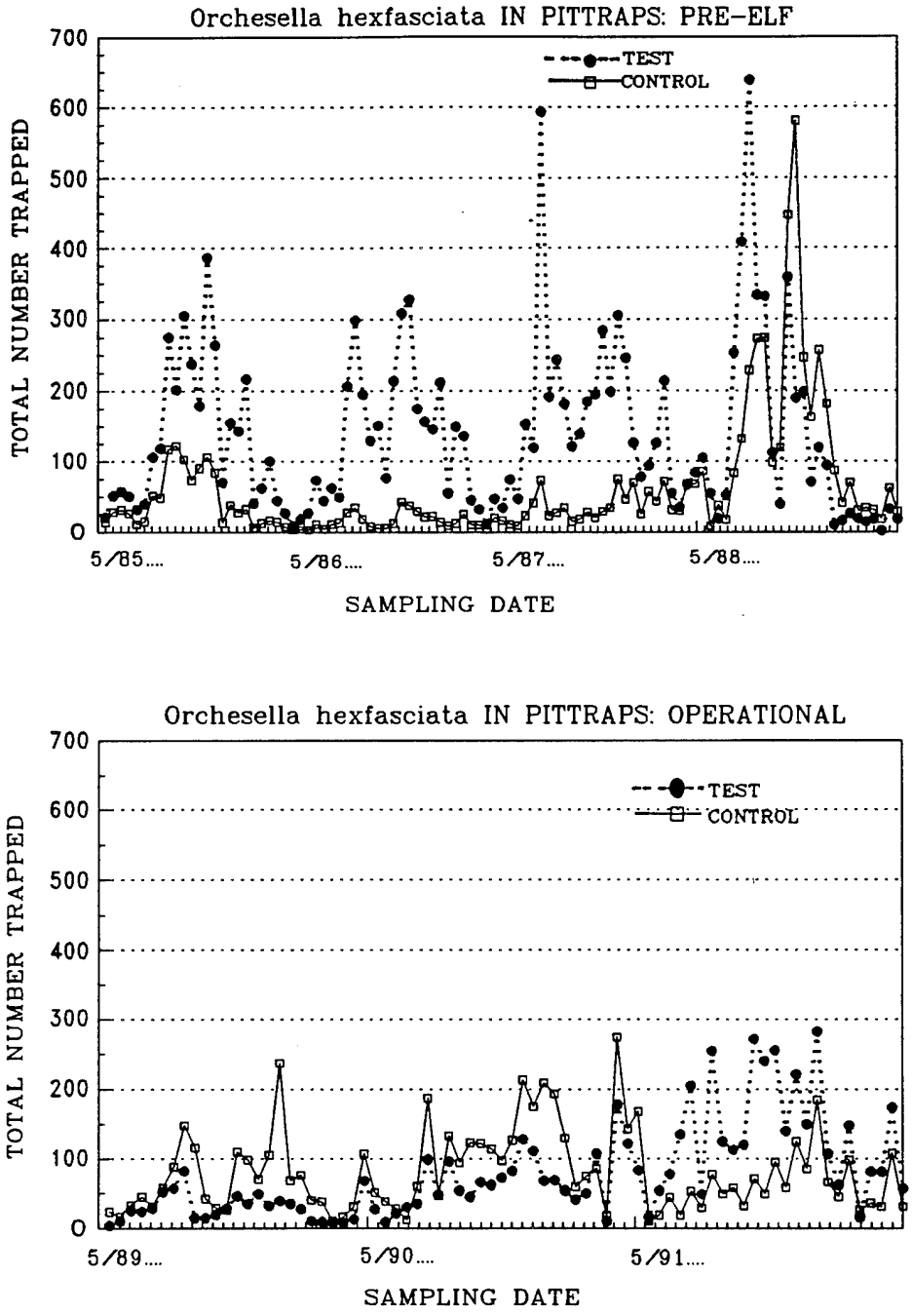



Fig. 46. Weekly catches of *Orchesella hexfasciata* (Entomobryidae) in Test and Control, from early May to late October of each year.

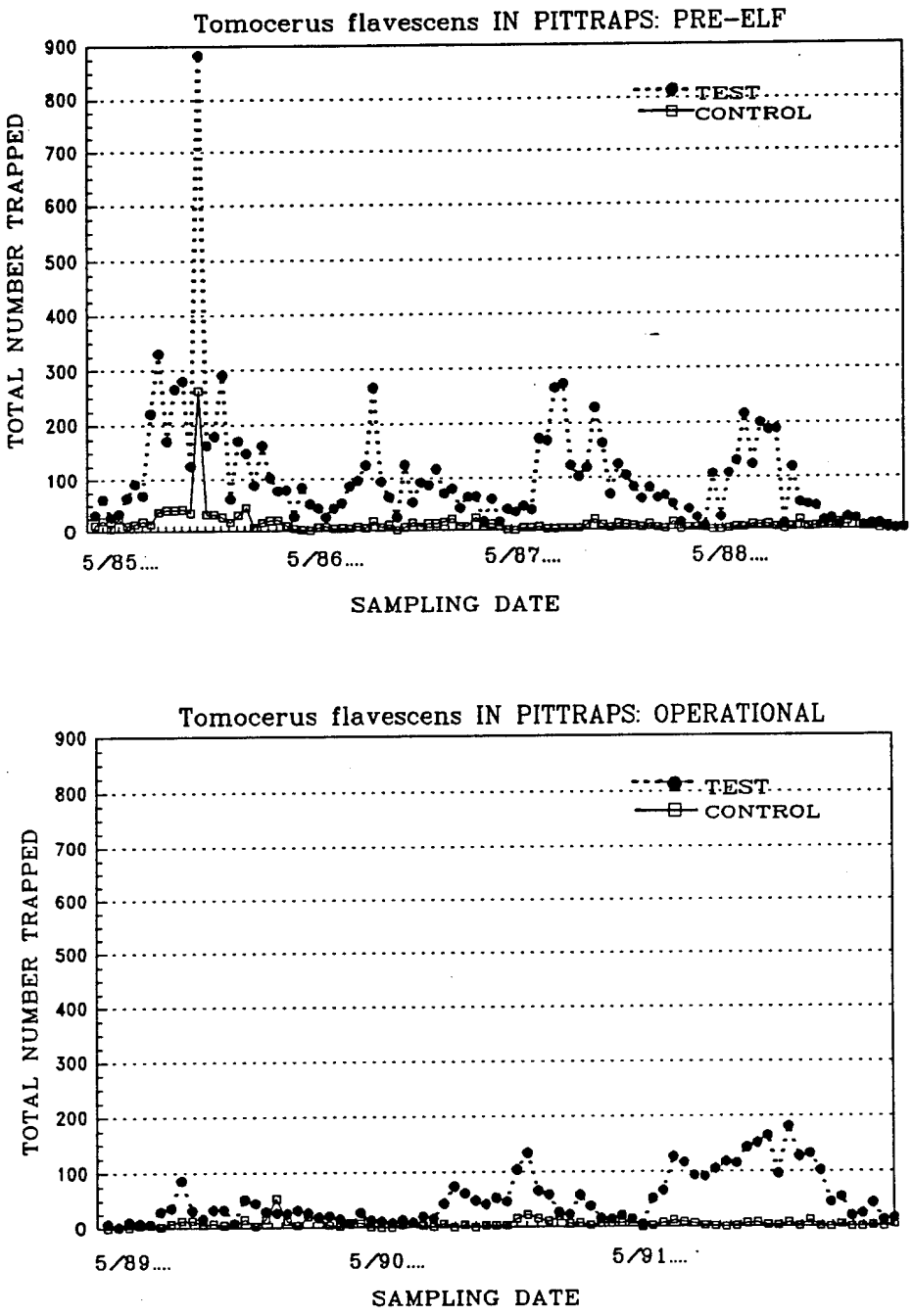



Fig. 47. Weekly catches of *Tomocerus flavescens* (Tomoceridae) in Test and Control, from early May to late October of each year.

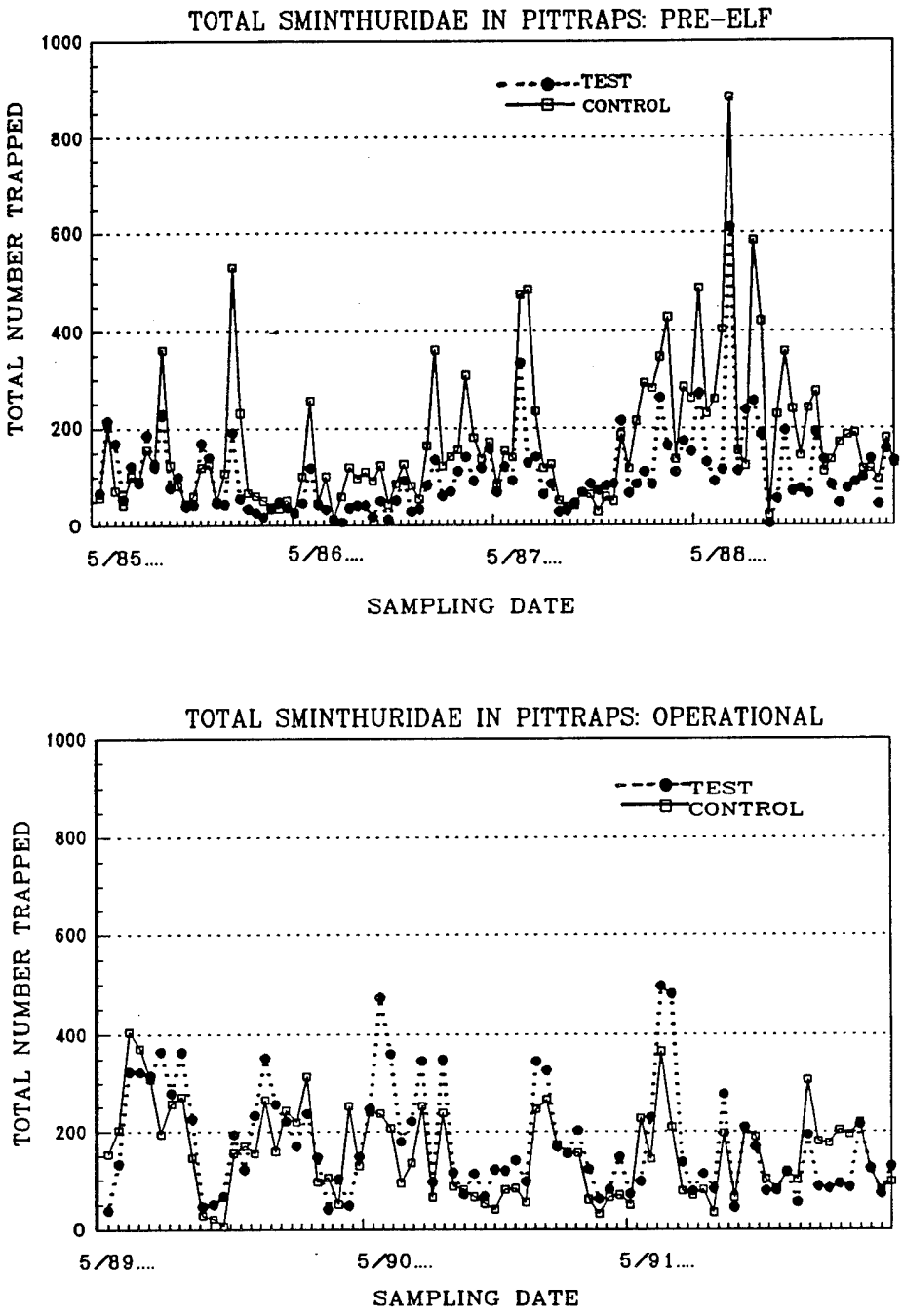



Fig. 48. Weekly catches of total Sminthuridae in Test and Control, from early May to late October of each year.

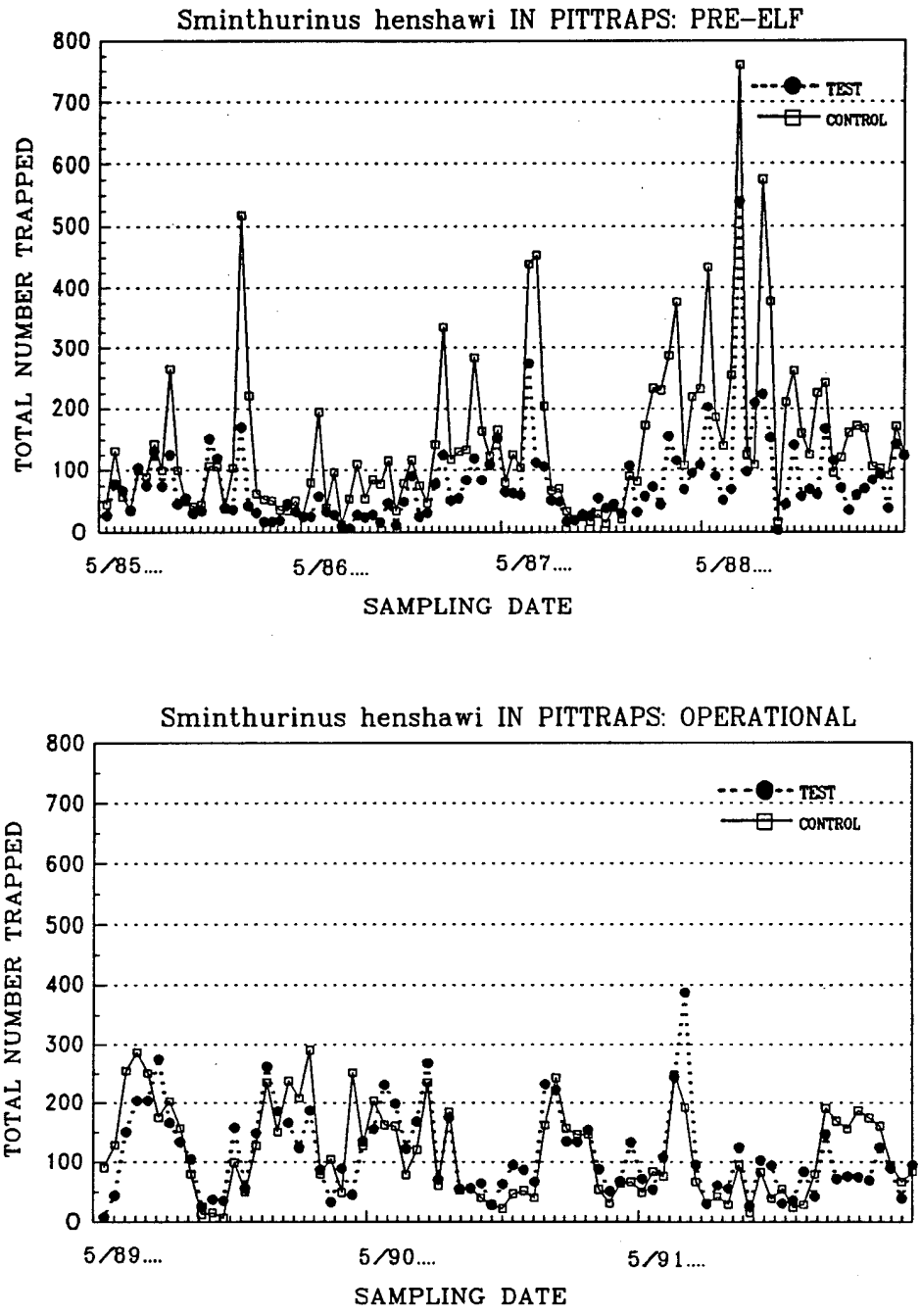



Fig. 49. Weekly catches of *Sminthurinus henshawi* (Sminthuridae) in Test and Control, from early May to late October of each year.

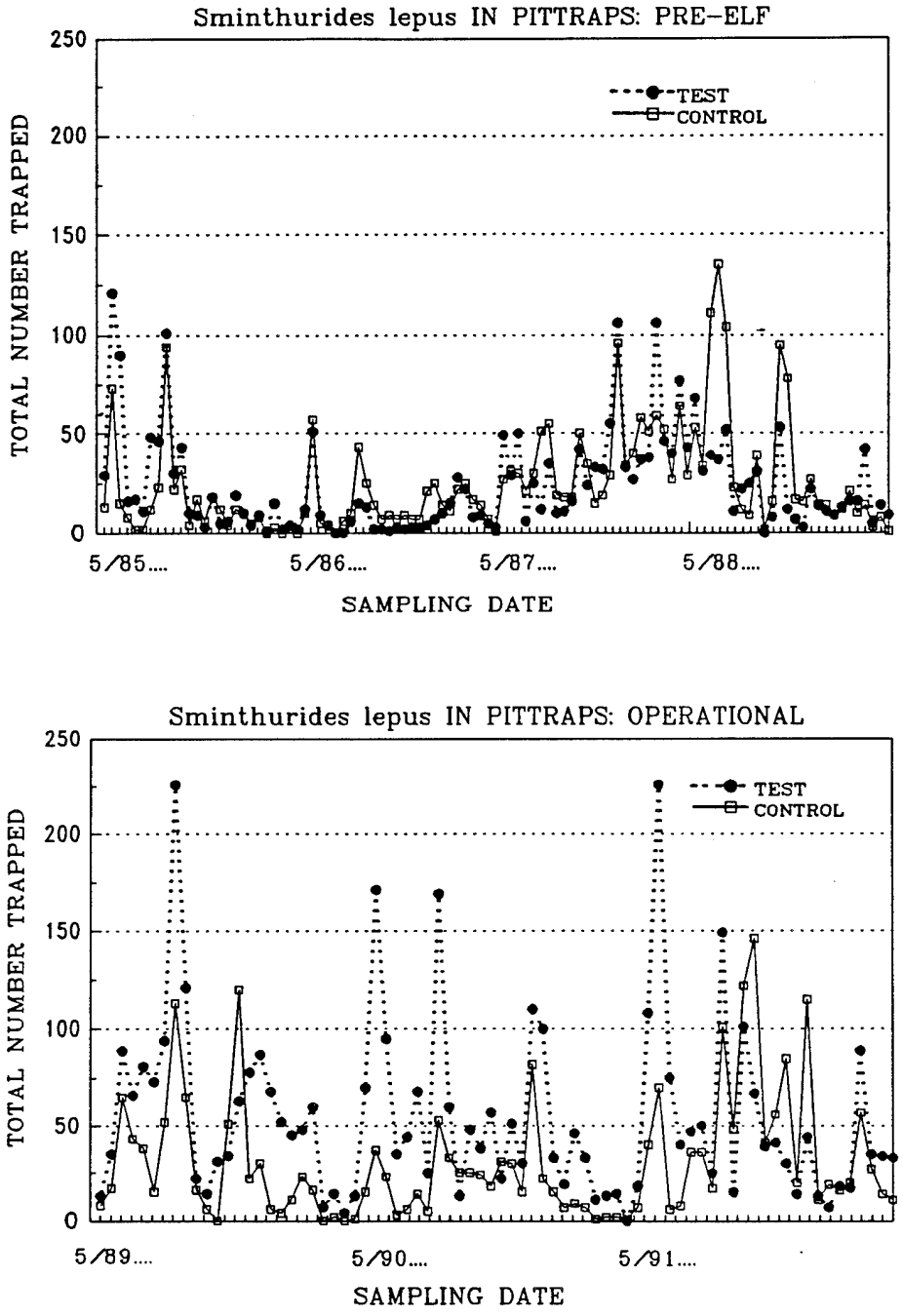



Fig. 50. Weekly catches of *Sminthurides lepus* (Sminthuridae) in Test and Control, from early May to late October of each year.

### 1.2. Diel activity

For four commonly captured species, percent diurnality is summarized in **Table 13.** *Sminthurinus henshawi* was almost equally day- and night-active, *S. lepus* and *O. hexfasciata* tended to be more diurnal. *Tomocerus flavescens*, however, was strongly nocturnal.

**Table 13.** Diurnality [(total day catches / total 24-hour catches) x 100] per year, for four frequently trapped species in Test and Control sites.

| | | DIURNALITY (PERCENT) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| YEAR/SPECIES | | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 |
| S. henshawi | T | 49.2 | 44.7 | 59.4 | 63.0 | 51.1 | 54.5 | 57.9 |
| | C | 60.4 | 48.5 | 62.9 | 61.5 | 58.6 | 56.1 | 56.6 |
| S. lepus | T | 78.9 | 67.9 | 79.2 | 87.4 | 72.2 | 68.2 | 72.9 |
| | C | 51.1 | 73.7 | 70.5 | 66.7 | 71.4 | 57.8 | 67.8 |
| O. hexfasciata | T | 71.2 | 64.5 | 64.1 | 67.7 | 65.8 | 66.8 | 54.8 |
| | C | 77.1 | 75.6 | 72.1 | 71.1 | 67.0 | 63.5 | 64.5 |
| T. flavescens | T | 20.3 | 19.5 | 18.3 | 22.9 | 21.7 | 25.0 | 21.6 |
| | C | 25.1 | 26.7 | 20.5 | 14.4 | 23.6 | 24.7 | 33.3 |

Weekly day- and night-catches of two species are illustrated below, using only single-year subsets of data randomly chosen as examples (**Figs. 51-52**). Week-specific diurnality patterns were significantly correlated between sites (in these two examples, $P = 0.001$ for both species), although correlation coefficients were relatively low ($R^2 = 0.40$ for *S. henshawi* and 0.43 for *O. hexfasciata*). Overall (**Table 13**) there were no obvious changes in species-specific diurnality patterns or in between-site relationships after antenna activation.

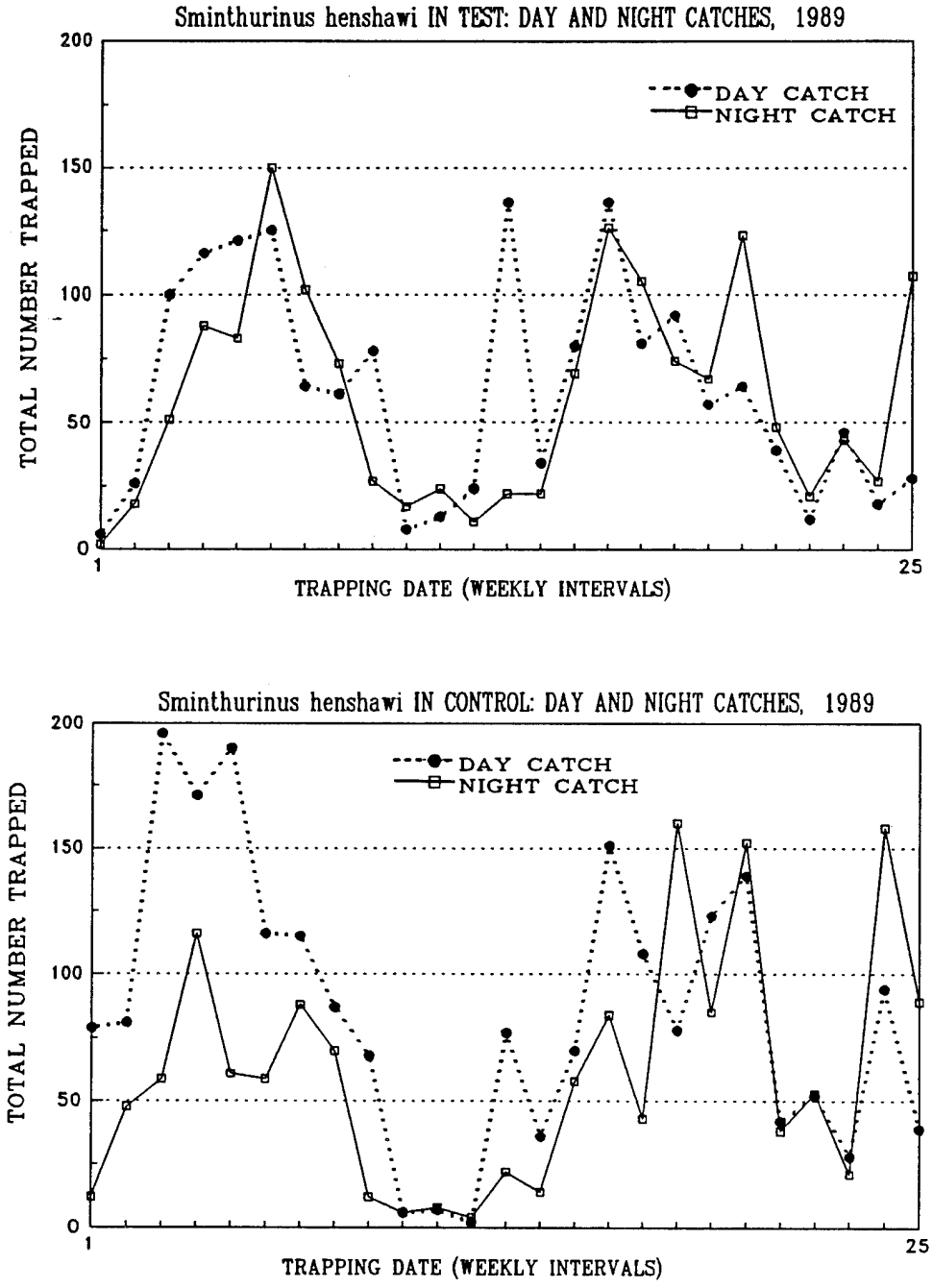



Fig. 51. Total numbers of *S. henshawi* captured at weekly intervals in day- and night-traps in Test and Control sites in 1989; Date 1 = May 8-9, Date 25 = October 23-24.

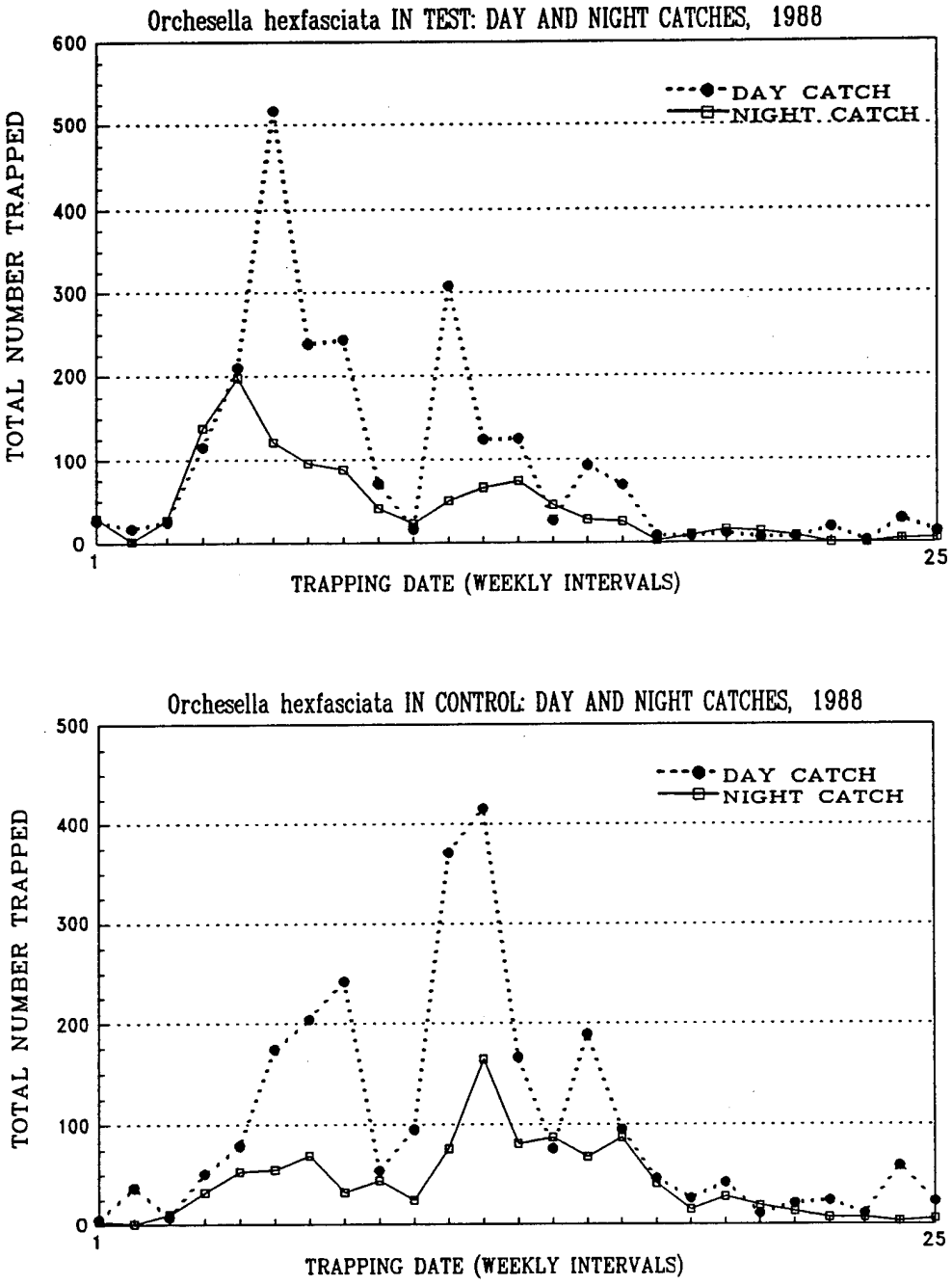



Fig. 52. Total numbers of *O. hexfasciata* captured at weekly intervals in day- and night-traps in Test and Control sites in 1988; Date 1 = May 10-11, Date 25 = October 25-26.

### 1.3. Community structure

Community diversity (H') and equitability (S'/S) calculations were based on date-specific catches of each species, so that yearly means were calculated from 25 or 26 dates /year. **Figs. 53-54** illustrate that both community indices tended to vary between years, and in both sites. This is not surprising, given the often drastic between-year variability in numbers trapped as evidenced by preceding Figures and **Table 12.** Summarized by pre-ELF and operational periods, we find that all significant differences, within each site as well as in terms of differences between sites, were due to increases in diversity and equitability in both sites (**Table 14**). Lacking a true **causative** explanation for annual or seasonal fluctuations in numbers trapped for individual species, we contend that these variations in community structure may simply be due to normal long-term fluctuations in populations coupled with their locomotory responses to year-specific climatic patterns.

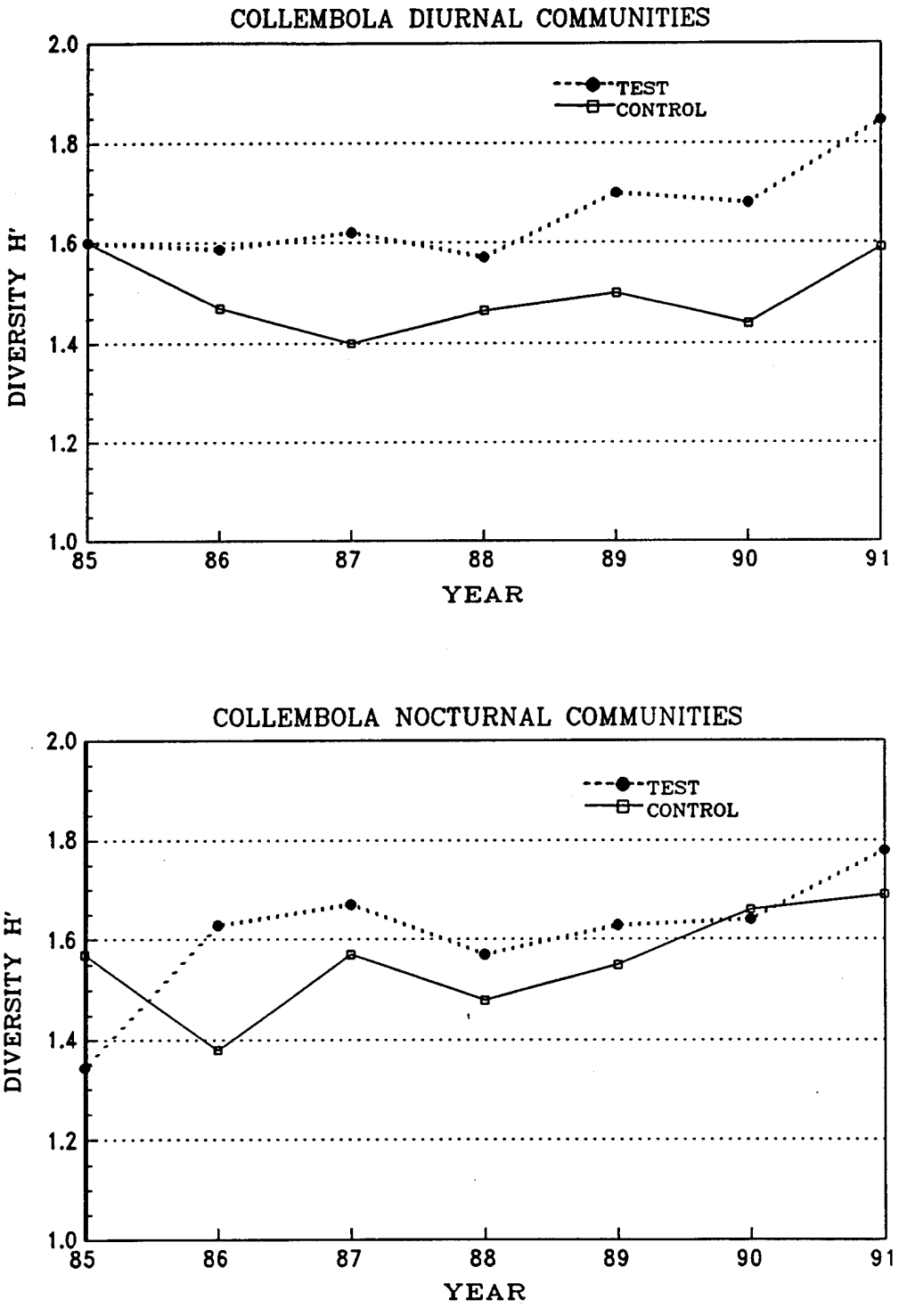



Fig. 53. Mean annual diversity indices for diurnal and nocturnal collembolan communities in Test and Control, 1985-1991 (N= 25 or 26 dates /year).

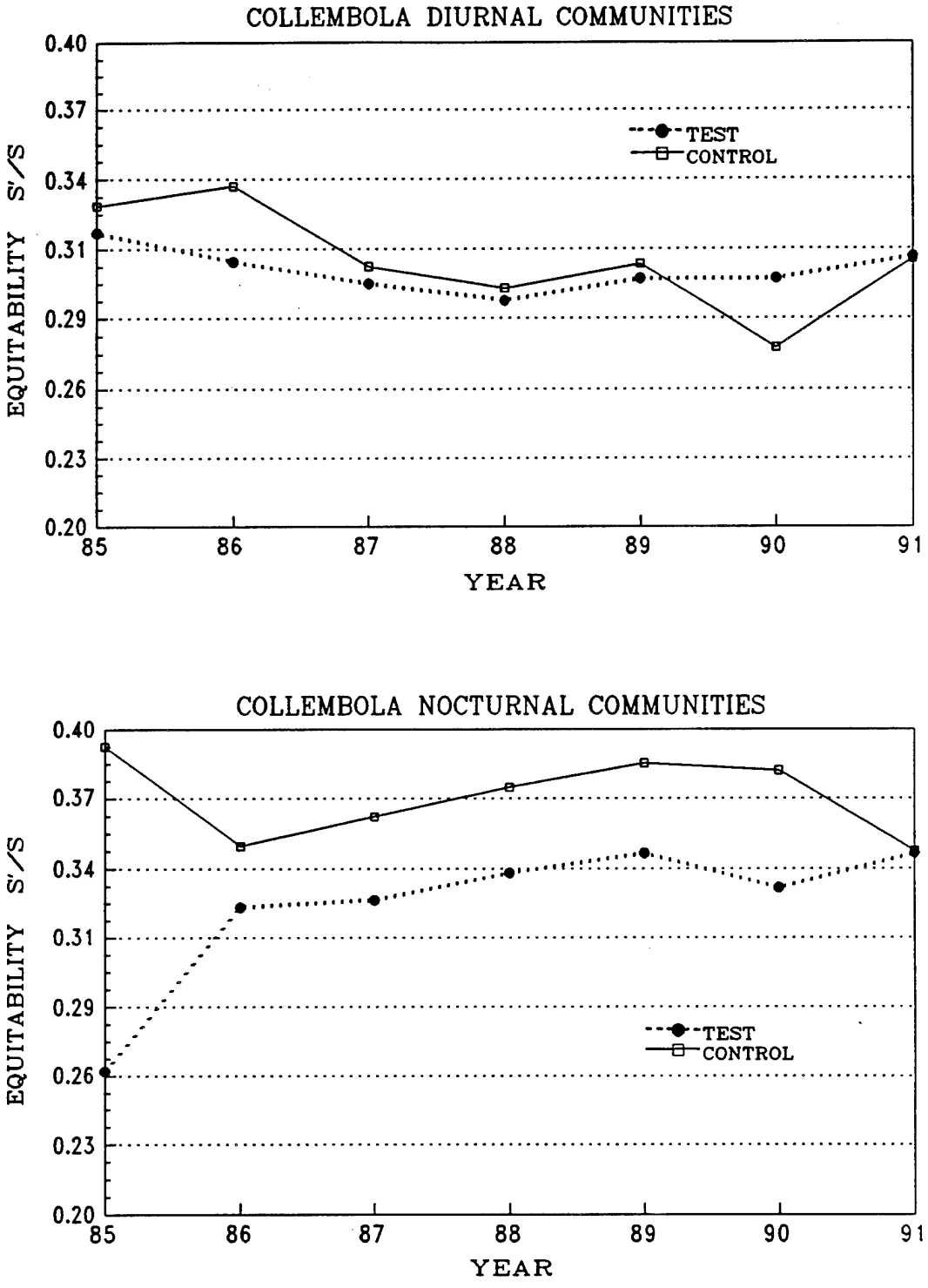



Fig. 54. Mean annual equitability indices for nocturnal and diurnal collembolan communities in Test and Control, 1985-1991 (N= 25 or 26 dates /year).

**Table 14.** Diversity (H') and equitability (S'/S) indices (means ± SD) for surface-active collembolan communities in pre-operational and operational periods. N dates 1985-88 = 103; N dates 1989-91 = 76. "Diurnal" and "Nocturnal" = data based on day- and night-catches respectively; "Total" = data based on total catches of each species during each 24 hour (Day + Night) trapping period.

| | TEST | | | CONTROL | | | CONTROL-TEST BACI |
|---|---|---|---|---|---|---|---|
| | 1985-88 | 1989-91 | P= | 1985-88 | 1989-91 | P= | P= |
| Diurnal | | | | | | | |
| H' | 1.59 ± 0.31 | 1.74 ± 0.34 | 0.03 | 1.48 ± 0.27 | 1.51 ± 0.35 | NS | 0.03 |
| S'/S | 0.31 ± 0.07 | 0.31 ± 0.07 | NS | 0.32 ± 0.07 | 0.30 ± 0.07 | NS | NS |
| Nocturnal | | | | | | | |
| H' | 1.55 ± 0.28 | 1.68 ± 0.23 | 0.001 | 1.50 ± 0.33 | 1.64 ± 0.25 | 0.004 | NS |
| S'/S | 0.31 ± 0.07 | 0.34 ± 0.08 | 0.007 | 0.37 ± 0.09 | 0.37 ± 0.07 | NS | NS |
| Total | | | | | | | |
| H' | 1.71 ± 0.29 | 1.84 ± 0.27 | 0.002 | 1.60 ± 0.27 | 1.65 ± 0.28 | NS | NS |
| S'/S | 0.27 ± 0.05 | 0.28 ± 0.06 | NS | 0.30 ± 0.07 | 0.29 ± 0.06 | NS | NS |

### 1.4. Statistical analyses

Each year was divided into three "seasons" (spring, summer and fall), each consisting of eight dates. Total numbers per trap (day + night summed) were then analyzed by ANOVA, with ELF (pre-ELF and operational periods) and sites as main factors, ELF x site interactions, and traps [within sites] as additional factor. In addition to total Collembola, data for four species satisfied the assumptions for ANOVA: *T. flavescens, O. hexfasciata, S. henshawi* and *S. lepus*.

Condensed results are shown in **Table 15**. Whether entire years or single seasons were examined, it was clear that catches of total Collembola showed no significant numerical deviations (ELF effect) after antenna activation. Neither did *S. henshawi*, despite increased numbers in Test and decreased numbers in Control during operational years. ELF effects were significant in all other species, but no general trends across species was discernible: neither the relative magnitude nor the direction of change were consistent between species (**Table 15**).

In all species, not surprisingly, significant site effects were the rule (ref. also **Table 12**). ELF x site interactions, significant in virtually all cases, indicated that the degree or direction of numerical changes after antenna activation differed between sites.

BACI analyses of full-year data, on the other hand, answered a different question: by using catch ratios ($date_i$ / $date_{i-1}$ ), differences in date-to-date fluctuations (or relative increases and decreases over time) were tested; mean [Control - Test] differences represented the response variables. Results of these tests indicated that seasonal (date-to-date) fluctuations were well synchronized in all four species (**Table 16**).

**Table 15.** ANOVA of collembolan trap catches: selected summary results of testing pre-ELF vs. operational periods; N for LS (Least Squares) means 1985-88 = 240; N for LS (Least Squares) means 1989-91 = 180; ALL = all seasons, all years. Seasons 1, 2 and 3 encompass successive time intervals of approximately 8 weeks each, beginning in early May.

| SPECIES/SEASON | P VALUES FOR FACTORS: | | | LS MEAN TEST | | LS MEAN CONTROL | |
|---|---|---|---|---|---|---|---|
| | ELF | SITE | ELFxSITE | 1985-88 | 1989-91 | 1985-88 | 1989-91 |
| COLLEMBOLA ALL | 0.793 | 0.003 | 0.012 | 21.93 | 20.23 | 22.25 | 24.35 |
| season 1 | 0.110 | 0.877 | 0.007 | | | | |
| season 2 | 0.077 | 0.241 | 0.045 | DECREASE IN TEST, INCREASE IN CONTROL | | | |
| season 3 | 0.131 | 0.000 | 0.205 | | | | |
| *T. flavescens* ALL | 0.000 | 0.000 | 0.000 | 5.11 | 2.59 | 0.69 | 0.32 |
| season 1 | 0.000 | 0.000 | 0.000 | | | | |
| season 2 | 0.000 | 0.000 | 0.014 | EQUAL DECREASES IN BOTH SITES | | | |
| season 3 | 0.000 | 0.000 | 0.005 | | | | |
| *O. hexfasciata* ALL | 0.000 | 0.000 | 0.000 | 7.07 | 3.89 | 3.08 | 3.96 |
| season 1 | 0.000 | 0.000 | 0.000 | | | | |
| season 2 | 0.000 | 0.000 | 0.001 | DECREASE IN TEST, INCREASE IN CONTROL | | | |
| season 3 | 0.000 | 0.000 | 0.000 | | | | |
| *S. henshawi* ALL | 0.305 | 0.000 | 0.000 | 3.83 | 5.67 | 7.07 | 5.75 |
| season 1 | 0.119 | 0.003 | 0.001 | | | | |
| season 2 | 0.132 | 0.227 | 0.000 | INCREASE IN TEST, DECREASE IN CONTROL | | | |
| season 3 | 0.374 | 0.000 | 0.000 | | | | |
| *S. lepus* ALL | 0.000 | 0.000 | 0.000 | 1.19 | 2.78 | 1.29 | 1.59 |
| season 1 | 0.000 | 0.000 | 0.000 | | | | |
| season 2 | 0.000 | 0.897 | 0.124 | MUCH GREATER INCREASE IN TEST | | | |
| season 3 | 0.008 | 0.000 | 0.001 | | | | |

**Table 16.** Results of BACI tests of (Control - Test) differences in trap catches, using ratios of ( catch on $date_i$ / catch on $date_{i-1}$ ), for four collembolan species.

| SPECIES/ PERIOD | N | MEAN DIFF | SD | P |
|---|---|---|---|---|
| *T. flavescens* | | | | |
| 1985-88 | 96 | +0.2259 | 1.5535 | |
| 1989-91 | 68 | +0.0497 | 2.1306 | 0.56 |
| *O. hexfasciata* | | | | |
| 1985-88 | 99 | -0.1197 | 1.6034 | |
| 1989-91 | 73 | -0.0646 | 1.0347 | 0.78 |
| *S. henshawi* | | | | |
| 1985-88 | 99 | -0.0921 | 1.0727 | |
| 1989-91 | 72 | -0.0804 | 1.0513 | 0.94 |
| *S. lepus* | | | | |
| 1985-88 | 94 | -0.0316 | 1.1445 | |
| 1989-91 | 70 | +0.0572 | 1.2074 | 0.63 |

## 2. Acarina

### 2.1. Annual and seasonal fluctuations

Three species were trapped in sufficient numbers to warrant discussion and analysis: *Nanorchestes* sp. A (Actinedida: Nanorchestidae), and the velvet mites *Trombidium auroraense* (Actinedida: Trombidiidae) and *Abrolophus* sp. (Actinedida: Erythraeidae). Total numbers obtained are listed in **Table 17**. Between-year variation was particularly pronounced in *Nanorchestes*, but was appreciable in velvet mites as well.

**Table 17.** Total annual catches of Acarina in Test and Control (nocturnal and diurnal catches, and all developmental stages, summed). T = Test, C = Control.

| | | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 |
|---|---|---|---|---|---|---|---|---|
| *T. auroraense* | T | 206 | 281 | 202 | 291 | 371 | 318 | 253 |
| | C | 599 | 731 | 634 | 748 | 724 | 385 | 246 |
| *Abrolophus* sp. | T | 309 | 335 | 155 | 387 | 200 | 580 | 267 |
| | C | 713 | 431 | 226 | 714 | 282 | 293 | 108 |
| *Nanorchestes* sp. | T | 1322 | 4405 | 1746 | 2216 | 1810 | 3872 | 2539 |
| | C | 808 | 5926 | 2329 | 4984 | 2697 | 2370 | 1350 |

Both *T. auroraense* and *Abrolophus* were strongly diurnal, while *Nanorchestes*, although diurnality predominated, was also captured frequently during nights (**Table 18**), differences between neither sites nor years showing a consistent pattern.

**Table 18.** Percent diurnality [(day catch / total catch per year) x 100] of mites trapped in 1985 - 1991. T = Test, C = Control.

| | | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 |
|---|---|---|---|---|---|---|---|---|
| *T. auroraense* | T | 99.2 | 98.9 | 95.0 | 95.2 | 96.8 | 97.2 | 88.1 |
| | C | 99.5 | 98.5 | 98.6 | 95.2 | 96.1 | 98.2 | 92.7 |
| *Abrolophus* sp. | T | 95.1 | 95.2 | 82.1 | 96.1 | 94.5 | 92.4 | 86.1 |
| | C | 96.9 | 96.3 | 93.8 | 95.8 | 97.2 | 93.2 | 89.8 |
| *Nanorchestes* sp. | T | 60.4 | 66.3 | 58.0 | 82.8 | 63.5 | 52.4 | 59.2 |
| | C | 81.4 | 63.7 | 68.1 | 66.5 | 76.8 | 85.9 | 67.8 |

Weekly catches of *Nanorchestes* (**Fig. 55**) showed that the species was most active during summer months, with particularly pronounced activity peaks in 1986 and 1988 in both sites. Only adults were captured (although it is probable that larvae and nymphs of this as yet undescribed species were simply not recognized).

Activity of *T. auroraense* was highly seasonal: **Fig. 56** illustrates (using the sum of all developmental stages) that the main period of activity occurred from early May to early June. These initial peaks were due almost entirely to adults, which were observed ovipositing in the field at that time. Subsequent lesser peaks were due to larvae and deutonymphs. The species was collected only rarely during the latter part of each season (**Fig. 56**).

The second species of velvet mites, *Abrolophus* sp., exhibited a different life cycle, reflected in distinct, temporally separated activity peaks (**Figs. 57-58**). Larvae were the first to appear in May, followed by deutonymphs, then adults. Deutonymph activity tended to occur earlier in Test than in Control, with the exception of 1985 and 1991, but larval and adult occurrence was well synchronized between sites.

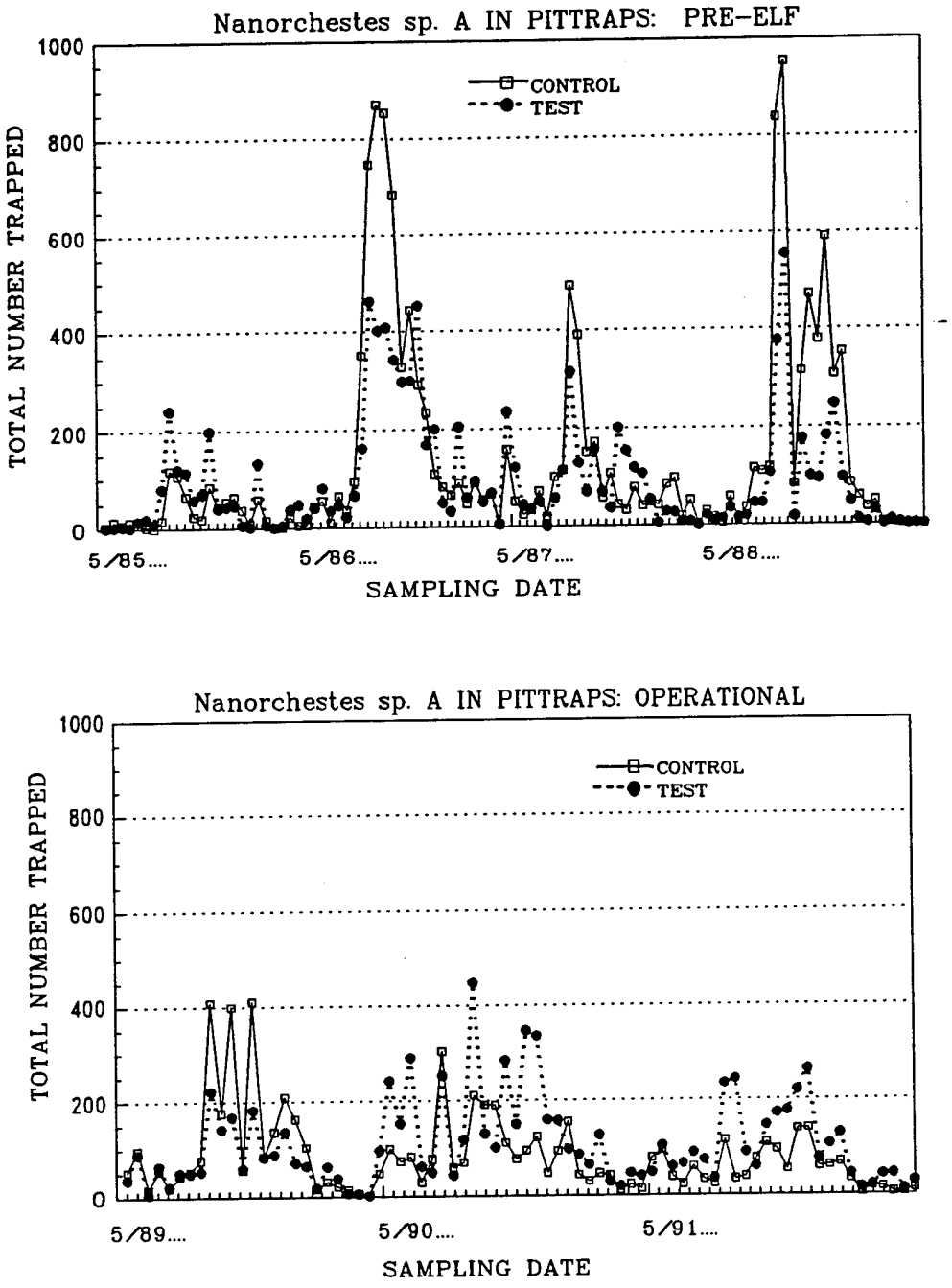



Fig. 55. Total catches of *Nanorchestes* sp. A in Test and Control during pre-ELF and operational years (night and day catches summed for each date).

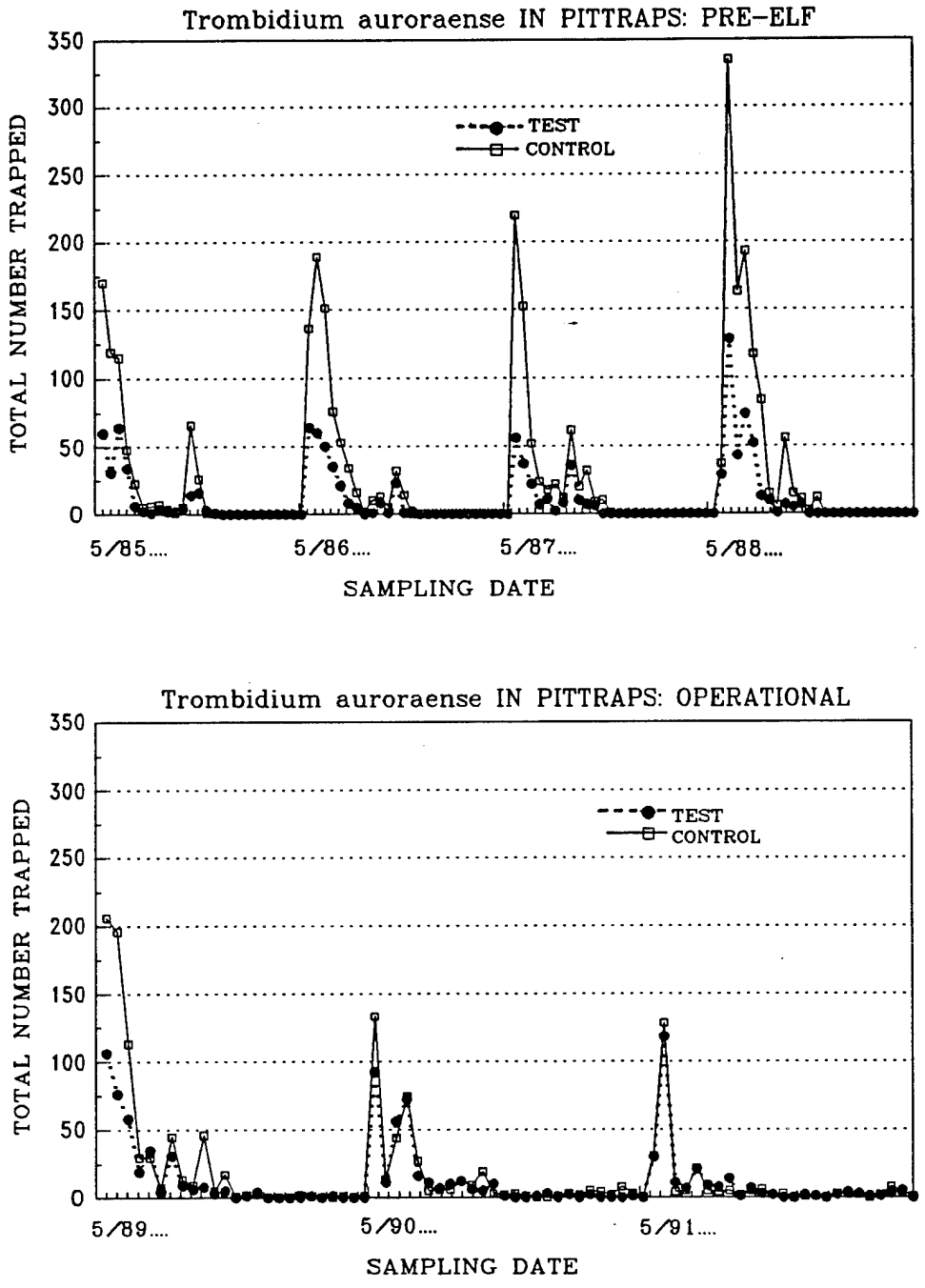



Fig. 56. Total catches of *Trombidium auroraense* per date in Test and Control during pre-ELF and operational years (night and day catches, and developmental stages, summed per date).

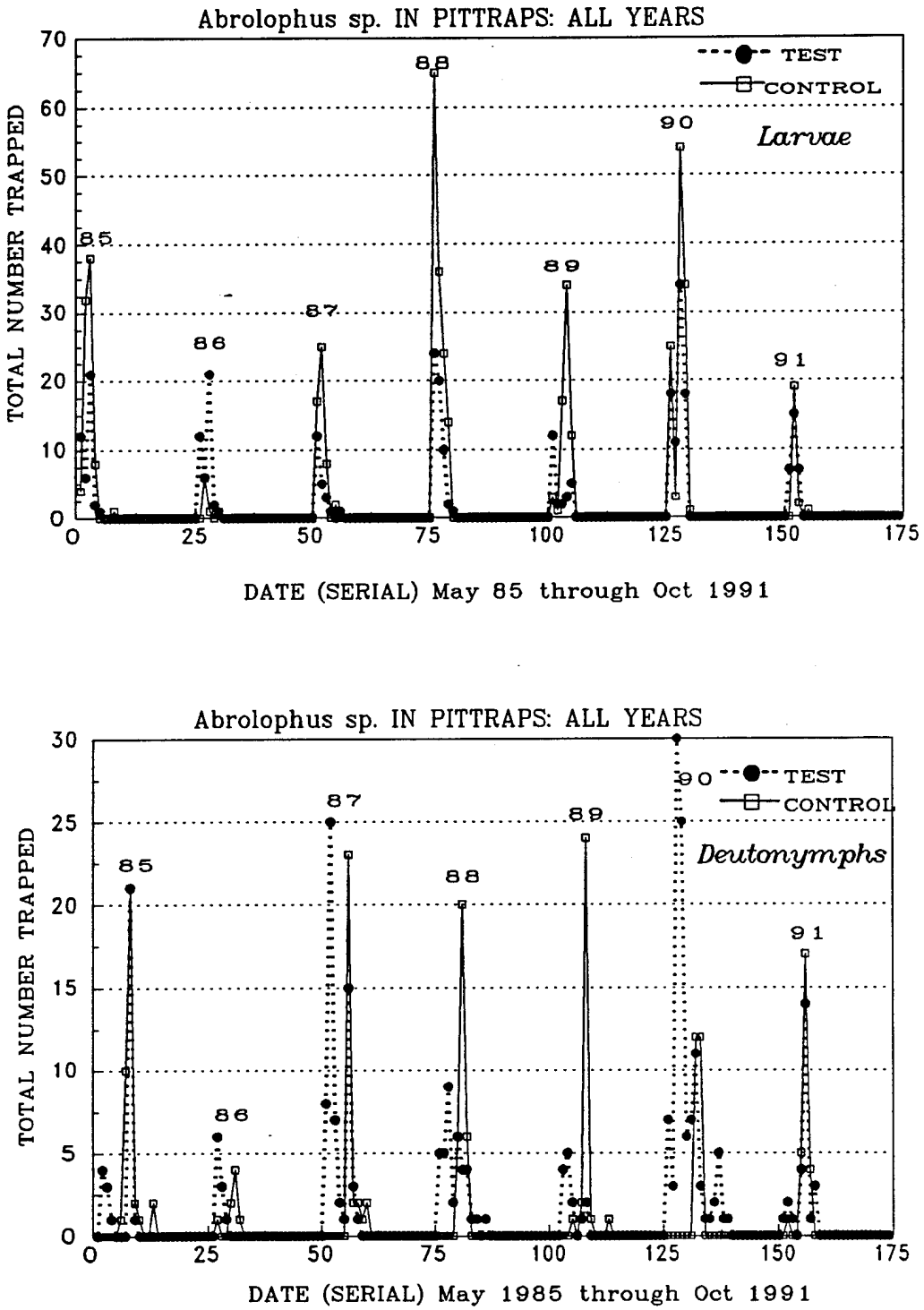



Fig. 57. Total catches per date (night and day catches summed) of larvae and deutonymphs of *Abrolophus* sp. in Test and Control.

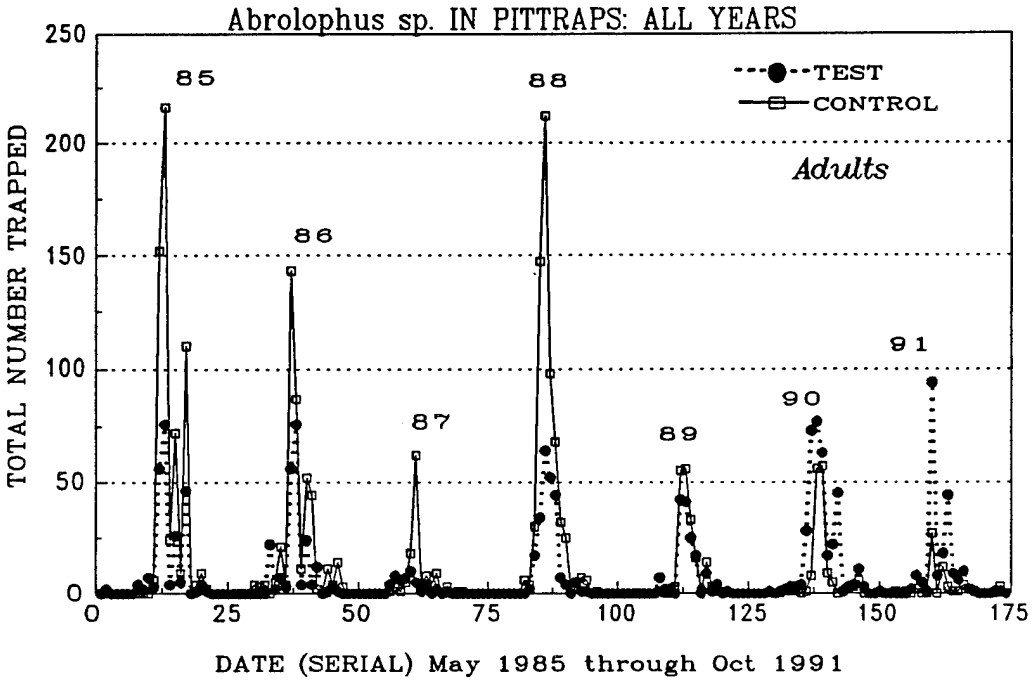



Fig. 58. Total catches of *Abrolophus* sp. adults per date (night and day catches summed) in Test and Control.

Year-specific correlations between weekly Test and Control catches showed that activity was most synchronous in *T. auroraense* (**Table 19**). In the other two species, $R^2$ was generally lower and more variable between years, but no pre-ELF *vs.* operational years pattern was discernible.

**Table 19.** Correlation coefficient ($R^2$) for Test and Control trap catches of Acarina. Night and day catches, and developmental stages, summed per date (N = 25 or 26 dates per year).

| | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 |
|---|---|---|---|---|---|---|---|
| *T. auroraense* | 0.85 | 0.92 | 0.86 | 0.92 | 0.96 | 0.92 | 0.98 |
| *Abrolophus* sp. | 0.94 | 0.86 | 0.62 | 0.72 | 0.83 | 0.63 | 0.57 |
| *Nanorchestes* sp.A | 0.72 | 0.74 | 0.50 | 0.85 | 0.86 | 0.30 | 0.61 |

### 2.2. Statistical analyses

All late-season dates for *Abrolophus* and *T. auroraense* were disregarded, since these species hibernate or become inactive long before the end of the trapping season. Data for these two species were also summed over all stages, and those for *Abrolophus* were further combined over 2-week intervals in order to overcome occasional low numbers trapped.

In all three mite species, trap catches were transformed to ratios of [present date / previous date catch]. Differences between ratios (Control - Test) were then subjected to BACI analysis. None of the means for pre-ELF and operational periods differed significantly (**Table 20**).

**Table 20.** Results of BACI analysis of (Control-Test) differences in trap catches, after serial differencing (catch on $date_i$ / catch on $date_{i-1}$), for three acarine species.

| SPECIES/ PERIOD | N | MEAN DIFF. | SD | P |
|---|---|---|---|---|
| *Abrolophus sp.* | | | | |
| 1985-88 | 44 | -0.773 | 48.573 | |
| 1989-91 | 33 | +0.848 | 30.808 | 0.86 |
| *T. auroraense* | | | | |
| 1985-88 | 34 | -0.572 | 3.299 | |
| 1989-91 | 31 | +0.122 | 1.155 | 0.26 |
| *Nanorchestes sp. A* | | | | |
| 1985-88 | 96 | -0.364 | 2.090 | |
| 1989-91 | 73 | -0.023 | 1.373 | 0.25 |

## 3. Carabidae

### 3.1. Annual fluctuations and seasonal activity

Total numbers captured per year of each of the 20-odd species in each site are summarized in **Table 21**. With the exception of a few rare species, species composition of the carabid communities was similar in Test and Control, although dominance relationships were unequal: i.e., *Pterostichus melanarius* was strongly dominant in Test, while several species were essentially co-dominant in Control (variable between years).

Between-year variation in numbers captured was often considerable (e.g., *P. melanarius* in Test or *Synuchus impunctatus* in Control). A general decline in total numbers during the last 2 or 3 years was one of the reasons which prompted us to discontinue trapping after 1991.

Examples of seasonal activity patterns, which are determined mainly by reproductive cycles (Loreau 1985) are shown in **Figs. 59-63**. Typical "summer breeders" were represented by *P. melanarius*, *S. impunctatus*, *P. coracinus* and *Harpalus fuliginosus* (**Figs. 59-62**), in which the majority of individuals overwinter as larvae, and adults are most active in mid-summer. *Pterostichus pensylvanicus*, on the other hand, overwintered mainly as adults, which became active early in the season and oviposited. The resulting larvae matured during summer and fall, and teneral adults contributed to secondary activity peaks in late fall (**Fig. 63**).

**Table 21.** Total annual numbers of Carabidae captured in Test and Control sites throughout the study period (a complete checklist of species is given in **Appendix 7**).

| | TEST SITE | | | | | | | CONTROL SITE | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 |
| *P. melanarius* | 1087 | 1163 | 643 | 1528 | 1066 | 851 | 504 | 183 | 222 | 356 | 299 | 161 | 177 | 118 |
| *P. coracinus* | 146 | 163 | 134 | 61 | 85 | 70 | 120 | 263 | 450 | 335 | 306 | 321 | 303 | 262 |
| *P. pensylvanicus* | 206 | 179 | 102 | 74 | 98 | 135 | 77 | 278 | 247 | 176 | 130 | 85 | 90 | 109 |
| *P. adstrictus* | 19 | 6 | 11 | 3 | 1 | - | - | 253 | 172 | 106 | 18 | 38 | 23 | 15 |
| *P. adoxus* | 2 | 14 | 20 | 4 | 11 | 7 | 22 | 30 | 20 | 22 | 9 | 13 | 29 | 25 |
| *P. mutus* | 232 | 203 | 210 | 102 | 153 | 182 | 300 | 24 | 15 | 26 | 12 | 57 | 25 | 58 |
| *Calathus* spp. | 81 | 40 | 32 | 23 | 31 | 41 | 76 | 290 | 157 | 130 | 71 | 72 | 44 | 84 |
| *C. frigidum* | 67 | 139 | 406 | 132 | 12 | 2 | 2 | 29 | 107 | 185 | 31 | 5 | 6 | 4 |
| *S. impunctatus* | 103 | 261 | 104 | 74 | 49 | 145 | 205 | 700 | 894 | 367 | 157 | 88 | 293 | 471 |
| *A. retractum* | 17 | 20 | 26 | 3 | 6 | 13 | 2 | 13 | 3 | - | - | 1 | 2 | - |
| *A. decentis* | 17 | 23 | 17 | 6 | 5 | 10 | 9 | 73 | 58 | 37 | 15 | 5 | 11 | 2 |
| *H. fuliginosus* | 76 | 139 | 71 | 124 | 79 | 88 | 80 | 55 | 116 | 61 | 88 | 83 | 84 | 101 |
| *C. fossor* | 49 | 49 | 52 | 48 | 44 | 28 | 23 | 5 | 6 | 7 | 3 | 5 | 3 | 5 |
| *C. cribricollis* | 25 | 54 | 23 | 24 | 32 | 21 | 21 | 35 | 115 | 66 | 44 | 35 | 31 | 61 |
| *N. aeneus* | 31 | 34 | 44 | 41 | 54 | 26 | 32 | 46 | 26 | 36 | 3 | 7 | 13 | 2 |
| *M. cyanescens* | 1 | 4 | 3 | 3 | 1 | 3 | 5 | 14 | 14 | 6 | 3 | 9 | 25 | 24 |
| *S. lecontei* | 5 | 5 | 10 | - | 4 | 2 | 2 | 9 | 13 | 10 | 13 | 9 | 6 | 2 |
| *A. placidum* | 2 | - | - | - | 1 | - | 1 | - | - | - | - | - | - | - |
| *C. sylvosus* | 1 | - | - | - | 3 | 3 | 5 | 3 | 3 | 11 | 8 | 2 | - | - |
| *B. quadrimaculatum* | - | - | 3 | 2 | 3 | 1 | 5 | 2 | - | 1 | - | - | 1 | 2 |
| *H. fulvilabris* | - | 6 | 1 | 4 | 2 | - | 1 | 2 | - | - | 10 | - | - | - |
| *M. americanus* | - | - | - | 2 | - | - | - | - | - | - | - | - | - | 1 |
| *H. lewisi* | - | - | - | 1 | - | 3 | - | - | - | - | 2 | - | 2 | - |
| *A. permundus* | - | - | - | 1 | - | - | - | - | - | - | - | - | - | - |
| *Dischirius* sp. | - | - | - | 2 | - | - | 1 | - | - | - | - | - | - | - |
| *Amara* sp. | - | - | - | 8 | 1 | 3 | - | - | - | - | 1 | - | - | - |
| *P. corvus* | - | - | - | - | - | - | - | - | - | - | - | - | 1 | - |
| *D. assimilis* | - | - | - | - | - | - | - | - | - | - | - | - | 1 | - |
| *C. serratus* | - | - | - | - | - | - | - | - | - | - | - | 1 | - | - |
| *P. honestus* | - | - | - | - | - | - | - | - | - | - | - | - | - | 1 |
| *P. haematopus* | - | - | - | - | - | 1 | - | - | - | - | - | - | - | - |
| *P. bryantoides* | - | - | - | - | - | - | 1 | - | - | - | - | - | - | - |
| *B. pseudocautum* | - | - | - | - | - | 1 | - | - | - | - | - | - | - | - |
| *C. granulatus* | - | - | - | - | 1 | - | 1 | - | - | - | - | - | - | - |
| **TOTAL** | 2168 | 2506 | 1913 | 2261 | 1748 | 1637 | 1499 | 2307 | 2639 | 1936 | 1222 | 997 | 1170 | 1346 |
| **NUMBER OF SPECIES** | 20 | 19 | 19 | 23 | 23 | 22 | 23 | 20 | 19 | 18 | 20 | 19 | 21 | 19 |

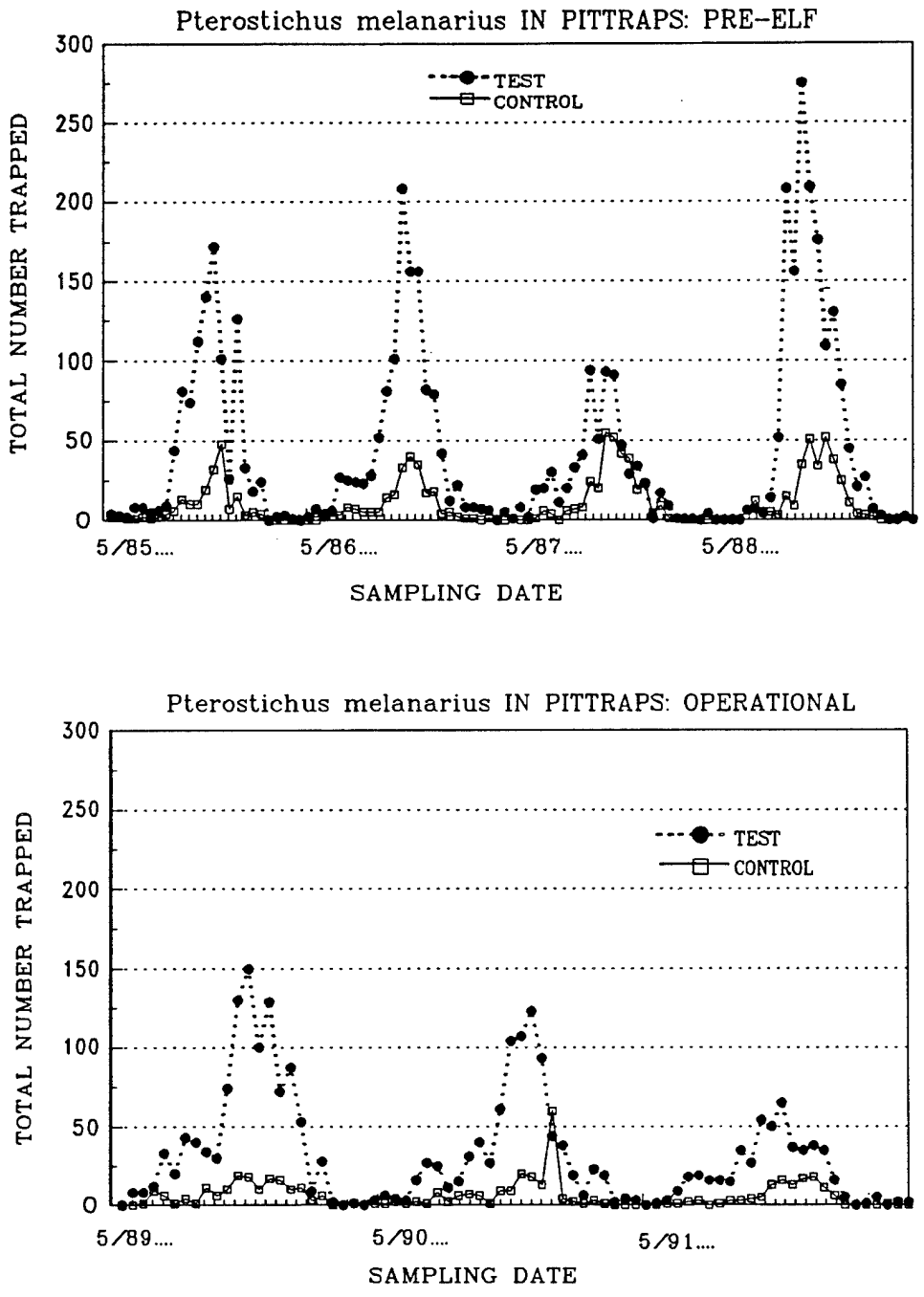



Fig. 59. Total weekly catches of *Pterostichus melanarius* in Test and Control sites, early May to late October of pre-ELF and operational years.

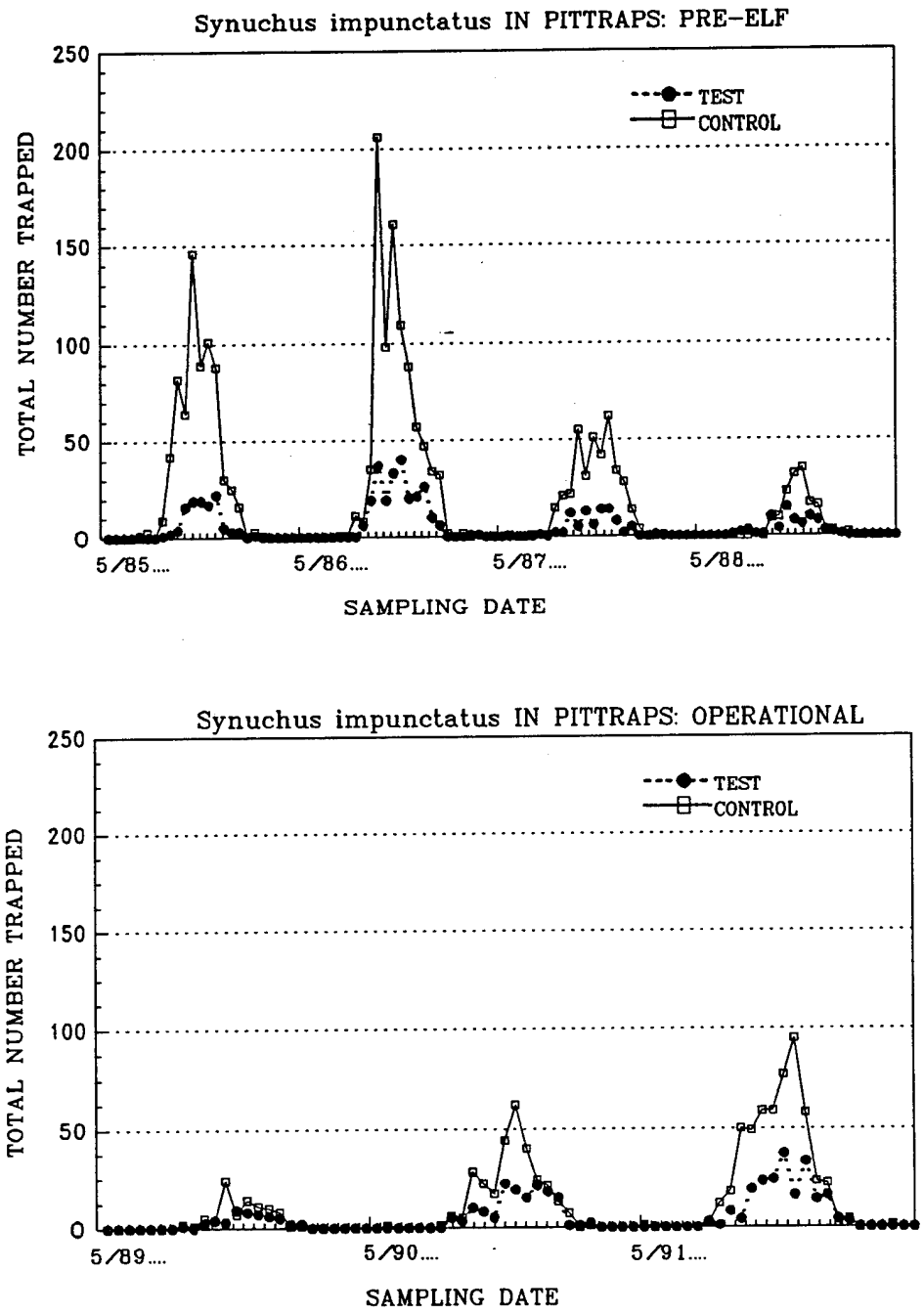



Fig. 60. Total weekly catches of *Synuchus impunctatus* in Test and Control sites, early May to late October of pre-ELF and operational years.

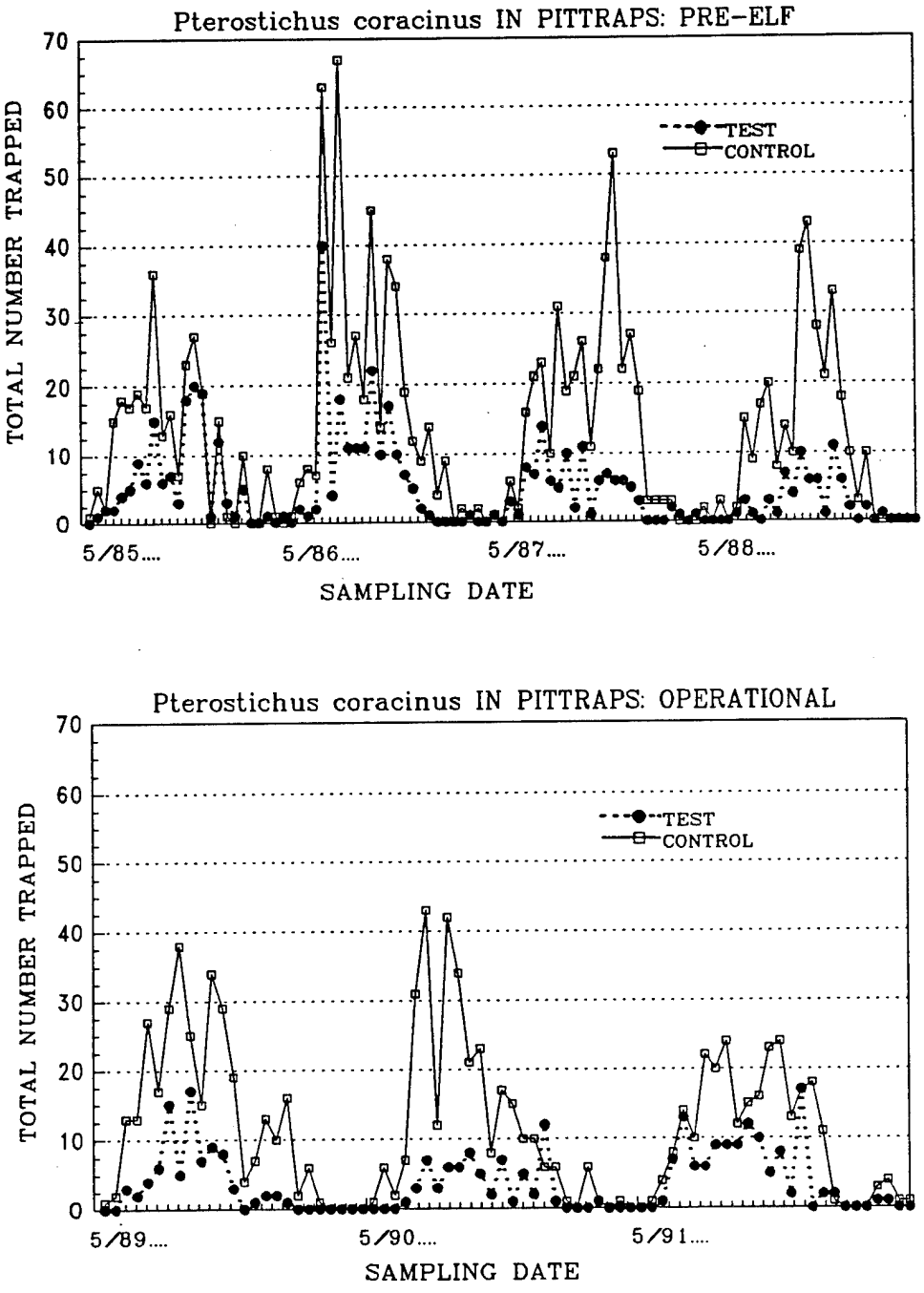



Fig. 61. Total weekly catches of *Pterostichus coracinus* in Test and Control sites, early May to late October of pre-ELF and operational years.

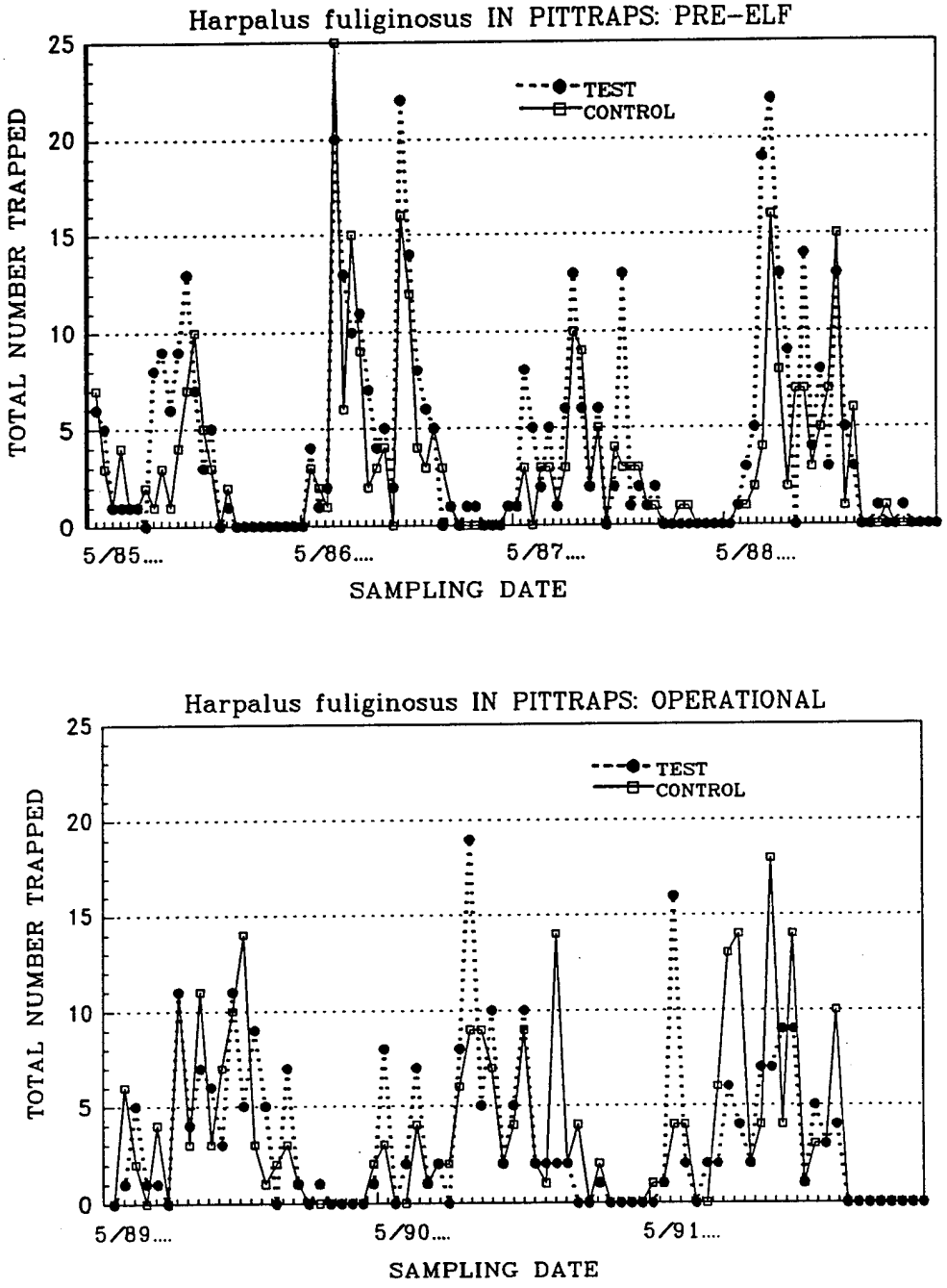



Fig. 62. Total weekly catches of *Harpalus fuliginosus* in Test and Control sites, early May to late October of pre-ELF and operational years.

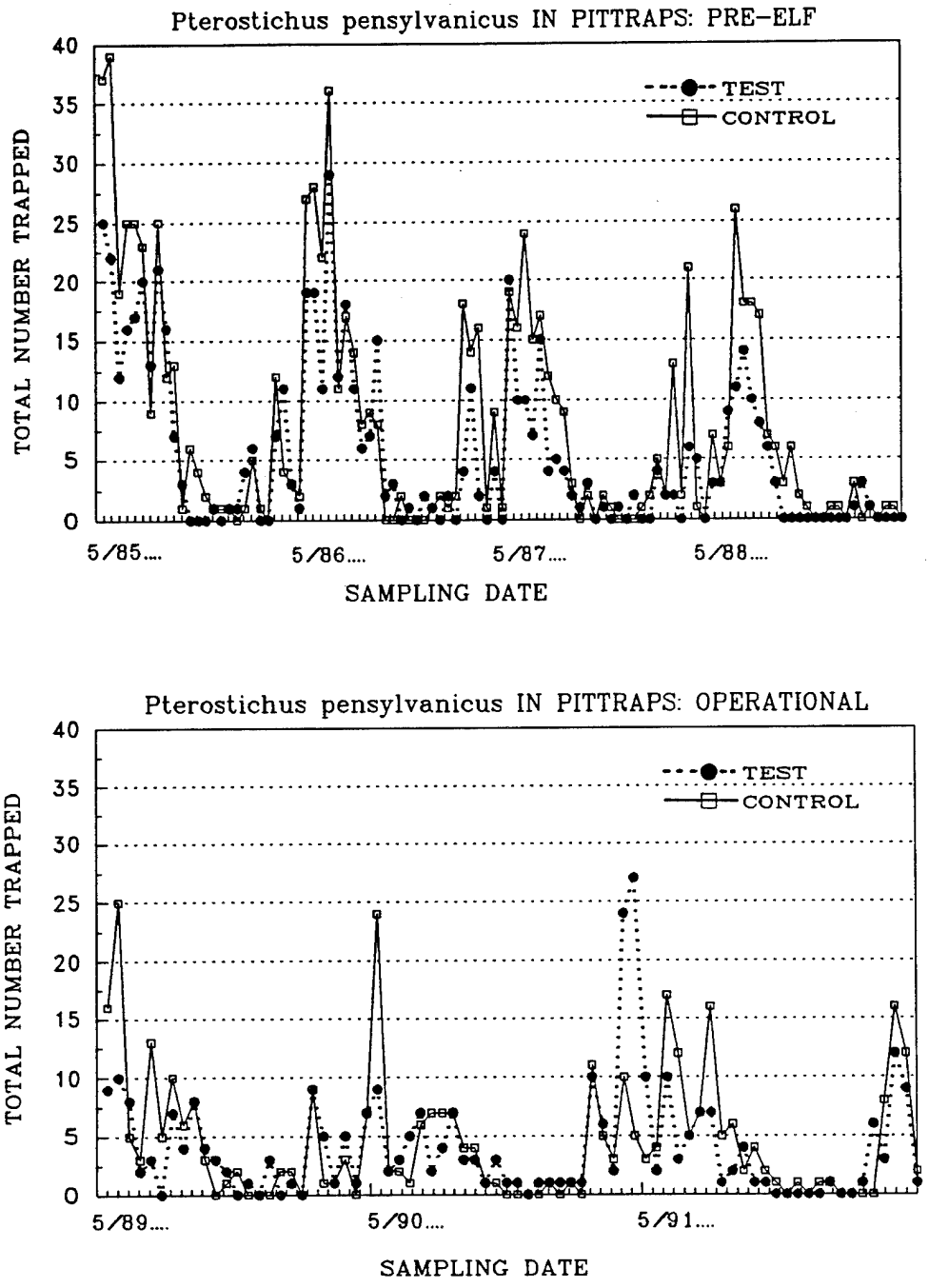



Fig. 63. Total weekly catches of *Pterostichus pensylvanicus* in Test and Control sites, early May to late October of pre-ELF and operational years.

### 3.2. Diel activity and sex ratios

In some species, a surprising degree of variability between years was observed with respect to diel activity. For instance, based on total numbers captured per year, *P. melanarius* was mainly day-active in 1985 and 1990, almost equally day- and night-active in 1986 and 1989, and mainly nocturnal in all other years (**Table 22**). Other species showed more constant diel preferences: *Clivina fossor, H. fuliginosus* and particularly *Notiophilus aeneus* were strongly diurnal; *Cymindis cribricollis* was almost exclusively nocturnal. To some degree, our results were in accordance with Thiele (1979) and Thiele and Weber (1968), namely that forest carabids tend to be night-active, and field carabids (such as *Clivina fossor*) tend to be day-active.

In *Calosoma frigidum*, decreased diurnality in 1988 (**Table 22**) coincided with reproductive failure in both sites (none of the females ever carried ripe ova), followed by virtual disappearance of the species from both sites. Potential causes for this anomaly range from discrepancies in environmental factors needed for full ovarian development (Thiele 1979) to low prey density (Jeffords and Case 1987). In other species as well, we have been unable to succinctly relate changes in diurnality to any known reproductive or environmental factors.

Year-to-year shifts in diurnality were often synchronous in both sites (e.g., $R^2$ for *P. melanarius* = 0.62, $R^2$ for *P. coracinus* = 0.72), and did not seem related to antenna activation in any of the common species. Furthermore, the annual summary data in **Table 22** were not a result of a few single-date outlying catches. Rather, diel patterns seemed consistent throughout each trapping season. For example, numbers of *P. melanarius* in the Test site were consistently higher in day traps in 1985, and were consistently higher in night traps in 1991 (**Fig. 64**).

**Table 22.** Percent diurnality [(day catch / total catch) x 100] of carabid species commonly occurring in either or both sites, based on total annual catches in Test (T) and Control (C).

| SPECIES | YEAR | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | SITE | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 |
| *P. melanarius* | T | 71.8 | 47.7 | 34.7 | 38.6 | 49.6 | 71.3 | 30.7 |
| | C | 73.8 | 50.0 | 31.2 | 39.1 | 27.3 | 58.2 | 39.8 |
| *P. pensylvanicus* | T | 33.5 | 26.8 | 31.4 | 16.2 | 30.1 | 63.0 | 44.2 |
| | C | 36.0 | 33.6 | 32.4 | 18.5 | 33.6 | 34.3 | 48.4 |
| *P. coracinus* | T | 55.5 | 27.6 | 22.4 | 14.5 | 29.4 | 40.0 | 34.2 |
| | C | 60.5 | 38.4 | 25.3 | 5.9 | 18.1 | 28.7 | 23.7 |
| *S. impunctatus* | T | 50.5 | 37.9 | 22.1 | 36.5 | 36.7 | 31.7 | 27.3 |
| | C | 36.4 | 31.9 | 34.1 | 33.1 | 69.3 | 35.8 | 31.8 |
| *H. fuliginosus* | T | 86.8 | 82.7 | 81.7 | 82.3 | 78.5 | 87.5 | 70.0 |
| | C | 89.1 | 87.1 | 85.2 | 82.9 | 68.7 | 69.0 | 74.2 |
| *C. frigidum* | T | 98.5 | 85.6 | 80.8 | 56.1 | - | - | - |
| | C | 86.2 | 86.0 | 71.4 | 38.7 | - | - | - |
| *N. aeneus* | T | 100.0 | 100.0 | 100.0 | 97.6 | 100.0 | 100.0 | 90.6 |
| | C | 95.7 | 100.0 | 97.2 | 100.0 | - | - | - |
| *C. cribricollis* | T | 0.0 | 0.0 | 0.0 | 0.0 | 6.4 | 9.5 | 9.5 |
| | C | 0.0 | 0.0 | 1.5 | 2.2 | 2.9 | 0.0 | 0.0 |
| *C. fossor* | T | 89.8 | 71.4 | 80.8 | 83.3 | 86.4 | 75.0 | 78.3 |
| | C | - | - | - | - | - | - | - |
| *P. mutus* | T | 19.8 | 15.3 | 19.5 | 13.7 | 24.2 | 6.6 | 38.3 |
| | C | - | - | - | - | - | - | - |

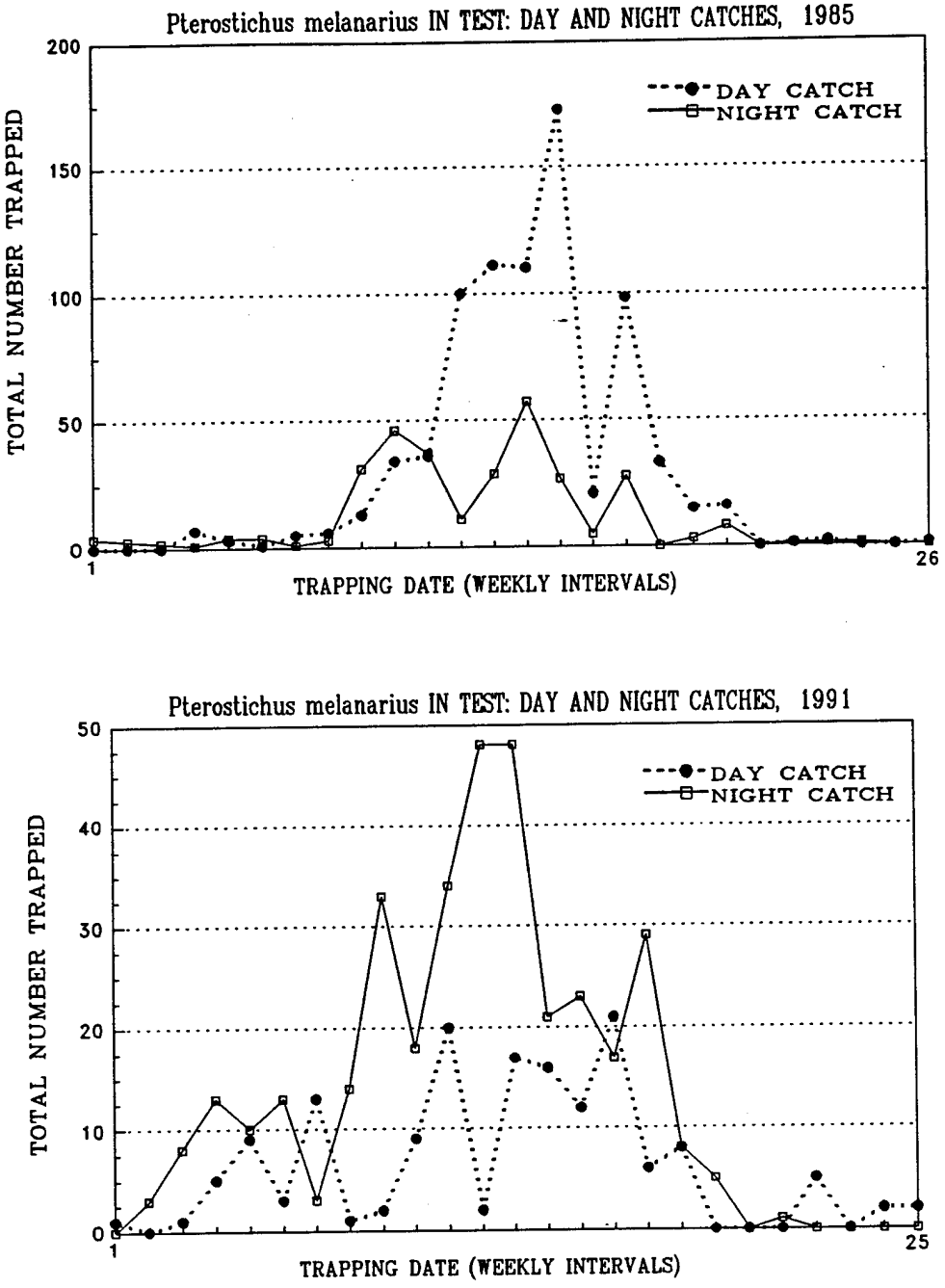



Fig. 64. Diurnal and nocturnal catches of *P. melanarius* in the TEST site at weekly intervals in 1985 and 1991; total N individuals = 1087 and 504 in 1985 and 1991 respectively. In 1985, Date 1 = May 7-8, Date 26 = Oct 28-29; In 1991, Date 1 = May 6-7, Date 25 = Oct 22-23.

Attempts to correlate diel activity patterns and variations in sex ratios were not successful. With only a few exceptions (and these were not related to diel activity preferences) males tended to outnumber females in all years (**Table 23**). Only in *P. mutus* (data not shown in detail) could we detect somewhat stable frequencies of males in day- and night-traps: night catches consisted of 58 to 68 percent males in all years, while day catches tended to be dominated by females in all years.

We are currently unable to explain between-year variations in either diel activity shifts or sex ratios; there is no evidence, however, for linking these shifts to antenna activation, since they occurred during pre-ELF as well as operational periods.

**Table 23.** Annual percent males (day and night catches summed) in selected carabid species, 1985 to 1991, based on total numbers captured per year (T= Test, C = Control).

| SPECIES | SITE | YEAR | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 |
| *P. melanarius* | T | 61.6 | 59.6 | 68.1 | 57.8 | 70.8 | 71.4 | 82.5 |
| | C | 73.1 | 70.9 | 87.5 | 66.8 | 72.7 | 78.5 | 80.5 |
| *P. pensylvanicus* | T | 61.3 | 59.2 | 51.9 | 38.9 | 41.9 | 59.3 | 54.5 |
| | C | 53.8 | 70.4 | 70.0 | 44.5 | 61.5 | 62.9 | 55.7 |
| *P. coracinus* | T | 58.9 | 64.8 | 62.9 | 55.4 | 67.1 | 75.7 | 76.7 |
| | C | 68.3 | 65.2 | 61.9 | 51.2 | 60.0 | 73.3 | 63.7 |
| *S. impunctatus* | T | 83.2 | 68.6 | 72.9 | 53.3 | 67.3 | 70.3 | 66.8 |
| | C | 46.4 | 49.9 | 50.0 | 44.7 | 54.5 | 50.2 | 51.6 |
| *H. fuliginosus* | T | 48.7 | 49.6 | 49.3 | 57.3 | 57.0 | 64.8 | 52.5 |
| | C | 69.1 | 63.8 | 55.4 | 53.5 | 48.2 | 50.0 | 51.5 |

### 3.3. Community structure

Community diversity (H') and equitability (S'/S) indices were obtained from date-specific catches of each species. Summarized by pre-ELF and operational periods, it is evident that community structure did not fluctuate in the Test site, but that diversity estimates decreased in the Control site during operational years (**Table 24**). This change in community structure (in Control only) resulted in BACI results being significant at $P < 0.04$, since the magnitude of differences between sites increased relative to the stable estimates in Test.

### 3.4. Statistical analyses

Catches from individual traps /date were summed (males + females and night + day), 20 traps /site thus providing the experimental unites on which ANOVA was based. Data for each year were divided into three seasons, each encompassing eight dates (approx. May-June, July-August, and September-October). Numerical changes were then tested by ANOVA for all seasons, and for each season separately, using the factors ELF (pre-ELF vs. operational periods), sites, ELF x site interactions, and traps [within sites].

Condensed results of ANOVA are given in **Table 25**. The season(s) in which activity of each species was most pronounced yielded most of the significant results with respect to ELF effects as well as with respect to ELF x site interactions. This is not surprising, since main periods of activity yielded the largest numbers of animals and were thus more susceptible to showing differences. Site effects were uniformly significant (for all seasons) in *P. melanarius, P. coracinus* and *S. impunctatus*, but not in *P. pensylvanicus* and *H. fuliginosus* (**Table 25**).

**Table 24.** Diversity (H') and equitability (S'/S) indices (means ± SD) for surface-active carabid communities in Test and Control sites, and results of [Control - Test] BACI analyses. N dates = 95 for 1985-1988; N dates = 73 for 1989-1991. "Diurnal" and "Nocturnal" = data based on day- and night-catches respectively; "Total" = data based on total catches of each species during each 24 hour (Day + Night) trapping period.

| | TEST | | | CONTROL | | | BACI |
|---|---|---|---|---|---|---|---|
| **Parameter** | 1985-88 | 1989-91 | P= | 1985-88 | 1989-91 | P= | P= |
| Diurnal H' | 1.11 ± 0.51 | 1.08 ± 0.51 | NS | 1.21 ± 0.40 | 1.03 ± 0.31 | 0.004 | 0.04 |
| S'/S | 0.43 ± 0.13 | 0.43 ± 0.12 | NS | 0.50 ± 0.11 | 0.53 ± 0.11 | NS | NS |
| Nocturnal H' | 1.18 ± 0.43 | 1.17 ± 0.34 | NS | 1.42 ± 0.38 | 1.31 ± 0.39 | NS | NS |
| S'/S | 0.40 ± 0.12 | 0.43 ± 0.12 | NS | 0.44 ± 0.10 | 0.46 ± 0.89 | NS | NS |
| Total H' | 1.32 ± 0.51 | 1.27 ± 0.44 | NS | 1.55 ± 0.40 | 1.36 ± 0.42 | 0.003 | 0.04 |
| S'/S | 0.38 ± 0.17 | 0.41 ± 0.16 | NS | 0.43 ± 0.14 | 0.44 ± 0.13 | NS | NS |

**Table 25.** ANOVA of carabid trap catches: selected summary results of testing pre-ELF vs. operational periods; N for LS (Least Squares) means 1985-88 = 240; N for LS (Least Squares) means 1989-91 = 180. Highlighted **seasons** indicate main activity periods. Seasons 1, 2 and 3 encompass successive time intervals of 8 weeks each, beginning in early May. ALL = data for entire pre-ELF *vs.* operational periods, without dividing years into seasons.

| SPECIES /SEASON | P VALUES FOR FACTORS: | | | LS MEAN TEST | | LS MEAN CONTROL | |
|---|---|---|---|---|---|---|---|
| | ELF | SITE | ELF X SITE | 1985-88 | 1989-91 | 1985-88 | 1989-91 |
| *P. melanarius* ALL | 0.000 | 0.000 | 0.098 | 2.264 | 1.640 | 0.534 | 0.304 |
| season 1 | 0.329 | 0.000 | 0.040 | | | | |
| **season 2** | 0.000 | 0.000 | 0.000 | DECREASE IN BOTH SITES | | | |
| season 3 | 0.010 | 0.000 | 0.740 | | | | |
| *P. pensylvanicus* ALL | 0.000 | 0.018 | 0.003 | 0.284 | 0.199 | 0.414 | 0.185 |
| **season 1** | 0.000 | 0.000 | 0.015 | | | | |
| season 2 | 0.002 | 0.751 | 0.114 | DECREASE IN BOTH SITES | | | |
| **season 3** | 0.000 | 0.870 | 0.000 | | | | |
| *P. coracinus* ALL | 0.003 | 0.000 | 0.403 | 0.250 | 0.188 | 0.718 | 0.608 |
| season 1 | 0.423 | 0.000 | 0.654 | | | | |
| **season 2** | 0.000 | 0.000 | 0.024 | DECREASE IN BOTH SITES | | | |
| season 3 | 0.252 | 0.000 | 0.619 | | | | |
| *S. impunctatus* ALL | 0.001 | 0.000 | 0.000 | 0.256 | 0.259 | 1.070 | 0.569 |
| season 1 | 0.360 | 0.000 | 0.222 | | | | |
| **season 2** | 0.000 | 0.000 | 0.000 | DECREASE IN CONTROL ONLY | | | |
| season 3 | 0.302 | 0.000 | 0.002 | | | | |
| *H. fuliginosus* ALL | 0.420 | 0.188 | 0.037 | 0.215 | 0.170 | 0.162 | 0.182 |
| **season 1** | 0.000 | 0.104 | 0.072 | | | | |
| **season 2** | 0.264 | 0.179 | 0.202 | DECREASE IN TEST, INCREASE IN CONTROL | | | |
| **season 3** | 0.000 | 0.006 | 0.016 | | | | |

BACI tests represent a simpler approach which, in effect, assesses potential **date-to-date differences** in activity. Tests of mean differences (Control - Test) in ratios of catches ($date_i$ / $date_{i-1}$) during pre-ELF and operational periods showed that fluctuations in activity did not differ significantly between sites after antenna activation **(Table 26)**.

**Table 26.** Results of BACI tests of (Control-Test) differences in trap catches, based on ratios of (catch on $date_i$ / catch on $date_{i-1}$), for five carabid species; males and females, and night and day catches, summed per date; N variable due to variable numbers of zero captures in each species.

| SPECIES/ PERIOD | N | MEAN DIFF. | SD | P |
|---|---|---|---|---|
| *P. melanarius* | | | | |
| 1985-88 | 77 | -0.2237 | 1.9924 | |
| 1989-91 | 57 | 0.4681 | 2.3443 | 0.075 |
| *P. pensylvanicus* | | | | |
| 1985-88 | 61 | 0.2379 | 1.4172 | |
| 1989-91 | 49 | -0.2455 | 1.6936 | 0.113 |
| *P. coracinus* | | | | |
| 1985-88 | 70 | -0.2792 | 2.3153 | |
| 1989-91 | 49 | -0.3687 | 1.7420 | 0.810 |
| *S. impunctatus* | | | | |
| 1985-88 | 47 | 0.0191 | 1.3974 | |
| 1989-91 | 38 | -0.0021 | 1.9921 | 0.956 |
| *H. fuliginosus* | | | | |
| 1985-88 | 61 | 0.3204 | 2.4668 | |
| 1989-91 | 45 | 0.0542 | 2.9981 | 0.628 |

## C. SUMMARY AND DISCUSSION

### 1. Collembola:

In none of the Collembola commonly trapped in either site (**Table 12**) could we detect significant correlations between catch size and annual abundance (**Appendix 5**). Only in *Orchesella hexfasciata* and *Tomocerus flavescens* did there appear to be some relationship: decreased abundance in 1988 was coincident with severe drought, and slow recovery of these (probably) univoltine species may have resulted in low catches in 1989. However, low abundances in Test in 1993 (**Appendix 5**) did not produce proportionally lower trap catches in that site (ref. also Discussion in section III. C.).

Factors determining catch size include trap design and spacing (Joosse 1965; Snider and Snider 1986), which were kept constant across sites and years. Extrinsic factors include temperature and relative humidity or saturation deficit (Joosse *et al.* 1970; Joosse 1981), barometric pressure (Zettel 1984) and light intensity (Desender *et al.* 1984). Given the close climatic similarity between sites, relative fluctuations over time in Test and Control catches should not have been significant; indeed, BACI tests showed that ratios of successive catches were not altered by antenna activation in several species.

Variations in total trap catches over the years (for single species) are not easily explained, especially in view of the lack of long-term information in the literature. Whether intrinsic tendencies for surface-activity can be altered by absolute abundance is not known. However, activity can vary with developmental state (Joosse 1969; Aitchison 1984; Desender *et al.* 1984). If population structure differed between sites at any given point in time, catch size could have been affected by an unquantifiable (short of measuring all specimens) source of variation.

In summary, we concluded that significant differences between pre-ELF and operational periods attested to changes in activity and/or density which could not be attributed to EM fields: increased or decreased catch sizes occurred in Control as well as in Test, with little relationship between sites. Where decreased trap catches seemed related to lower abundance, effects of drought in the last pre-ELF year offered an explanation equally as likely as that of ELF effects. BACI tests strongly indicated that relative weekly activity fluctuations were not detectably affected by antenna activation.

**2. Acarina:**

BACI tests of weekly catch ratios (**Table 20**) clearly showed that none of the three species monitored altered their seasonal activity patterns during and after 1989. We have found no comparable long-term records in the literature. The basic life cycle of *T. auroraense* observed in our sites complemented records given by others for this and other members of the genus *Trombidium* (Vercammen-Grandjean *et al.* 1977; Southcott 1961; Welbourn 1983).

*Abrolophus* sp. has just recently been described as *Abrolophus welbourni* Yao, in a comprehensive treatise on velvet mites occurring in and near this project's study sites (Yao 1994).

**3. Carabidae:**

In an 11-year study on carabid faunas in Manitoba, Holliday (1991) showed that annual trap catches in conifer and aspen forests varied greatly, by factors of approx. 2 to 6. Similar extreme variations were noted by Desender and Alderweireldt (1990) over a period of 4 years. In analogy to Collembola, large between-year differences observed in our study thus appear the rule for carabids as well.

Seasonal activity fluctuations in carabids are mainly related to patterns of reproduction and maturation (e.g., Loreau 1985). Patterns described here for five common species did not differ from those observed in other northern localities (Barlow 1970; Holliday 1991; Levesque and Levesque 1986; Bousquet 1986; Liebherr and Mahar 1979; Epstein and Kulman 1990). Most species in our study exhibited a single-year life cycle. Small numbers of *P. melanarius* females, however, occasionally survived into a second season and were ovigerous as early as May (distinct from the main oviposition period in mid-summer) (R.M. Snider, unpubl. data).

Short-term fluctuations in trap catches (within a species' main period of activity) may be closely related to prey availability (Loreau 1988; Niemelä *et al.* 1992), in interaction with changing litter morphology (Loreau 1987) and microclimatic events (Levesque *et al.* 1979). Differences between Test and Control sites could thus be mediated through differential density and activity of prey species, such as abundant epigeic *Dendrobaena octaedra* in Control, or specific components of the surface-active collembolan communities in either site. Specific knowledge of carabid diets would be required to investigate these relationships further.

"Well-known" (Loreau 1988) correlations between spring-breeding and diurnalism, and summer/autumn breeding and nocturnalism, are considered expressions of different microclimatic requirements of the two groups (Thiele and Weber 1968; Thiele 1979). In some species, however, diel patterns can be variable between seasons, years, and habitats: *P. melanarius*, for instance, responds to low light intensity (cloud cover) with increased diurnality (Ericson 1978), which can lead to widely differing mean annual diurnality estimates (range 29 to 65%, Desender and Alderweireldt 1990). The values reported by these authors are clearly reminiscent of the ranges in diurnality observed for *P. melanarius* in our study (**Table 22**).

Again, knowledge of prey specificity would have allowed more detailed analysis of carabid catches with respect to activity patterns of potential prey (Loreau 1988; Ottesen 1985). In a specialised predator of Collembola, for instance, diel activity patterns of the carabids and of their collembolan prey were found to coincide (Desender *et al.* 1984; Desender and Alderweireldt 1990).

Overall, in species common to both sites, no shifts in breeding patterns were observed following antenna activation. Site-specific variations in total numbers captured were likely due, in part, to site-specific shifts in prey species or communities. However, BACI tests of date-specific catch ratios showed that short-term activity fluctuations were generally well correlated between Test and Control, both prior to and during antenna operation.

## V. EARTHWORMS: FIELD POPULATIONS

### A. METHODS

Ten or 12 samples were taken per site and date at intervals of 2 weeks (except for the second half of 1987, when they were taken at 4 week intervals), from early May to mid- or late October. The number of sampling dates per year (10 in 1987, 12 or 13 in other years) will be specified where appropriate in Results sections. Samples were 25 x 25 cm square, cut and dug in the following depth increments: leaf litter (L), A horizon (A), and two (1984-1985) or three consecutive 10 cm increments of the B horizon (B-10, B-20 and B-30). They were hand-sorted and wet-sieved as detailed in Walther and Snider (1984). Specimens were killed in alcohol and preserved in 10% formalin. Counts and individual weights were obtained 3 - 5 weeks after sampling. Identifications were made according to Reynolds (1977). The designation *Aporrectodea turgida* (Eisen), rather than *A. caliginosa* (Savigny) was based on taxonomic considerations detailed by Gates (1972) and discussed by Reynolds (1977) and Fender (1985).

### B. RESULTS

#### 1. Species composition , density and biomass

The nine species encountered in Test and Control sites are listed below:

*Aporrectodea longa* (Ude)
*A. trapezoides* (Dugès)
*A. tuberculata* (Eisen)
*A. turgida* (Eisen)
*Dendrobaena octaedra* (Savigny)
*Dendrodrilus rubidus* (Savigny)
*Lumbricus rubellus* Hoffmeister
*L. terrestris* L.
*Octolasion tyrtaeum* (Savigny)

All species with the exception of *A. longa* (unique to Test) were common to both sites, but occurred in very different proportions. The Test community was strongly dominated by *A. tuberculata*, with *L. rubellus* numerically in second place. In Control, the numerically dominant endogeic was *A. turgida*, but numbers of the epigeic *D. octaedra* exceeded those of *A. turgida* in some years.

Rare species ($\leq$ 3% dominance) included *A. tuberculata, D. rubidus*, *Lumbricus* spp. and *O. tyrtaeum* in the Control community, and *A. trapezoides, A. turgida, D. rubidus, L. terrestris* and *O. tyrtaeum* in the Test community.

Annual fluctuations in density and biomass of the most abundant species are illustrated in **Figs. 65-66**. Between-year numerical variations were most pronounced in the epigeic *D. octaedra* in the Control site (**Fig. 66**), with effects of the severe 1988 drought carrying over into 1989. In the Test site, *D. octaedra* also declined in 1988-89, but did not recover during subsequent years (**Fig. 65**). Other species, in particular the deep-dwelling *A. longa*, exhibited less pronounced between-year fluctuations.

Variations in mean biomass were roughly correlated with numerical fluctuations in some species (e.g., *A. turgida* and *A. trapezoides* in Control, **Fig. 66**), but not in all. In *L. rubellus*, for instance, a significant population increase occurred in 1990, but biomass did not increase until 1992, after recruits had grown to large immature and adult size (**Fig. 65**). Year-specific moisture conditions probably influenced mean biomass both through individual body mass changes and through effects on recruitment and population structure (Snider and Snider 1994).

Detailed data on individual species useful for the purposes of this project concern only *A. tuberculata* and *L. rubellus* in Test (with some cautious interpolations between *A. tuberculata*

and its congener *A. turgida* in Control). The drastic decrease of *D. octaedra* in Test after 1987 (Fig. 65) precluded use of the species for between-site comparisons.

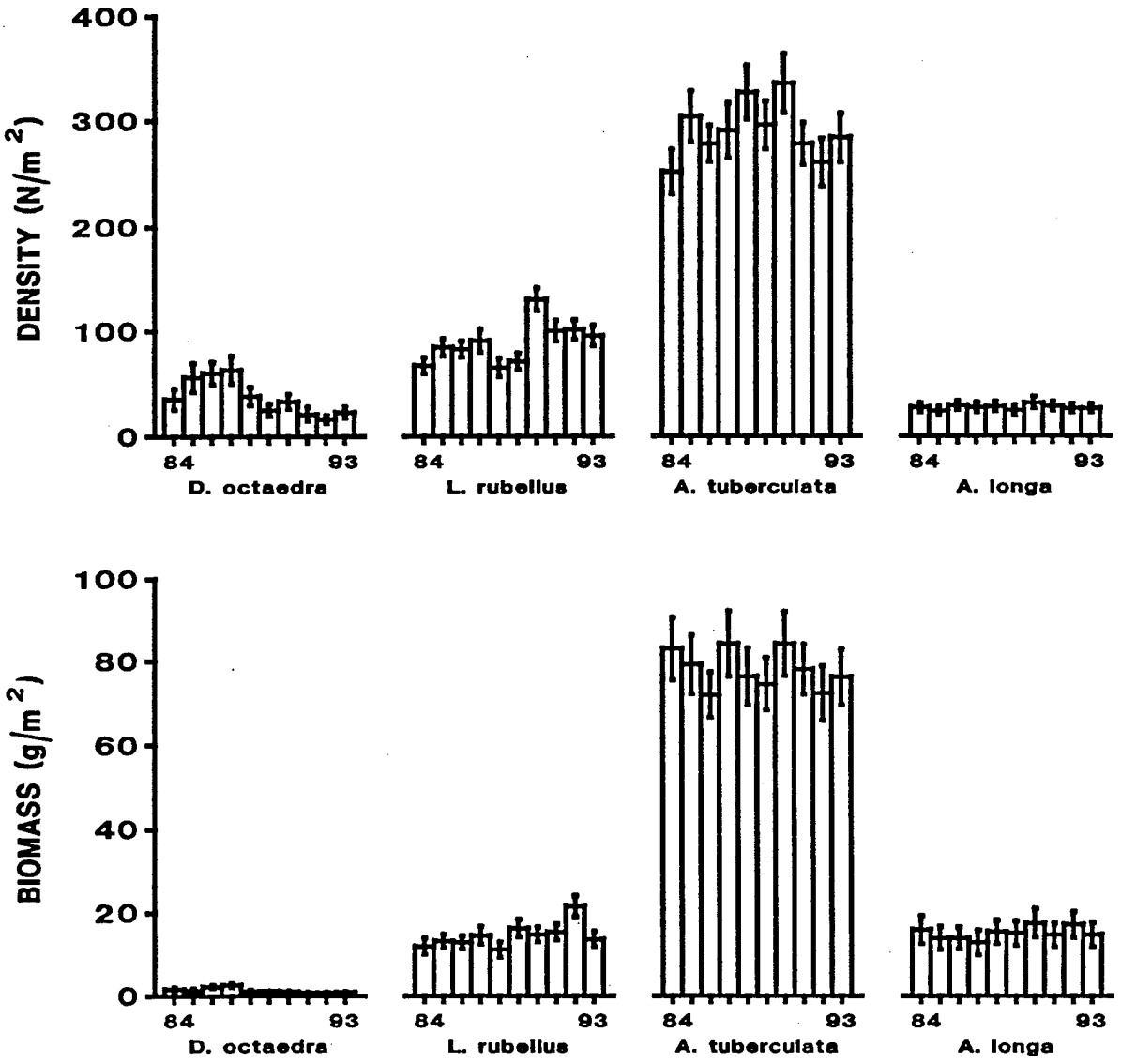



Fig. 65. Mean annual density and biomass (± 95% CL) of the common lumbricid species in the Test site, 1984-1993.

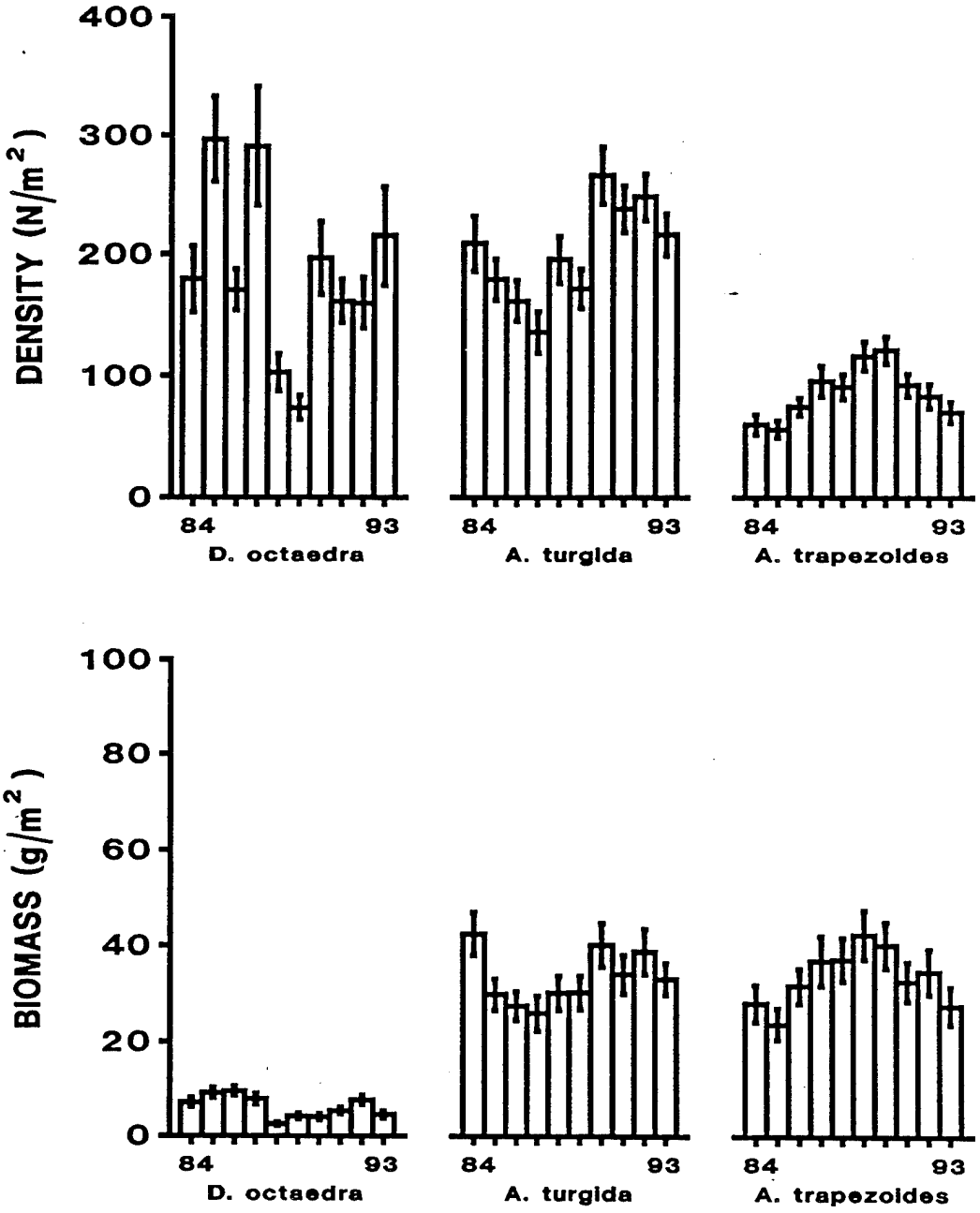



Fig. 66. Mean annual density and biomass (± 95% CL) of the most common lumbricid species in the Control site, 1984-1993.

**2. Community structure**

Mean annual diversity indices (Shannon-Wiener H') derived from date-specific estimates are illustrated in **Fig. 67**. Diversities began to diverge in 1988, estimates for Control rising steadily, those for Test decreasing. When data were grouped into pre-ELF and operational sets, changes in diversity were significant for the Control community, but not for the Test community (**Table 27**). It is not surprising, given the divergent trends in community diversity (**Fig. 67**) that BACI tests of between-site differences also yielded significant results ($P < 0.001$, **Table 27**).

The uneven numerical distribution of component species in Test and Control communities, and the differential impact of climatic events on each, lie at the root of these discrepancies. For instance, reduction of the abundant epigeic *D. octaedra* population in Control during the drought of 1988, coupled with increased numbers of *A. turgida*, resulted in higher diversity in that site. Further diversity increases in 1992 and 1993 (**Fig. 67**) were partly attributable to increases of species originally very rare in Control, i.e., *A. tuberculata* and *L. rubellus*.

In the Test site, overwhelming dominance of a single species, *A. tuberculata*, resulted in relatively more stable diversity over time. Decreased H' in 1988 and 1989 (**Fig. 67**) was the result of reduced numbers of *D. octaedra* and *L. rubellus* during and following the 1988 drought.

Equitability indices (S'/S) tended to be higher in Control in all years (**Fig. 68**). Pre-ELF estimates were higher than operational years' in both sites, significantly so in Test. Given that equitability decreased in both sites, between-site differences were not significant ($P = 0.4$, **Table 27**). Overall, it seems the communities in both sites have been (and are) undergoing long-term changes related to natural phenomena, not to potential effects of EM fields.

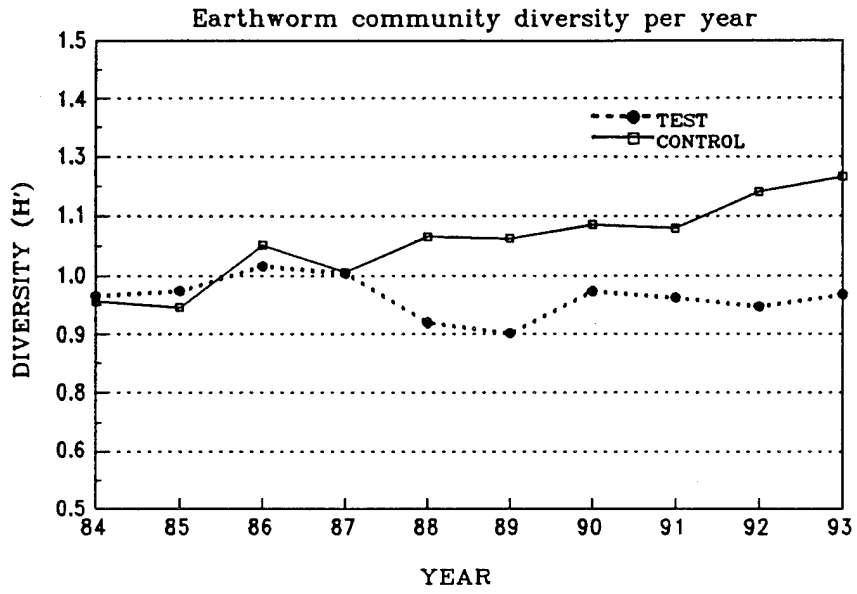



Fig. 67. Mean annual diversity (H') of lumbricid communities in Test and Control sites (N = 12 or 13 dates per year).

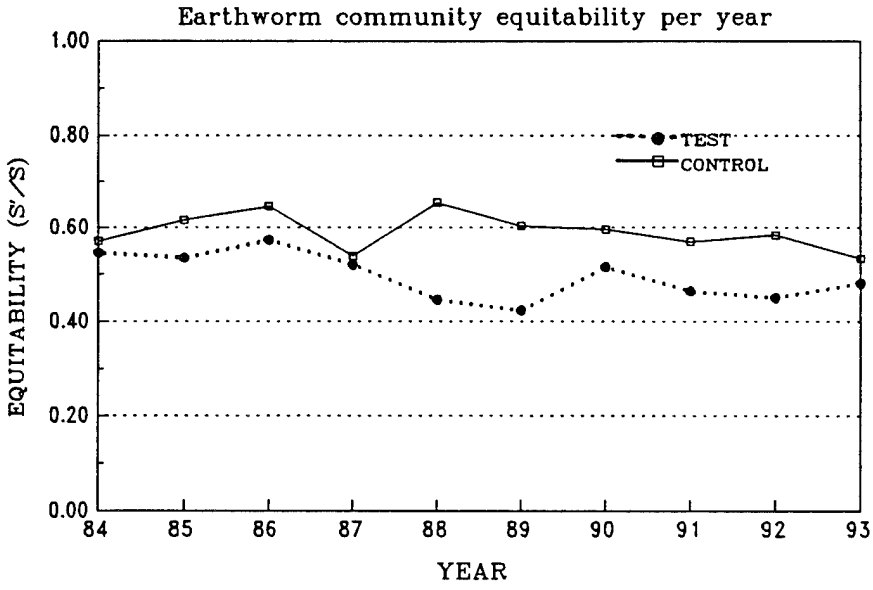



Fig. 68. Mean annual equitability (S'/S) of lumbricid communities in Test and Control sites (N = 12 or 13 dates per year).

**Table 27.** Mean (± SD) diversity and equitability indices of lumbricid communities in Test and Control sites, and mean [Control - Test] differences (BACI tests), for pre-ELF *vs.* operational periods; P values based on t-tests.

| | DIVERSITY (H') | | | EQUITABILITY (S'/S) | | |
|---|---|---|---|---|---|---|
| SITE | 84-88 | 89-93 | P< | 84-88 | 89-93 | P< |
| TEST | | | | | | |
| MEAN | 0.9692 | 0.9357 | 0.1 | 0.5250 | 0.4649 | 0.01 |
| SD | 0.0955 | 0.0918 | | 0.1075 | 0.0954 | |
| N | 60 | 60 | | 60 | 60 | |
| CONTROL | | | | | | |
| MEAN | 1.0061 | 1.1359 | 0.001 | 0.6083 | 0.5767 | 0.1 |
| SD | 0.0879 | 0.0817 | | 0.1201 | 0.0556 | |
| N | 60 | 60 | | 60 | 60 | |
| [CONTROL-TEST] | | | | | | |
| MEAN | 0.0369 | 0.1999 | 0.001 | 0.0833 | 0.1117 | 0.4 |
| SD | 0.1381 | 0.1127 | | 0.1758 | 0.1044 | |
| N | 60 | 60 | | 60 | 60 | |

## 3. *Lumbricus rubellus* in the Test site

### 3.1. Vertical distribution

*Lumbricus rubellus* can be considered a raw humus feeder (Piearce 1978) and ranks as an "intermediate" between epigeic and endogeic earthworms in Bouché's (1977) or Lee's (1959) ecological classifications. In our Test site, *L. rubellus* preferred the A horizon, although part of the population invaded the leaf litter under favorable moisture conditions (Snider and Snider 1988). Very few individuals were ever obtained from B horizon samples. Potential changes in vertical distribution thus concerned only relative distribution patterns in A and litter horizons, in response to litter moisture (A horizon moisture was irrelevant, since the species did not respond to low A horizon moisture by vertical migration to deeper layers).

Immatures of *L. rubellus* tended to invade leaf litter more readily than adults (**Table 28**).

**Table 28.** *Lumbricus rubellus* in Test: Percent of total adults and total immatures per year extracted from leaf litter.

| Year | % of adults in litter | % of immatures in litter |
|---|---|---|
| 1984 | 4.2 | 17.7 |
| 1985 | 2.4 | 12.0 |
| 1986 | 5.0 | 15.9 |
| 1987 | 5.2 | 25.2 |
| 1988 | 4.0 | 19.4 |
| 1989 | 6.6 | 16.4 |
| 1990 | 4.6 | 17.8 |
| 1991 | 5.1 | 19.3 |
| 1992 | 1.7 | 11.3 |
| 1993 | 10.8 | 25.0 |

Furthermore, among immatures, smaller size classes were more likely to dwell in litter than larger (older) ones: on several sampling occasions, 80 to 100% of immatures found in leaf litter

belonged in the smallest classes ($\leq$ 104 mg). Inclusion of the proportion of small immatures in regression analyses of vertical distribution was found to increase the coefficients of determination.

The proportion of the population present in leaf litter on each sampling date is illustrated in **Fig. 69**. Over all years, correlation between litter moisture and proportion of the population present in litter was significant, although less than 50% of variation was explained by moisture and small immature proportions ($R^2$ = 0.47, P <0.000). Peak litter moistures and highest numbers in litter frequently coincided. Exceptions occurred mainly in 1992 (**Fig. 69**), a year characterized by relatively low proportions of small immatures ( <40% on all dates, **Fig. 70**). Between-year variations in population structure, particularly drastic during operational years (**Fig. 70**) provide one explanation for differing $R^2$ in regression subsets (**Table 29**). Without doubt, more detailed documentation of the timing of rainfall events with respect to the time of sampling would have improved the explanatory power of regressions. Pairwise comparisons of regression parameters showed that vertical distribution of *L. rubellus* was not altered by ELF antenna activation.

**Table 29.** Results of multiple regression of the proportion of *L. rubellus* in leaf litter on litter moisture and proportion of the population in small immature stages ($\leq$ 104 mg body mass).

| Source | Period | SS | DF | MS | F-ratio | P | $R^2$ |
|---|---|---|---|---|---|---|---|
| Regression | 84-86 | 0.3864 | 2 | 0.1932 | 27.58 | 0.000 | 0.60 |
| Residual | | 0.2312 | 33 | 0.0070 | | | |
| Regression | 87-88 | 0.3723 | 2 | 0.1861 | 32.48 | 0.000 | 0.76 |
| Residual | | 0.1031 | 18 | 0.0057 | | | |
| Regression | 89-93 | 0.4436 | 2 | 0.2218 | 15.00 | 0.000 | 0.34 |
| Residual | | 0.8429 | 57 | 0.0148 | | | |

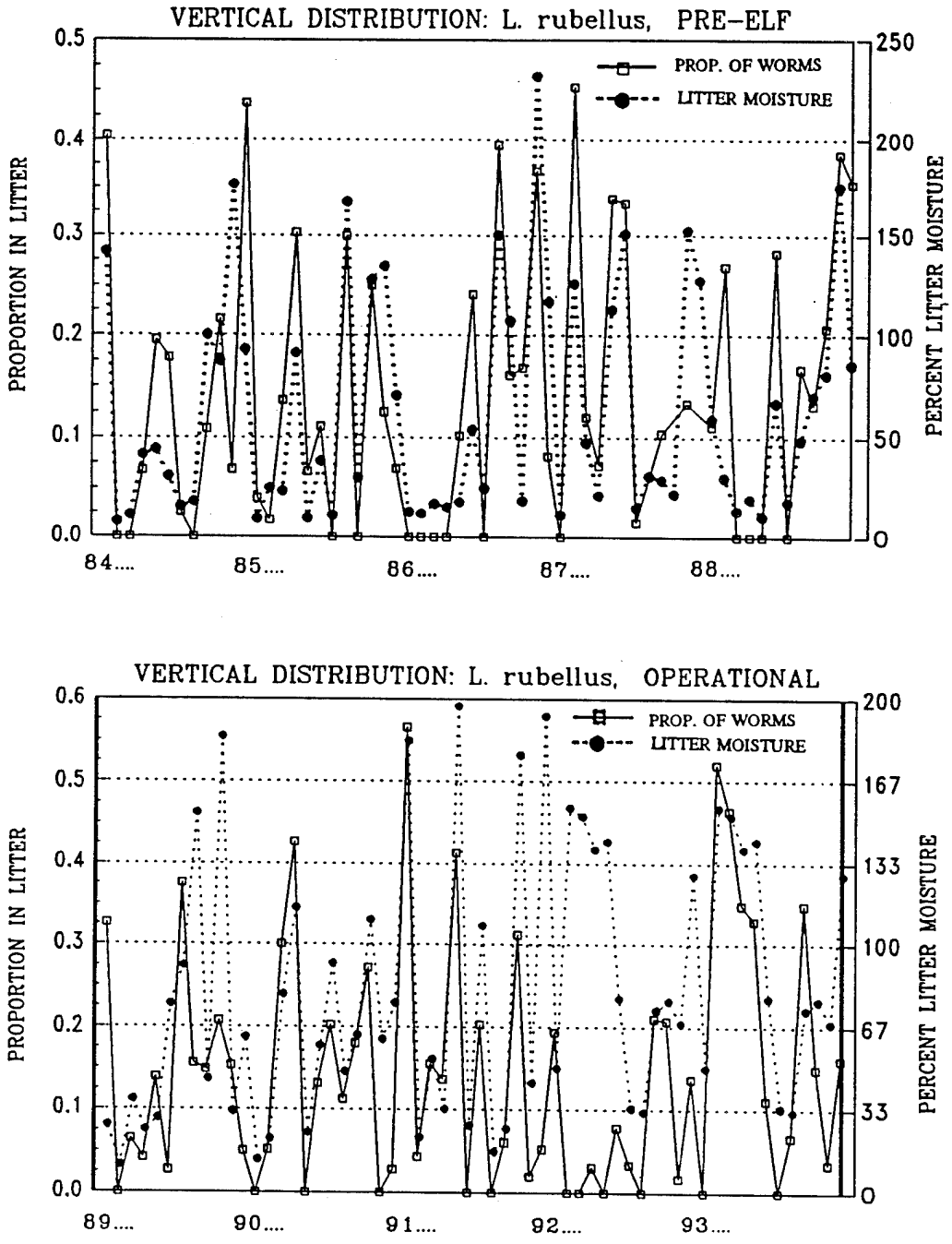



Fig. 69. Proportion of *L. rubellus* (Test site) present in leaf litter versus litter moisture during pre-ELF and operational years, at intervals of 2 weeks from May to October of each year.

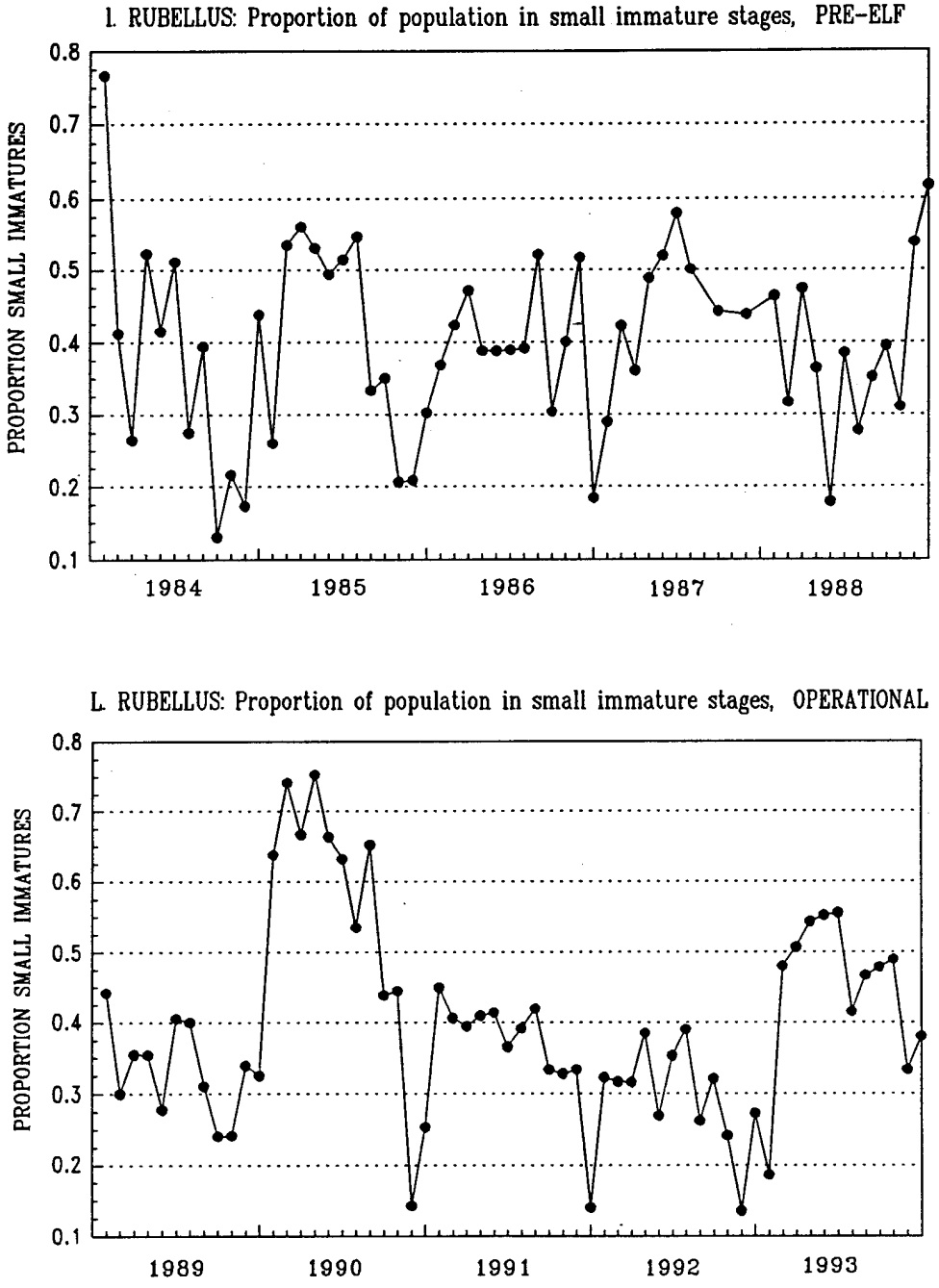



Fig. 70. Date-specific proportions of the *L. rubellus* (Test site) population in small immature stages ($\leq$ 104 mg body mass) during pre-ELF and operational years, at intervals of 2 weeks from May to October of each year.

### 3.2. Mean clitellate and cocoon mass

Mean annual body mass of clitellates (**Table 30**) ranged from 461 to 550 mg. Pairwise comparisons showed that, among pre-ELF years, mean clitellate mass in 1984 was higher than in any other year ($P < 0.05$ or better). Among operational years, 1989 yielded a highly significant peak in mean mass, differing from all other operational years at $P < 0.001$. Means for 1984 and 1989, however, did not differ significantly.

**Table 30.** Annual mean body mass of clitellate *Lumbricus rubellus* in the Test site.

| YEAR | MEAN (MG) | SD | N |
|---|---|---|---|
| **1984** | 532 | 114.4 | 78 |
| **1985** | 489 | 123.8 | 93 |
| **1986** | 461 | 119.0 | 95 |
| **1987** | 483 | 137.2 | 87 |
| **1988** | 480 | 118.7 | 67 |
| **1989** | 550 | 140.3 | 138 |
| **1990** | 479 | 123.2 | 80 |
| **1991** | 479 | 123.6 | 62 |
| **1992** | 476 | 117.6 | 156 |
| **1993** | 453 | 108.7 | 79 |

Mean mass of new cocoons (**Table 31**) was approximately 9 mg throughout the study period. Relatively small differences between years were often significant; e.g., 1985 vs. 1987 among pre-ELF years ($P < 0.001$), or 1989 vs. 1993 among operational years ($P < 0.001$). Cocoon size is closely related to adult size, according to Lavelle (1981) in a comparison **across species**;

in the present case, a similar relationship probably exists within *L. rubellus*: highest mean cocoon mass and highest mean clitellate mass coincided (in 1989). Regression results, however, yielded an $R^2$ of 0.40, at $P < 0.1$. Since cocoon mass is the dependent variable in this case, one is left with exploring whether the mass of reproductive adults was influenced by EM fields.

**Table 31.** Annual mean mass of new cocoons of *Lumbricus rubellus* in the Test site.

| YEAR | MEAN (MG) | SD | N |
|---|---|---|---|
| **1984** | 9.40 | 1.64 | 322 |
| **1985** | 9.49 | 1.62 | 400 |
| **1986** | 9.43 | 1.67 | 460 |
| **1987** | 8.91 | 1.64 | 405 |
| **1988** | 9.09 | 1.61 | 232 |
| **1989** | 9.72 | 1.80 | 600 |
| **1990** | 9.51 | 1.71 | 508 |
| **1991** | 9.14 | 1.81 | 352 |
| **1992** | 8.98 | 1.52 | 552 |
| **1993** | 8.69 | 1.72 | 541 |

### 3.3. Reproductive activity

There is little doubt that edaphic conditions influence reproductive activity of *L. rubellus* to some degree, although no significant relationships between environmental variables and reproductive parameters could be obtained. Adults dwell mainly in the A horizon, occasionally invade leaf litter, and are virtually never recovered from B horizon samples (ref. section 3.1.).

However, we were unable to develop predictive models for reproductive activity during pre-ELF years, based on A horizon moisture, A horizon temperature, litter moisture, rainfall during various periods prior to sampling, or a combination thereof. Since reproductive performance during operational years can thus not be strictly tested, we restrict our account to summary illustrations and tables.

Percent of adults in the clitellate state during pre-ELF years varied between approximately 40 and 100%. Relatively fewer adults were fully reproductive after 1989 (**Fig. 71**), maxima of 60 to 80% occurring more frequently than the 100% recurring during pre-ELF years. Yearly mean clitellate percentages reflect this apparent change (**Table 32**).

**Table 32.** Percent of adult *Lumbricus rubellus* (Test site) in the clitellate state (means ± SD), 1984 - 1993 (N dates in parentheses).

| YEAR | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 |
|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 85.3 | 69.0 | 69.1 | 79.1 | 69.3 | 84.2 | 60.9 | 56.9 | 64.4 | 65.8 |
| SD | 14.3 | 26.3 | 17.4 | 22.8 | 21.4 | 15.1 | 19.4 | 24.4 | 18.5 | 16.2 |
| (N) | (12) | (13) | (13) | (10) | (12) | (13) | (13) | (13) | (13) | (12) |

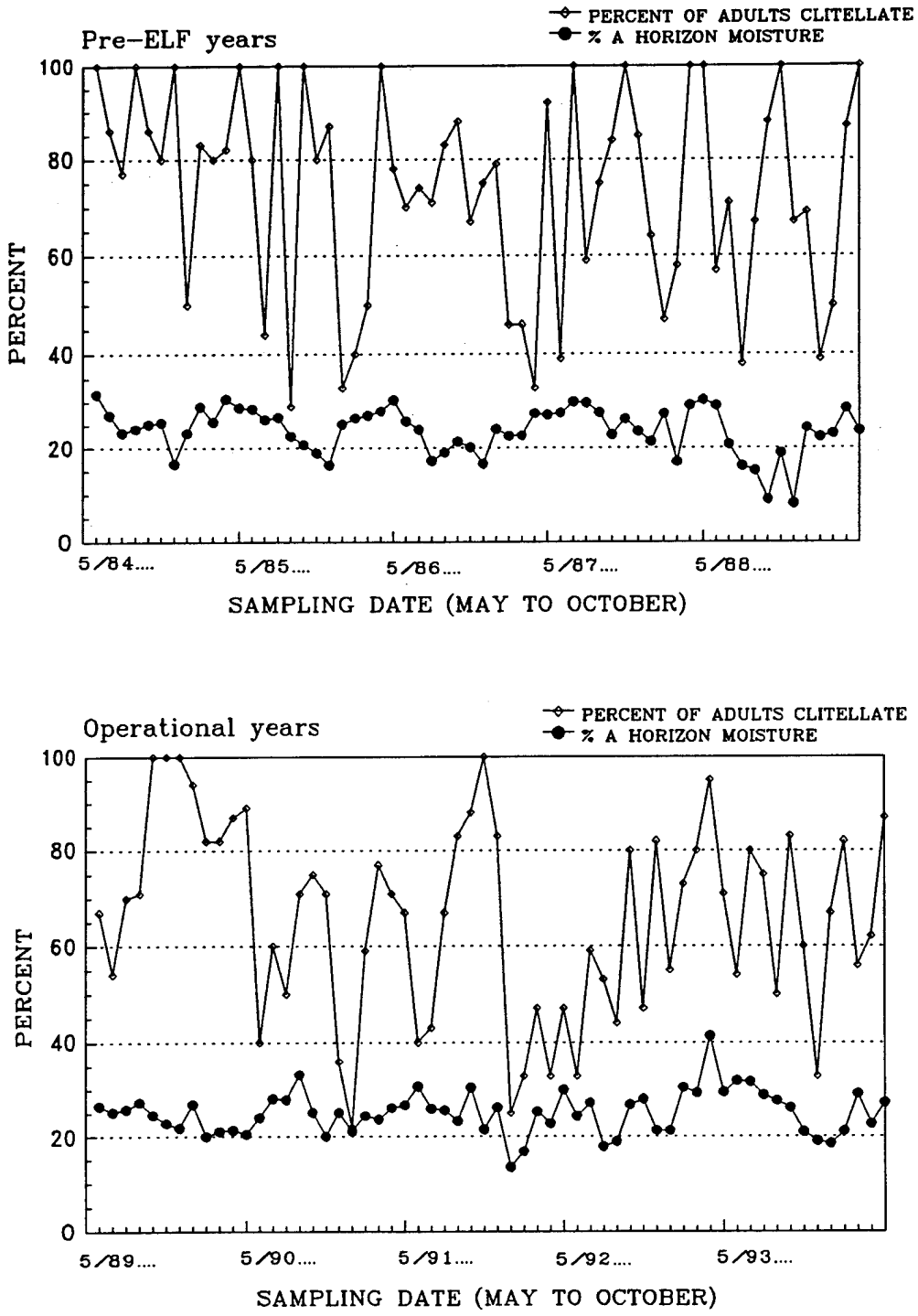



Fig. 71. Percent of adult *Lumbricus rubellus* in the clitellate state and percent moisture of the A horizon on each sampling date during pre-ELF and operational years (Test site).

In terms of proportions, reproductive adults tended to occur slightly less frequently during operational years; in terms of absolute numbers, however, 1989 and particularly 1992 were characterized by high densities of adults and clitellates (**Fig. 72**). Large between-year fluctuations in adult densities are traceable to cocoon production and survival rates of immatures during the preceding 2 to 3 years (ref. section 3.3.).

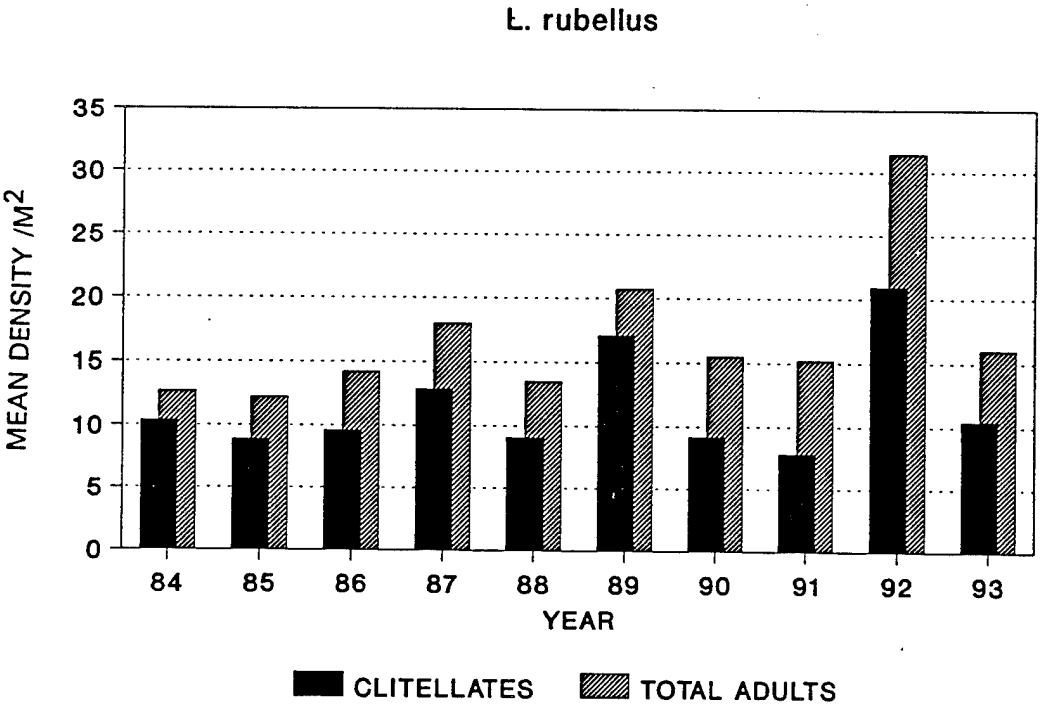



Fig. 72. Mean annual density of total adults and clitellates of *Lumbricus rubellus* in the Test site, 1984-1993.

Numbers of new cocoons produced (**Fig. 73**) were significantly correlated with numbers of clitellate adults ($P<0.05$, $R^2$ for 1984-1988 = 0.77, $R^2$ for 1989-1993 = 0.54). During pre-ELF years, some modulation of cocoon production by climatic patterns was evident, e.g., low

cocoon densities in the 1988 drought year, high cocoon density in the moist year 1987. Relationships between clitellate and cocoon densities were more variable during operational years ($R^2$ = 0.54), with virtually equal cocoon numbers observed in 1989, 1992 and 1993, years in which numbers of clitellates differed by as much as a factor of 2 (**Fig. 73**).

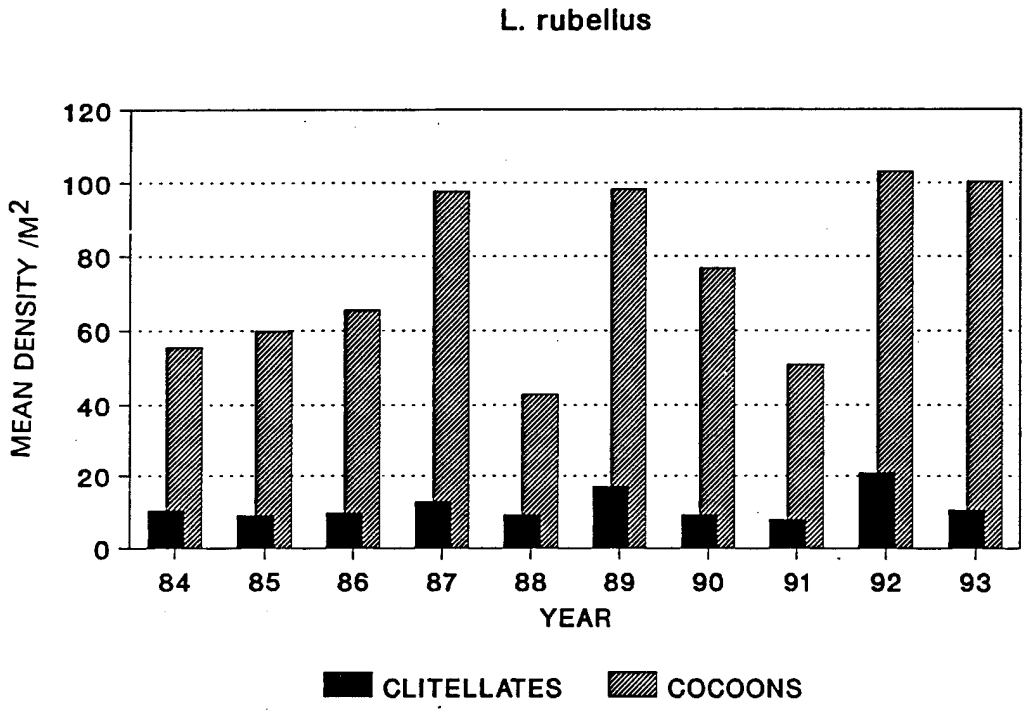



Fig. 73. Mean annual density of new cocoons and clitellate adults of *Lumbricus rubellus* in the Test site, 1984-1993.

Cocoon production **rates** (relating numbers or mass of cocoons to numbers or mass of clitellate adults) were calculated by several methods, three of which are detailed below. Annual mean rates (**Figs. 74-76**) were based on sampling dates when ≥ 3 clitellates were present in samples.

METHOD 1: cocoon production rate = number of new cocoons on $date_i$ / average number

of clitellates in the 2 weeks preceding $date_i$. Average clitellate numbers are calculated as [(N clitellates on $date_i$ + N clitellates on $date_{i-1}$) / 2]. This method takes into account increases or decreases in the number of reproductive individuals prior to the sampling occasion on which cocoon counts were obtained.

METHOD 2: cocoon production rate = number of new cocoons on $date_i$ / number of clitellates on $date_i$. Numbers of new cocoons and clitellates found on each sampling date are related directly, without regard to changes in clitellate numbers prior to sampling.

METHOD 3: cocoon production rate = total mass of new cocoons on $date_i$ /average total mass of clitellates, derived from $date_i$ and $date_{i-1}$ body mass data. Method 3 is thus the "mass equivalent" of Method 1, which is based on numbers.

All estimates of cocoon production rates have an inherent source of error. The basic data used for calculations consist of lumped numbers (or mass) of cocoons and clitellates obtained from all samples taken on a given date. While cocoons are obviously non-motile, but adults are not, some degree of error is unavoidable (e.g., adults which were the source of cocoon aggregations in single samples were often no longer present in that sample).

In pre-ELF as well as operational periods, between-year differences in cocoon production rates occurred. Based on numbers, 1993 cocoon production rates were slightly higher than any other (**Figs. 74-75**). Based on mass, 1990 data produced the highest estimate (**Fig. 76**), which did not differ significantly, however, from those of pre-ELF years 1985 and 1986. Cocoon production rates, using field-derived data, appeared to be variable between years irrespective of potential ELF EM field influence.

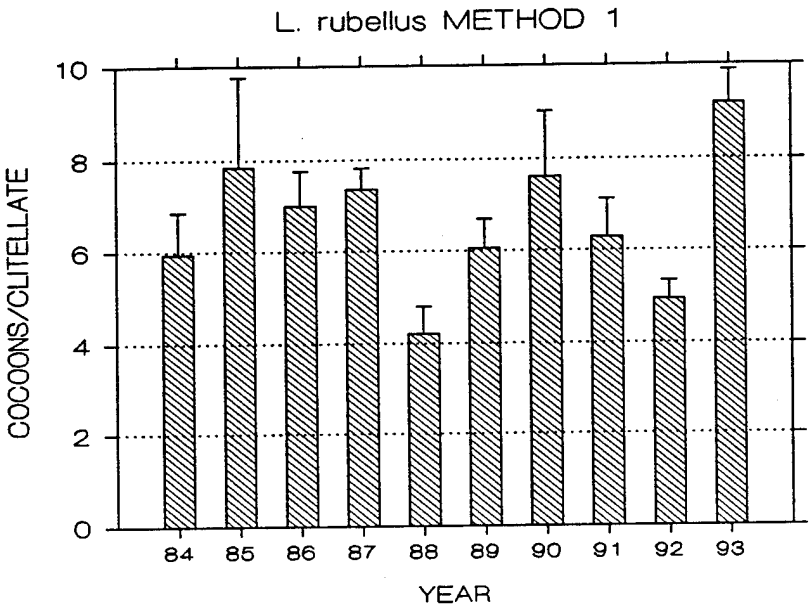



Fig. 74. Mean (± SE) annual cocoon production rates of *Lumbricus rubellus* in the Test site, 1984-1993. Method 1 based on (N cocoons / average N clitellates).

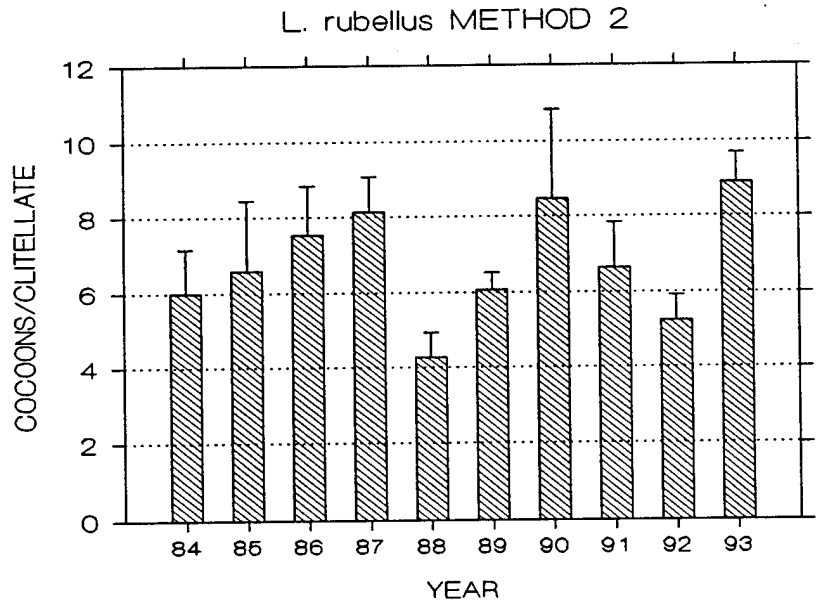



Fig. 75. Mean (± SE) annual cocoon production rates of *Lumbricus rubellus* in the Test site, 1984-1993. Method 2 based on (N cocoons / N clitellates) at the end of each incubation period.

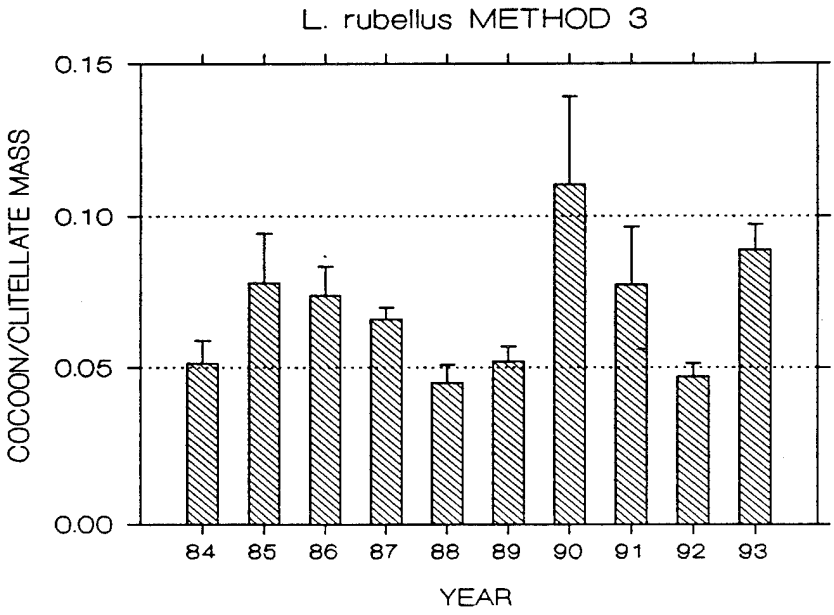



Fig. 76. Mean (± SE) annual cocoon production rates of *Lumbricus rubellus* in the Test site, 1984-1993. Method 3 based on cocoon and clitellate mass.

In general, reproductive patterns of *Lumbricus rubellus* have proven impervious to predictive analyses. It became clear that the species was capable of reproducing year-round, with some modulation by climatic patterns. Unlike *Aporrectodea* spp., for instance, reproductive adults were present at all times (**Fig. 71**). Production of new cocoons was never interrupted, although cocoon densities varied with clitellate densities (**Fig. 73**).

Mean monthly densities of cocoons and hatchlings are shown in **Fig. 77**, where new cocoon, old cocoon, and hatchling densities serve to illustrate basic reproductive patterns and their between-year variability.

New cocoons are produced throughout the season, although moderate to severe drought reduces their number (e.g., second half of 1985 and 1986, and most of 1988, **Fig. 77**). The years 1987 and 1989 were propitious due to ample rainfall; unusually high new cocoon densities

in 1992 were traceable to high survival rates of the 1989 cohort, which matured and reproduced in 1992 (ref. section 3.3.).

Densities of old (ready-to-hatch) cocoons tended to accumulate in the second half of the season, frequently not until September and October (e.g., 1984, 1989). Hatchlings, although present throughout the season, exhibited peak emergence in May and June of most years, at a time when old cocoons were essentially absent; i.e., *L. rubellus* hatched at relatively low temperatures, prior to the first early-May sampling dates.

### 3.4. Population structure

Patterns of growth and reproduction can be briefly summarized as follows: fully developed cocoons accumulate in the fall, and a pulse of recruitment occurs in early spring of the following year. We estimate that 2 - 3 years of growth are required to reach adulthood. Growth patterns,as reflected in abundance of individuals in successive weight classes, were often obscured by high mortality during pre-ELF drought years. Beginning in 1989, however, we were able to document the development of a single cohort.

High cocoon numbers in 1989 resulted in high densities of hatchlings and medium-sized immatures in 1990 (**Fig. 78**). Numbers of large immatures and adults began increasing in 1991, adults reaching an all-time numerical peak in 1992 (**Fig. 78**), two years after peak hatchling density. High cocoon production during 1987 would probably have produced the same patterns, but the severe drought year of 1988 curtailed survival of small immatures, thereby eliminating a potential population increase which would have been realized in 1988-89-90.

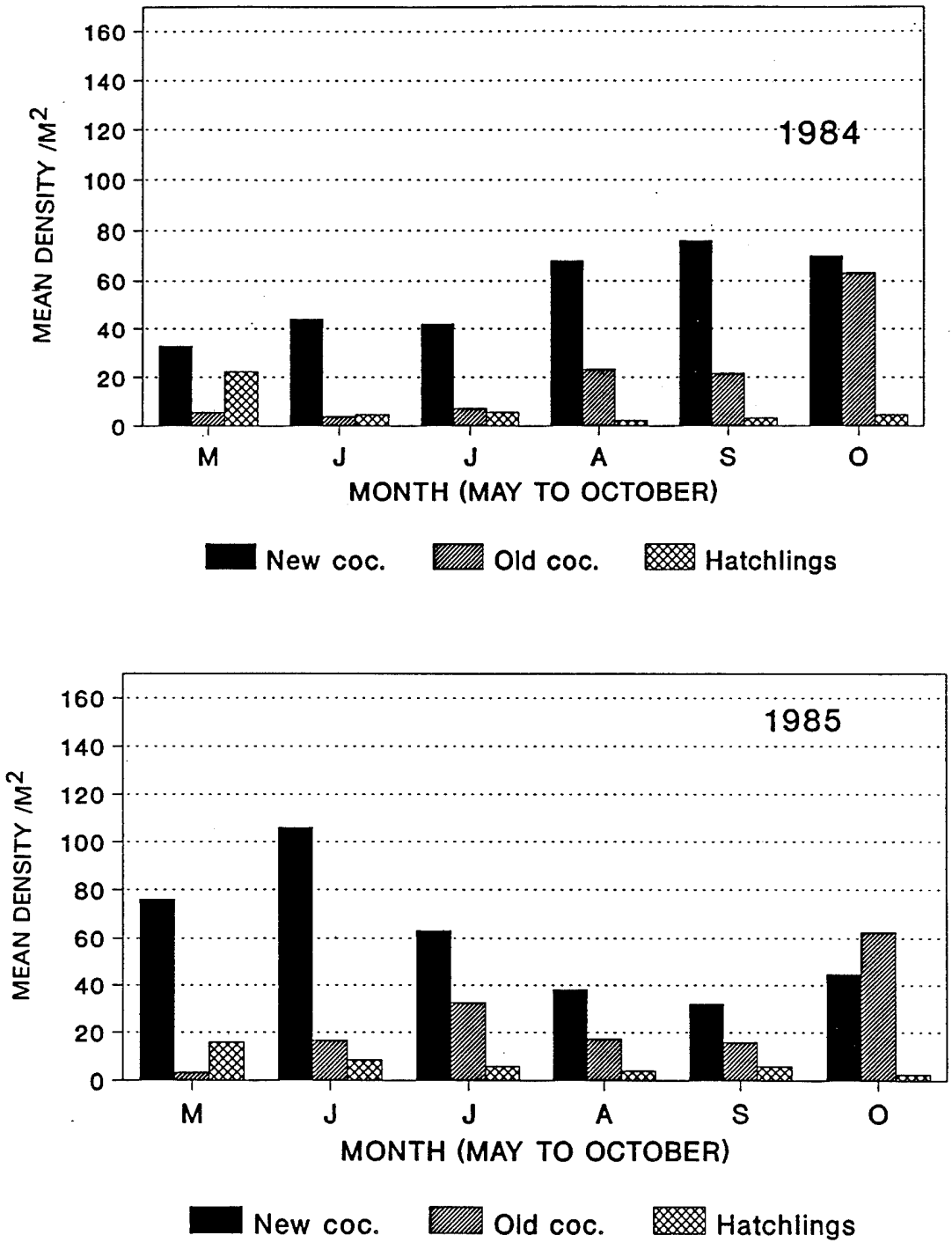



Fig. 77. Mean monthly densities (May to October) of new cocoons, old cocoons and hatchlings of *Lumbricus rubellus* in the Test site, 1984 through 1993 (continued on following pages).

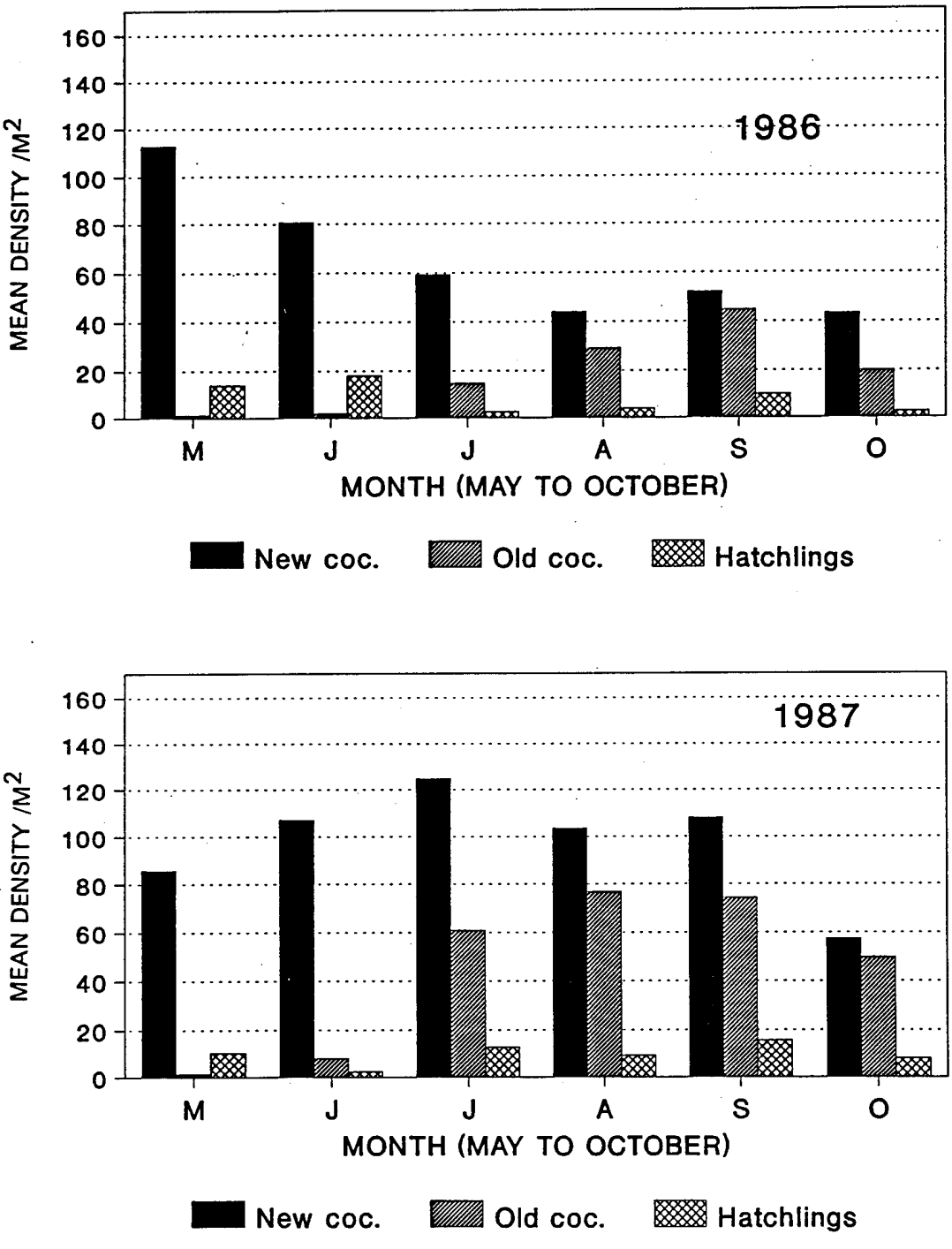



Fig. 77 (continued).

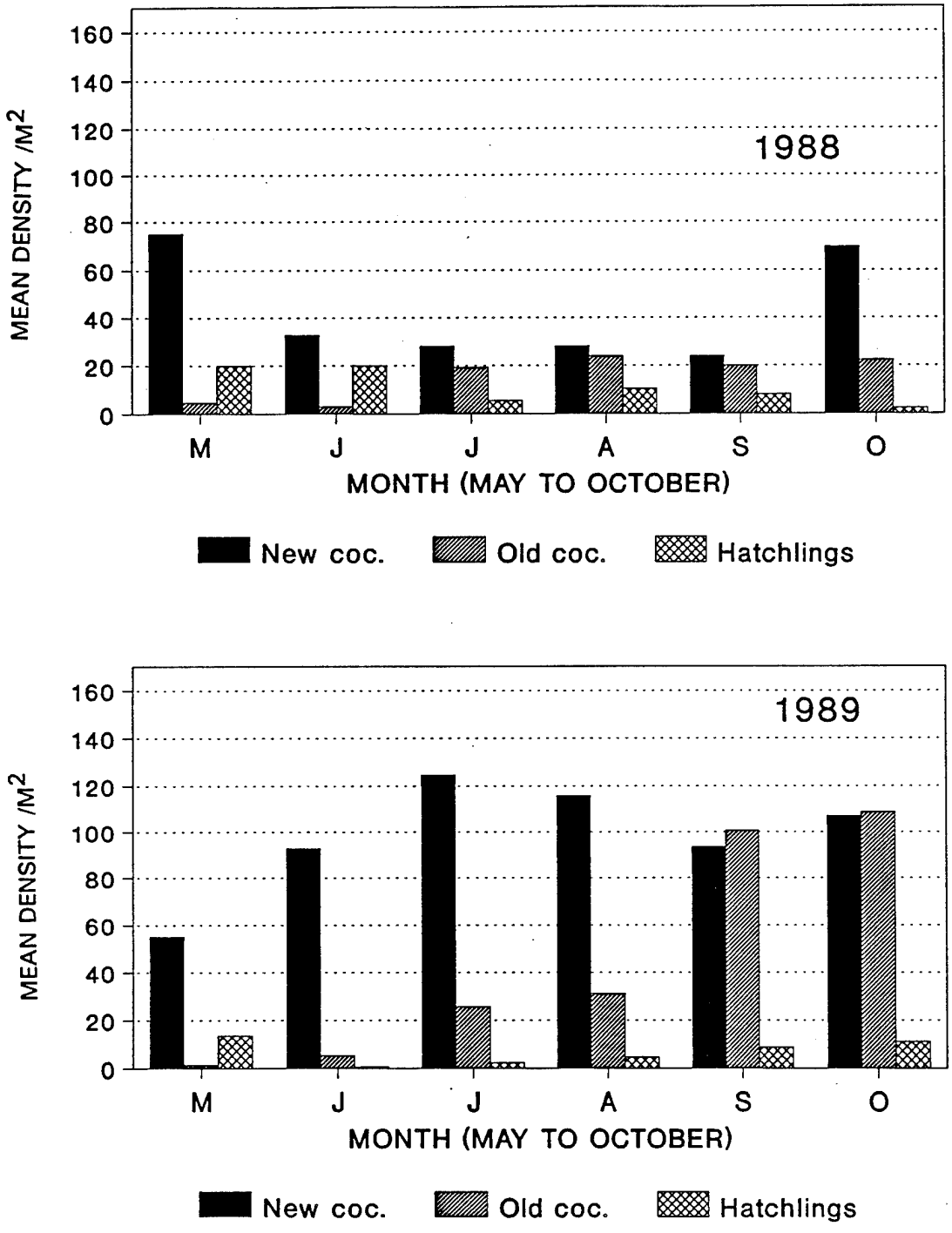



Fig. 77 (continued).

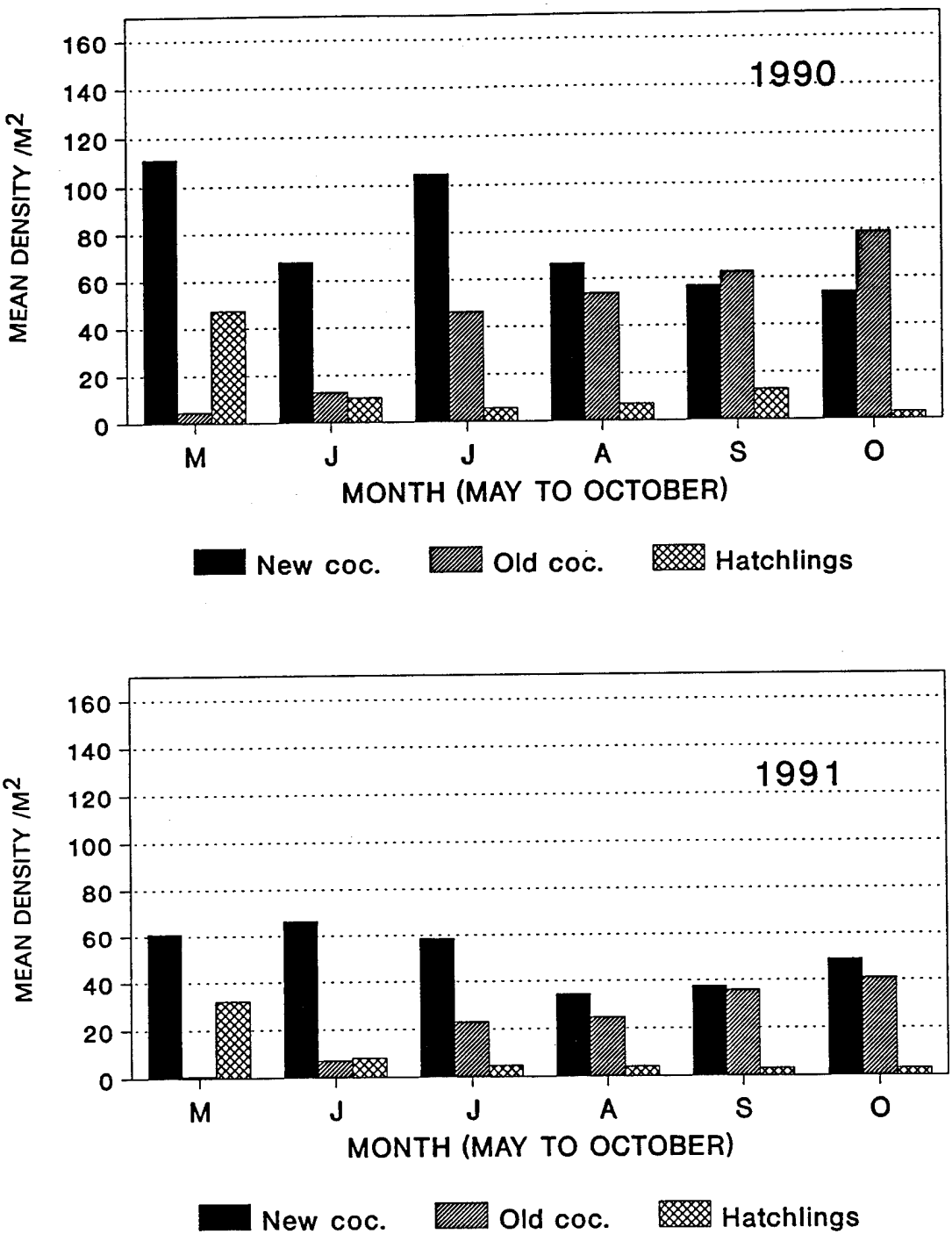



Fig. 77 (continued).

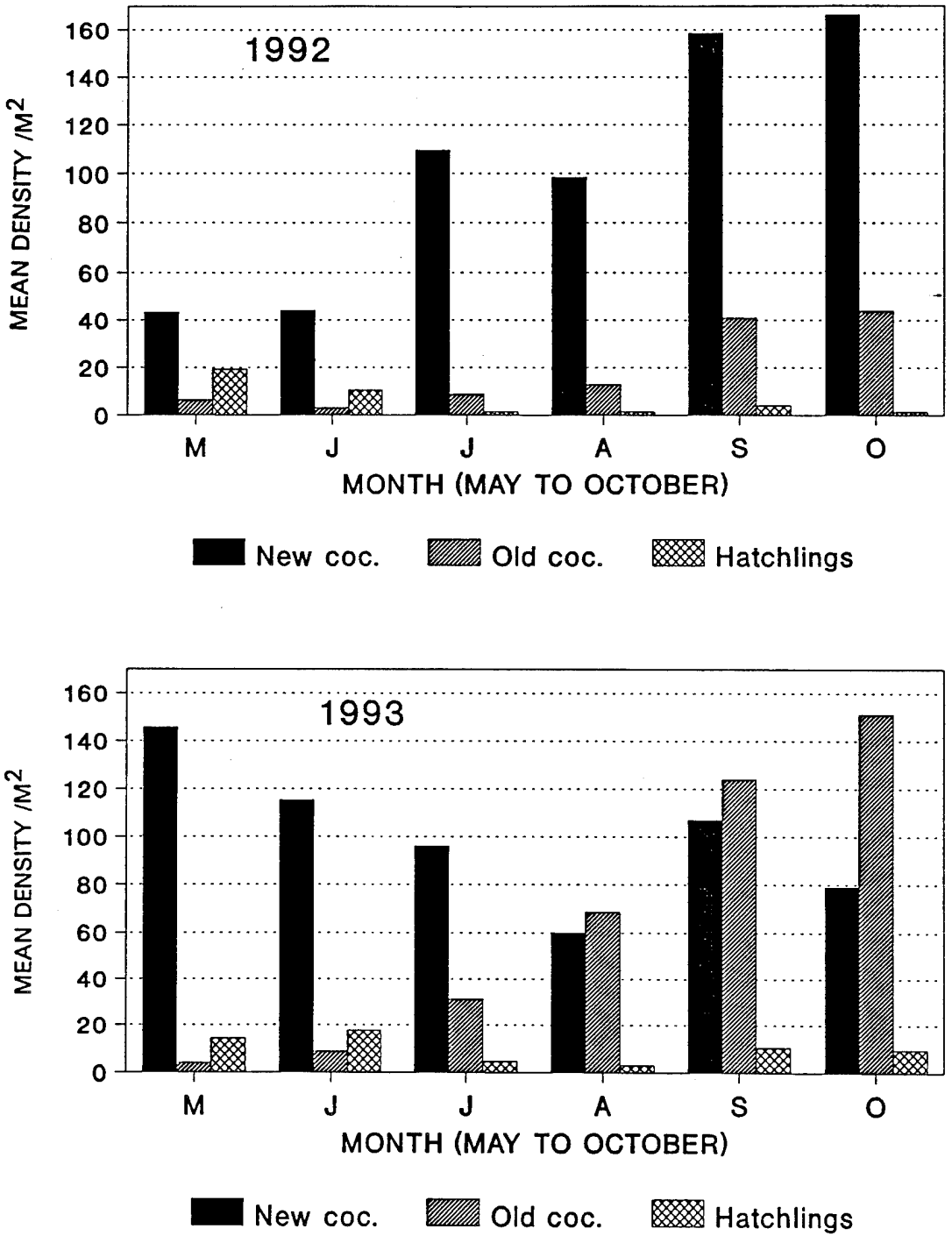



Fig. 77 (continued).

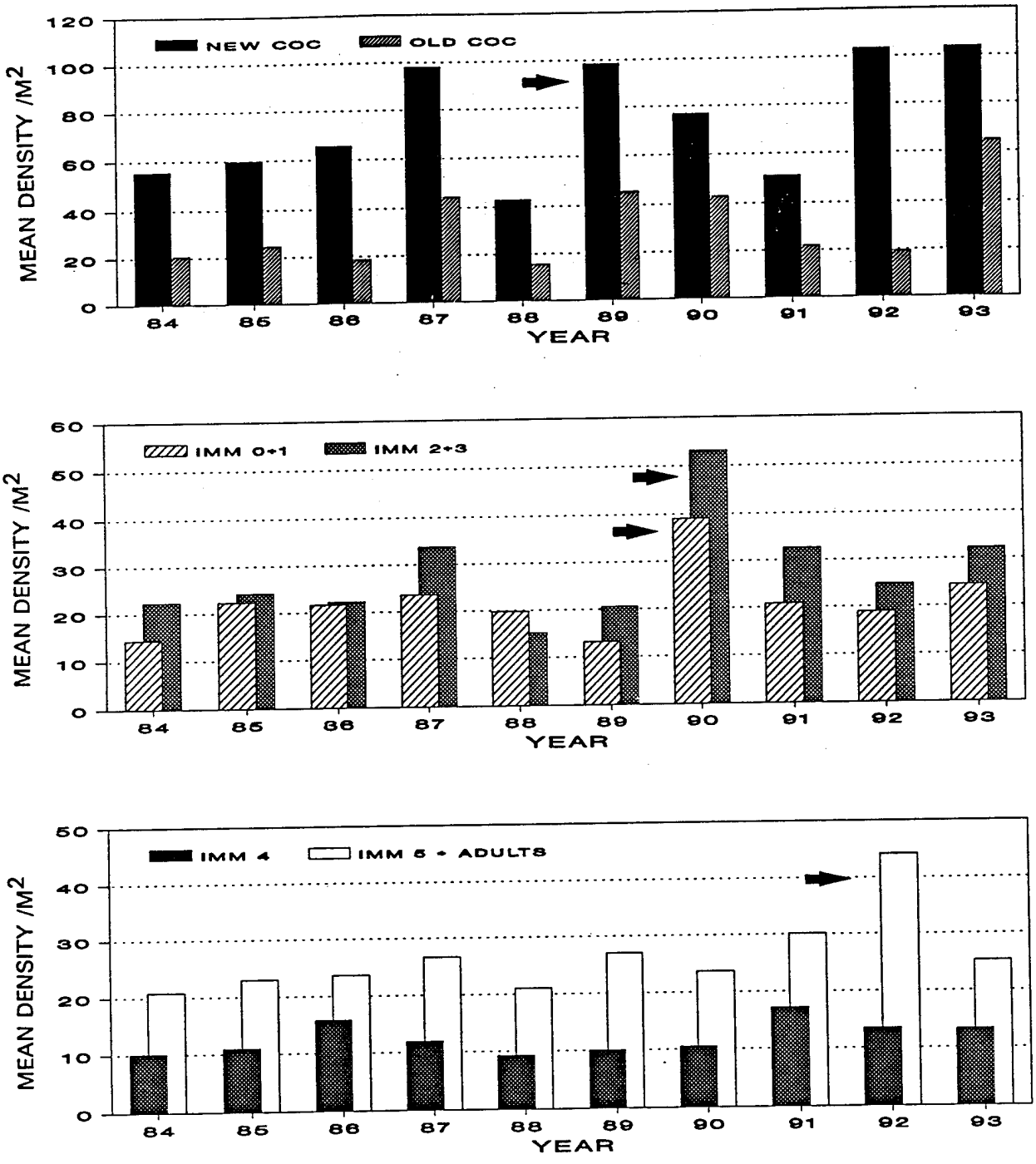



Fig. 78. Mean annual density of new and old cocoons, and of successive weight classes of *Lumbricus rubellus* in the Test site; arrows point out the growth of the 1989 new cocoon cohort. IMM 0+1 = ≤ 26 mg; IMM 2+3 = 26.1 to 104 mg; IMM 4 = 104.1 to 208 mg; IMM 5 + ADULTS = > 208 mg.

Population structure can also be expressed as the ratio of immature : adult densities. Mean annual immature proportions were approximately equal during all five pre-ELF years, then began to fluctuate significantly (**Fig. 79**). Low immature : adult ratios in 1989 were attributable to low survival of immatures during the 1988 drought year. On the other hand, high ratios in 1990 and 1991 were the result of high cocoon production in 1989: with moisture not limiting during those two years, a larger proportion of immatures than ever before survived and reached adulthood, resulting in decreased immature : adult ratios in 1992 (**Fig. 79**).

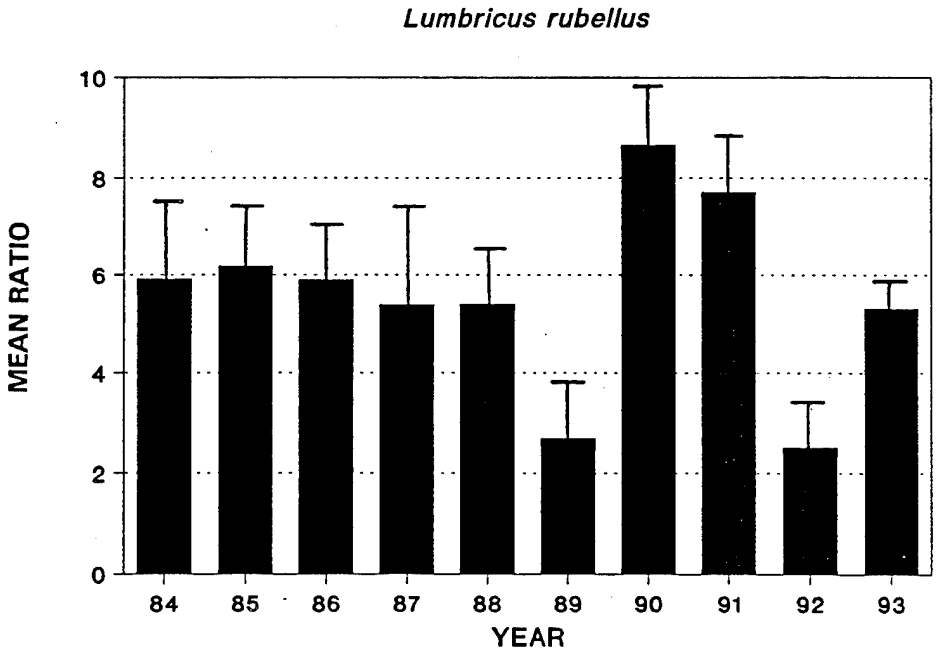



Fig. 79. Mean ± SE immature/adult ratios for *Lumbricus rubellus* in the Test site, 1984 - 1993 (N variable from 10 to 13 dates /year, ref. section V.A.).

## 4. *Aporrectodea tuberculata* in the Test site

### 4.1. Vertical distribution

Vertical migration of individuals in response to decreasing A horizon moisture tended to be more pronounced in adults than in immatures in all years (**Fig. 80**). No differences in vertical distribution patterns were detectable following antenna operation. Using transformed proportions of all worms in the A horizon [ln (p/1-p)], and A horizon moisture, temperature and temperature$^2$ as independent variables, analysis of regression residuals showed that pre-ELF and operational periods did not differ ($P = 0.7$).

We may point out that moisture stress (as reflected in low proportions of worms remaining in the A horizon) was often more severe during pre-ELF years (1985, 1986, 1988, **Fig. 80**) than during operational years.

### 4.2. Mean clitellate and cocoon mass

Mean body mass of clitellate individuals (**Table 33**) varied between pre-ELF as well as operational years. The 1988 mean of 605 mg, for instance, was significantly lower than the 1986 mean of 655 mg (t test, $P < 0.05$). The highest mean was recorded for 1990, differing significantly from 1989 ($P < 0.05$), from all pre-ELF years except 1986, and from operational years 1992 and 1993 ($P < 0.01$). Whether the mean mass increase in 1990 is related to some physiological response to EM fields is difficult to assess (refer, however, to section VII in which mean body mass of isolated *A. tuberculata* is discussed).

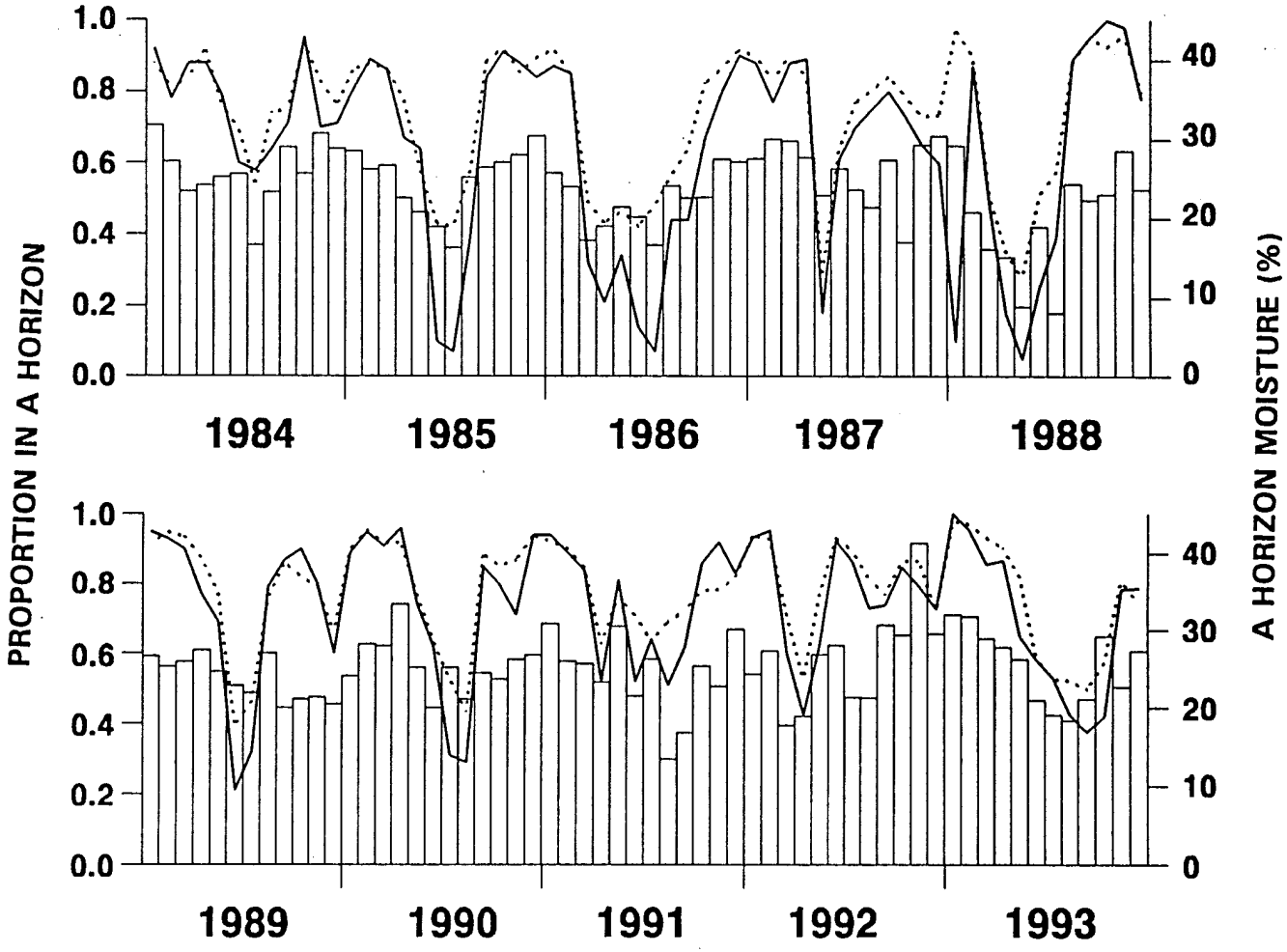



Fig. 80. Proportion of *Aporrectodea tuberculata* present in the A horizon (Test site) on each sampling date. Bars = mean A horizon moisture; solid line = adults; dotted line = immatures.

**Table 33.** Mean body mass of clitellate *Aporrectodea tuberculata* in the Test site, 1984 to 1993.

| YEAR | MEAN (MG) | SD | N |
|---|---|---|---|
| 1984 | 648 | 115 | 250 |
| 1985 | 631 | 118 | 121 |
| 1986 | 655 | 125 | 66 |
| 1987 | 637 | 129 | 272 |
| 1988 | 605 | 135 | 60 |
| 1989 | 652 | 139 | 166 |
| 1990 | 692 | 123 | 79 |
| 1991 | 662 | 117 | 147 |
| 1992 | 645 | 115 | 155 |
| 1993 | 647 | 108 | 120 |

Mean mass of new cocoons (**Table 34**) clearly showed that cocoons tend to have less mass during years with moderate to severe rainfall deficits. Means in 1985, 1986 and 1988 did not differ from each other, but the 1988 mean in particular differed from all other means ($P < 0.01$ or $< 0.001$). During years with relatively ample rainfall, including all operational years, an average cocoon mass of approximately 20 to 21 mg appeared the norm (**Table 34**).

### 4.3. Reproductive activity

In this section we deal mainly with reproductive parameters of *A. tuberculata*, although we will occasionally illustrate reproductive activity of *A. turgida*, where a comparison between these congeneric species may be appropriate.

**Table 34.** Mean annual mass of new cocoons of *A. tuberculata* in the Test site, 1984-1993.

| YEAR | MEAN (MG) | SD | N WEIGHED |
|---|---|---|---|
| 1984 | 21.52 | 4.07 | 193 |
| 1985 | 19.58 | 4.17 | 137 |
| 1986 | 19.36 | 4.94 | 44 |
| 1987 | 20.73 | 4.08 | 223 |
| 1988 | 18.69 | 4.01 | 63 |
| 1989 | 20.39 | 4.61 | 174 |
| 1990 | 21.31 | 4.10 | 55 |
| 1991 | 21.42 | 3.57 | 155 |
| 1992 | 20.93 | 4.43 | 192 |
| 1993 | 20.65 | 4.24 | 174 |

### 4.3.1. Clitellate and cocoon numbers

Densities of adults peaked in 1987 and 1988 (**Fig. 81**), probably as a result of reproductive events prior to 1984. Adult numbers remained stable thereafter. Abundance of clitellates was highest in 1984 and 1987; low numbers of reproductive adults in 1985, 1986 and 1988 were related to moderate or severe drought conditions. In none of the operational years did clitellate densities reach the highest pre-ELF means observed (33 and 43 /$m^2$ in 1984 and 1987 respectively). In 1990 in particular, propitious A horizon moisture conditions (**Appendix 3**) were not reflected in high clitellate numbers (**Fig. 81**).

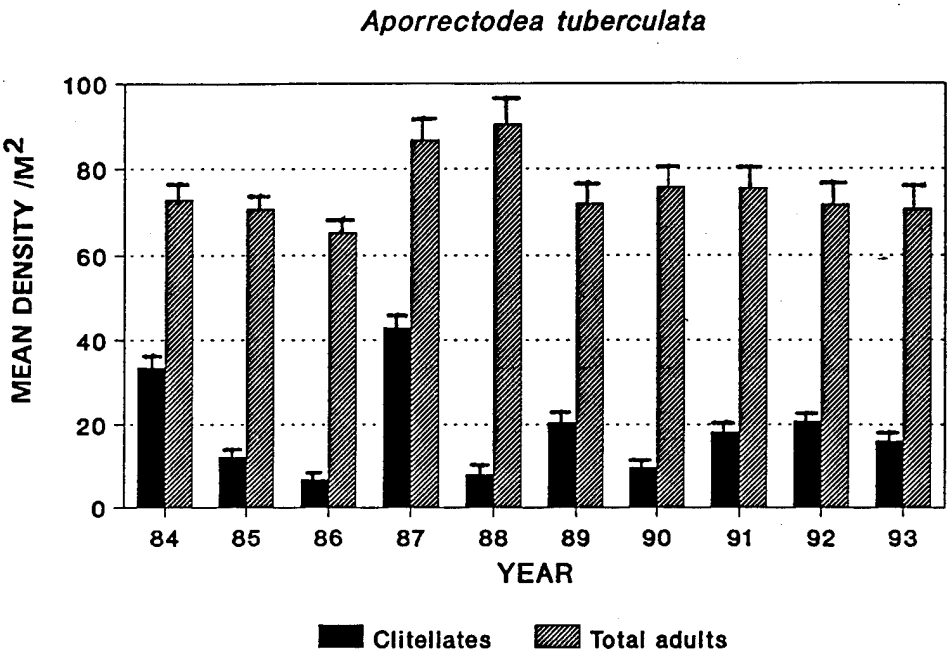



Fig. 81. Annual mean densities /$m^2$ ($\pm$SE) of total adult and clitellate *Aporrectodea tuberculata* in the Test site, 1984 to 1993.

Since adult densities were not completely stable over the entire study period, proportions (or percent) of all adults in the clitellate state represents a more accurate criterion of reproductive performance. In the following, we illustrate (**Fig. 82**) and describe relationships between A horizon moisture and the population's reproductive condition.

During pre-ELF years, brief moisture decreases immediately followed by prolonged rehydration resulted in brief reductions in clitellate percentages (i.e., 1984 and 1987, **Fig. 82**). Steadily decreasing (1985) or repeatedly low moisture levels (1986, 1988) in early- through mid-season had lasting effects on reproductive activity; recovery occurred in late fall of all three years, but tended to be delayed by $\geq$ 2 weeks even after soil moisture had returned to $\geq$ 25% (ref. also **Appendix 3**), i.e., to levels at which maximal reproduction was observed at other

times of the year. Reproduction was thus seasonally "modulated" by A horizon moisture. The degree to which reproductive activity was increased or decreased seemed to depend on interacting factors including: seasonal timing of moisture fluctuations, magnitude (particularly of moisture decreases) and duration of moisture-stress period.

During operational years 1991 through 1993, this "modulation" of reproductive activity by soil moisture was again apparent, although the pre-ELF highs of 55 - 80% clitellates never re-occurred after 1989 (**Fig. 82**). In 1989, the first year of antenna operation, clitellate percentages were variable at first, then dropped to 5% at season's end, although soil moisture neither fluctuated excessively nor ever dropped to pre-ELF minima (**Appendix 3**). In 1990, neither high early-season moisture levels nor their subsequent, relatively mild fluctuations elicited a clear temporal response pattern in terms of reproductive activity. Annual mean clitellate proportions (**Fig. 83**) showed a 1990 mean reminiscent of pre-ELF drought years and reflected the same between-year relationships discussed earlier with respect to clitellate densities (**Fig. 81**).

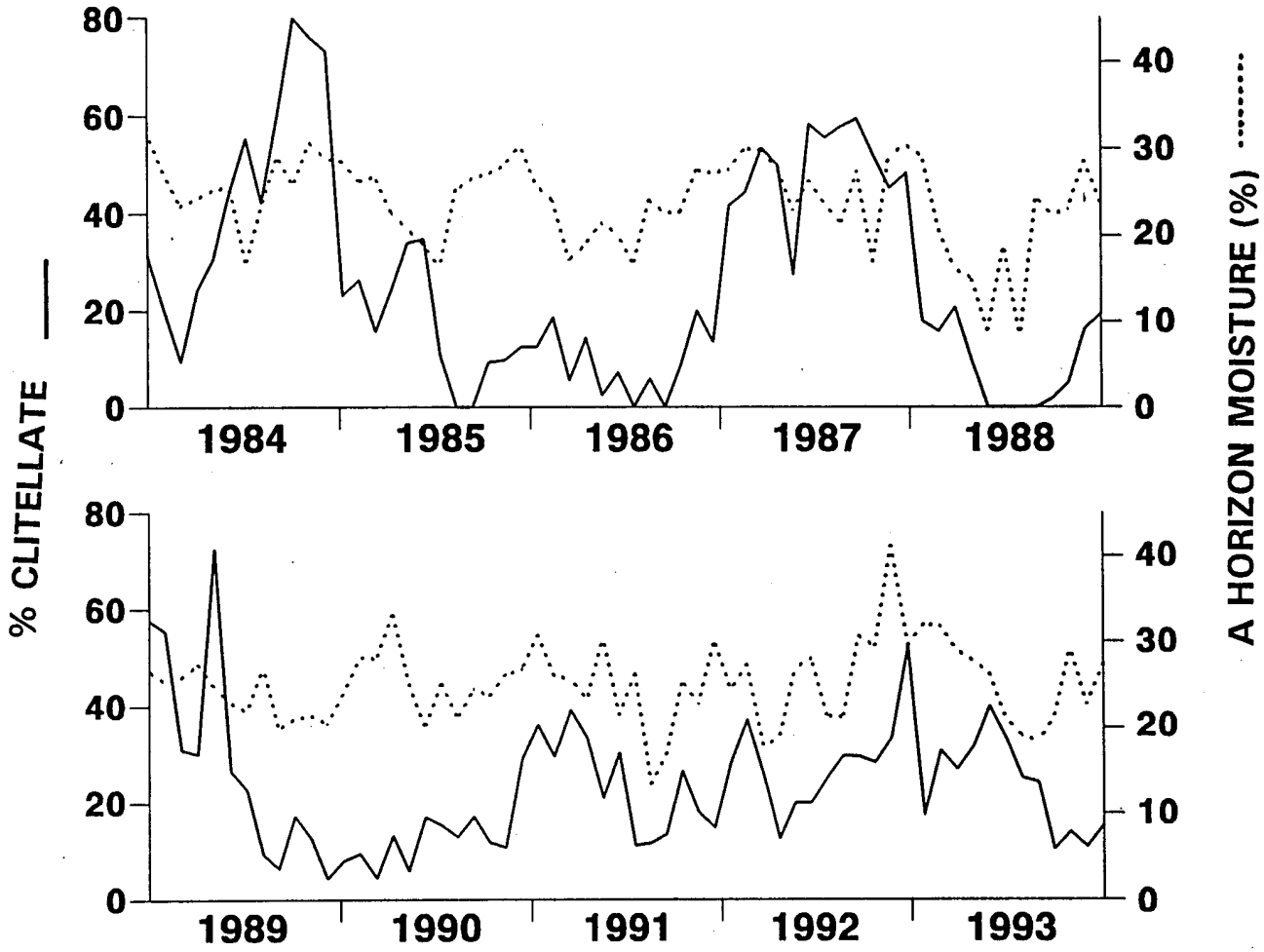



Fig. 82. Biweekly mean A horizon moisture and mean percent of adult *A. tuberculata* in the clitellate state, Test site, 1984 to 1993.

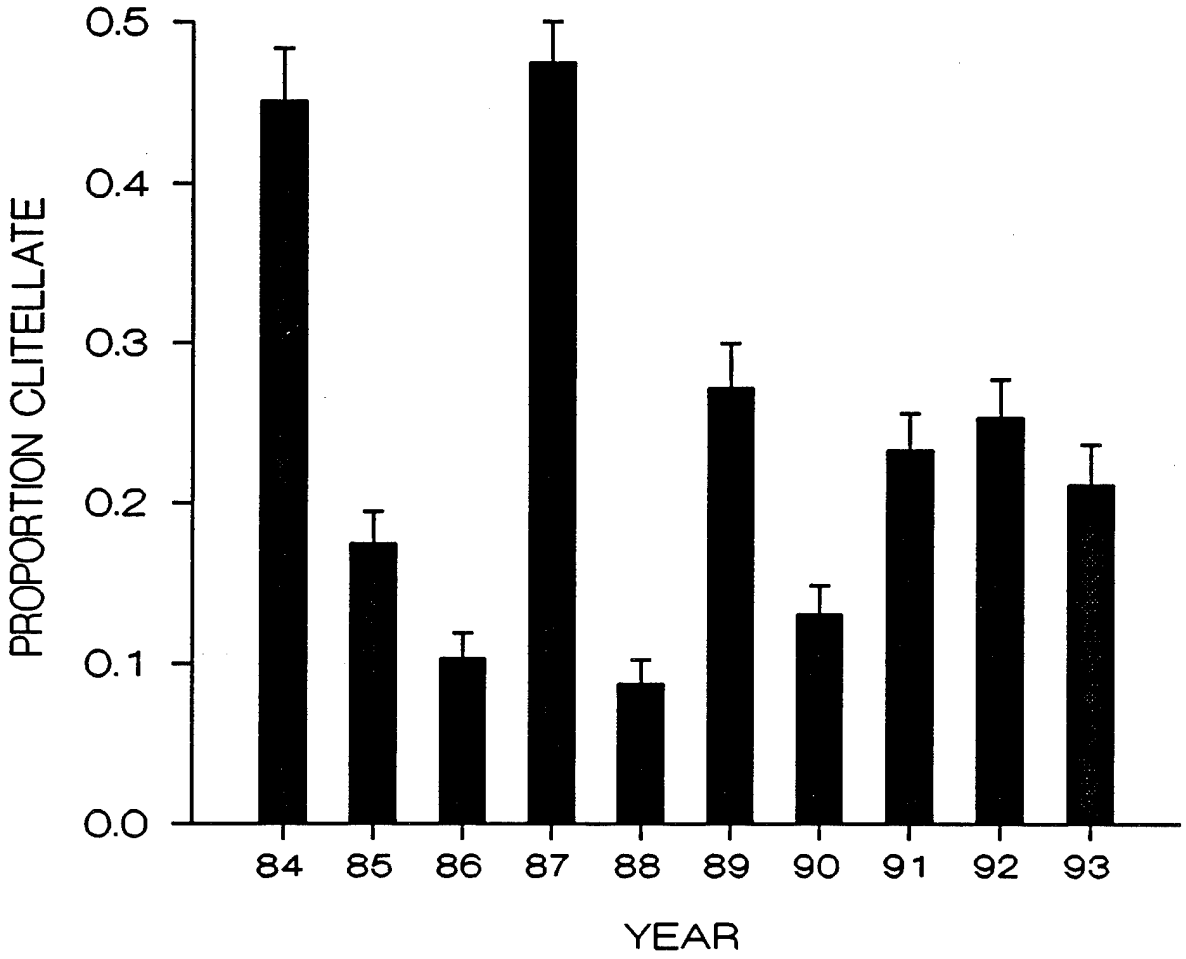



Fig. 83. Annual mean (± SE) proportion of *A. tuberculata* adults in the clitellate state, Test site, 1984-1993 (N = 10 to 13 dates, variable between years, ref. section V.A.).

Mean numbers of new cocoons and of clitellates are summarized by month in **Fig. 84**. These two parameters were closely related during pre-ELF as well as operational periods (for 1984-88, $R^2 = 0.83$; for 1989-93, $R^2 = 0.73$; $N = 30$, $P < 0.001$ in both cases). Reproduction in *A. tuberculata* clearly can proceed uninterrupted from spring to fall, except under extreme moisture stress (i.e., absence of clitellates over a 2-month period in 1988, **Fig. 84**).

Data shown above indicated a possible depression of reproduction in 1990, with low clitellate

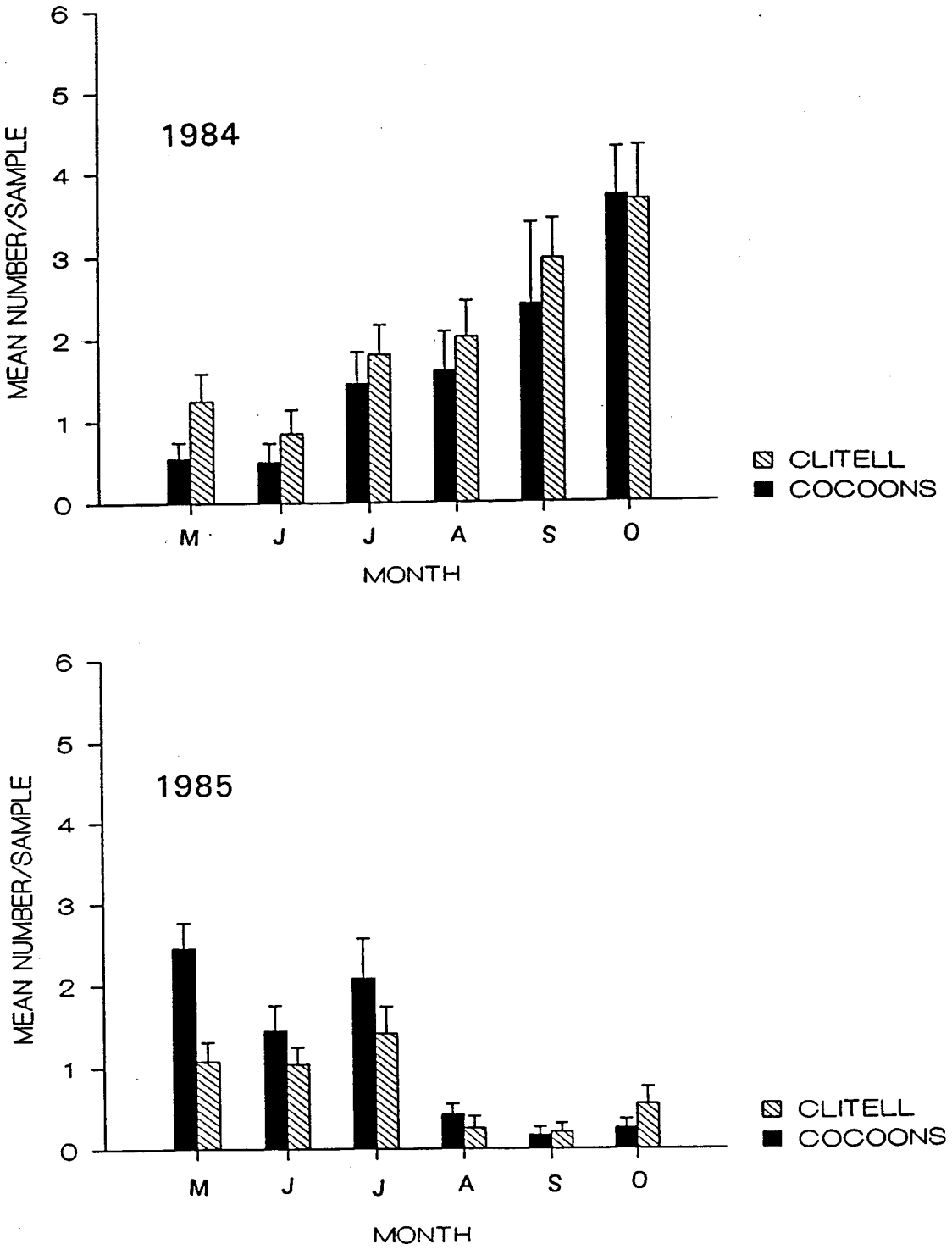
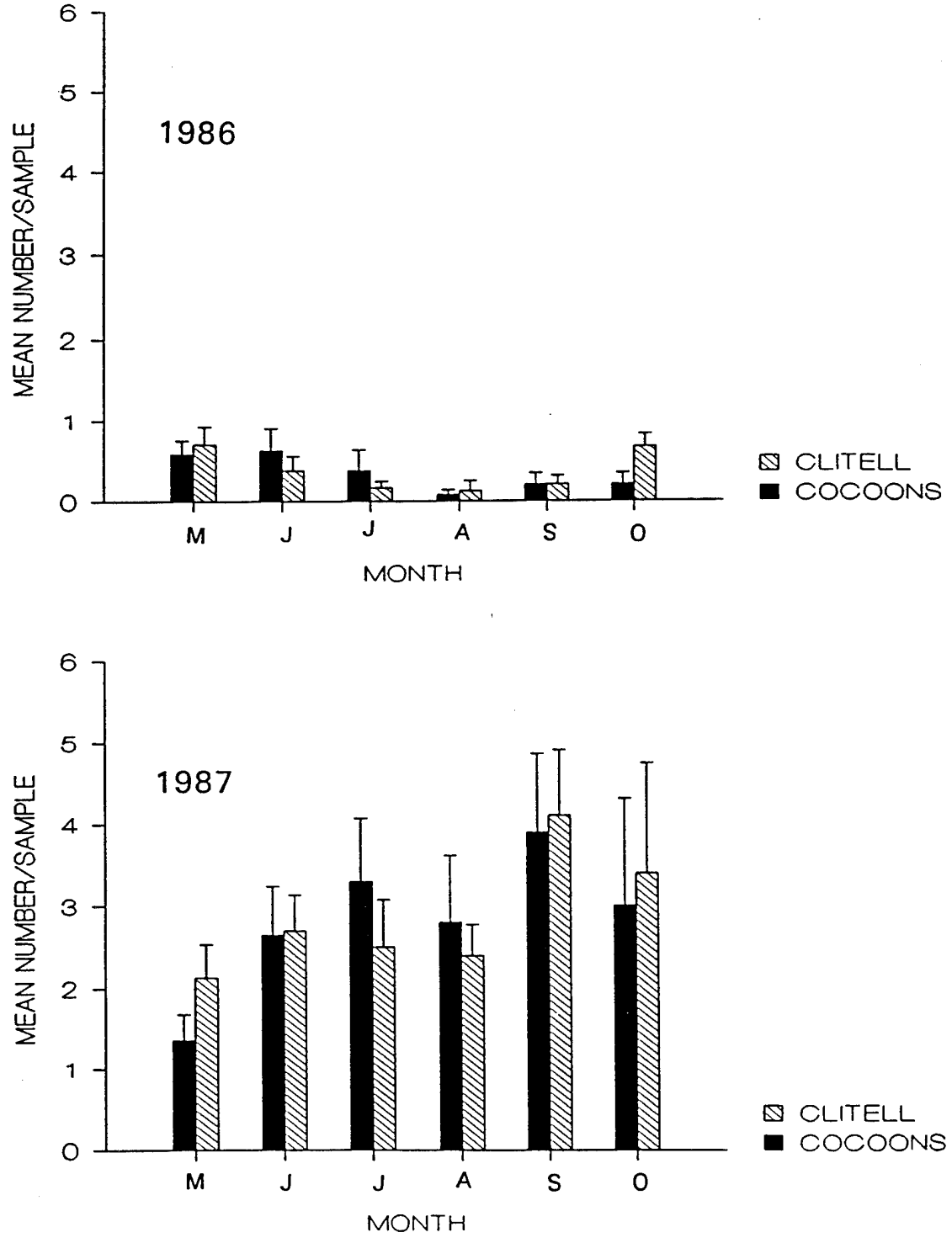



Fig. 84. Monthly numbers of new cocoons and clitellates of *A. tuberculata* per sample (means ± SE, N = 20 or 24 per month), 1984 through 1993, Test site (cont'd on following pages).


1986
MEAN NUMBER/SAMPLE
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4
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M
J
J
A
S
O
MONTH
CLITELL
COCOONS
1987
MEAN NUMBER/SAMPLE
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CLITELL
COCOONS

Fig. 84 cont'd.

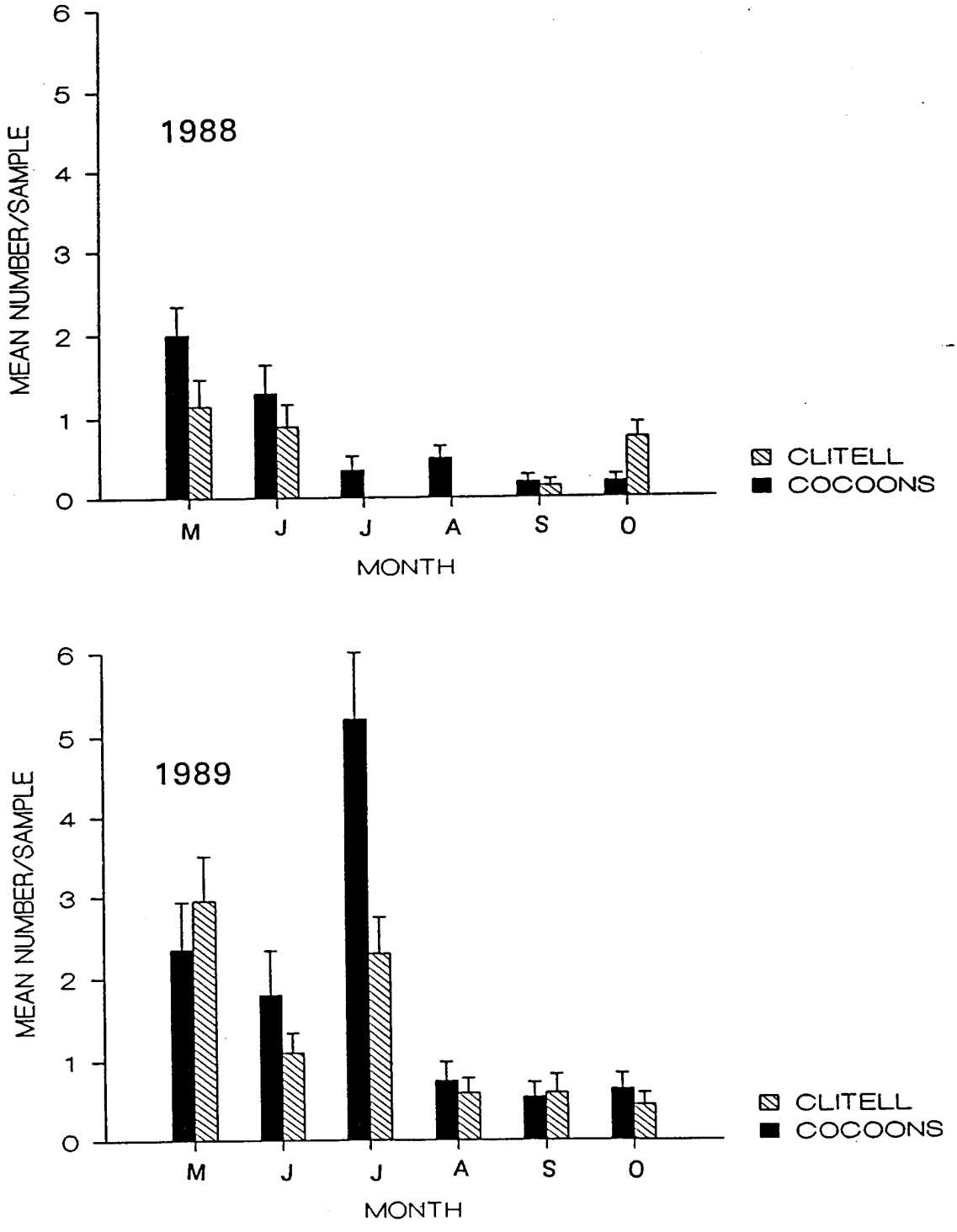
1988
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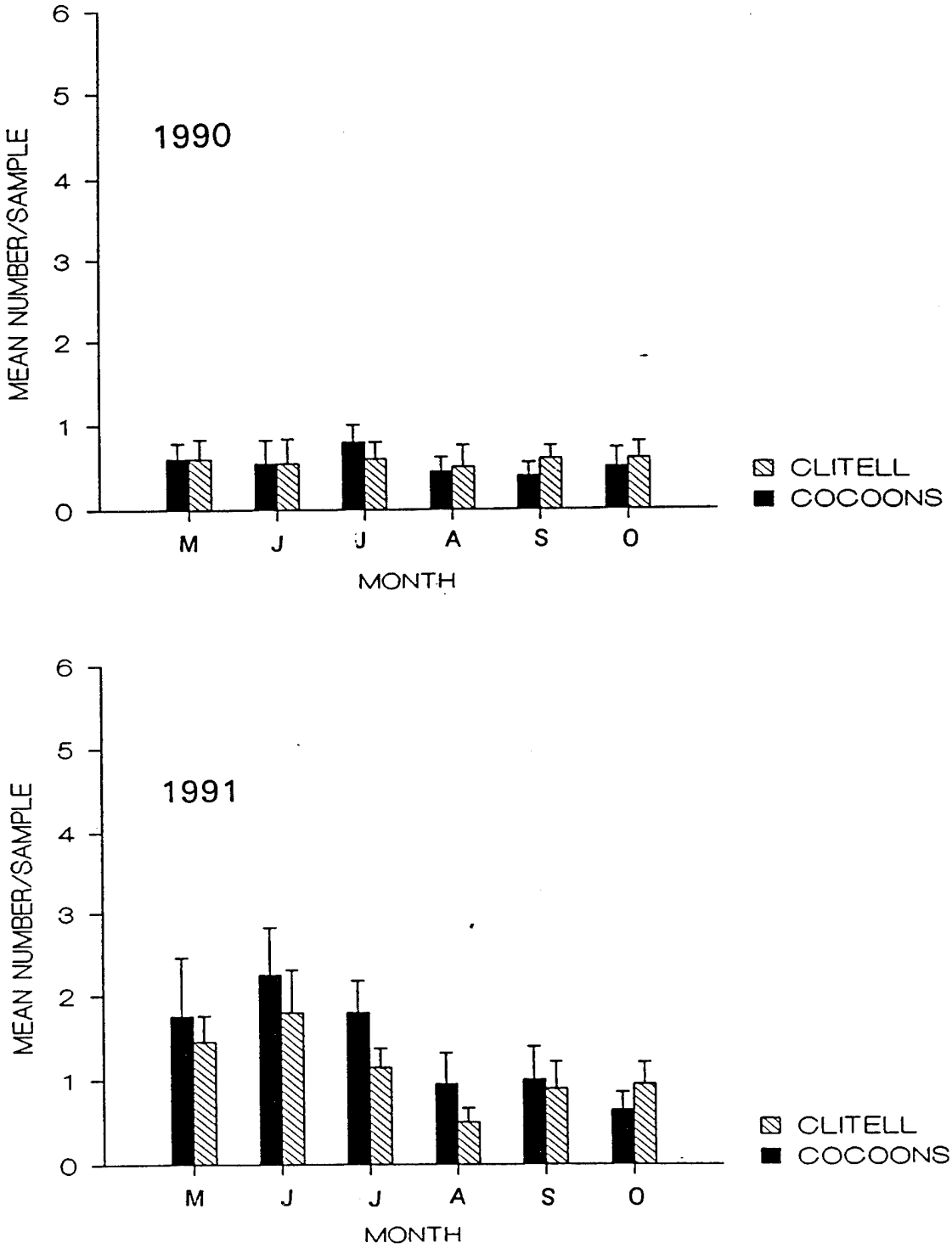
Fig. 84 cont'd.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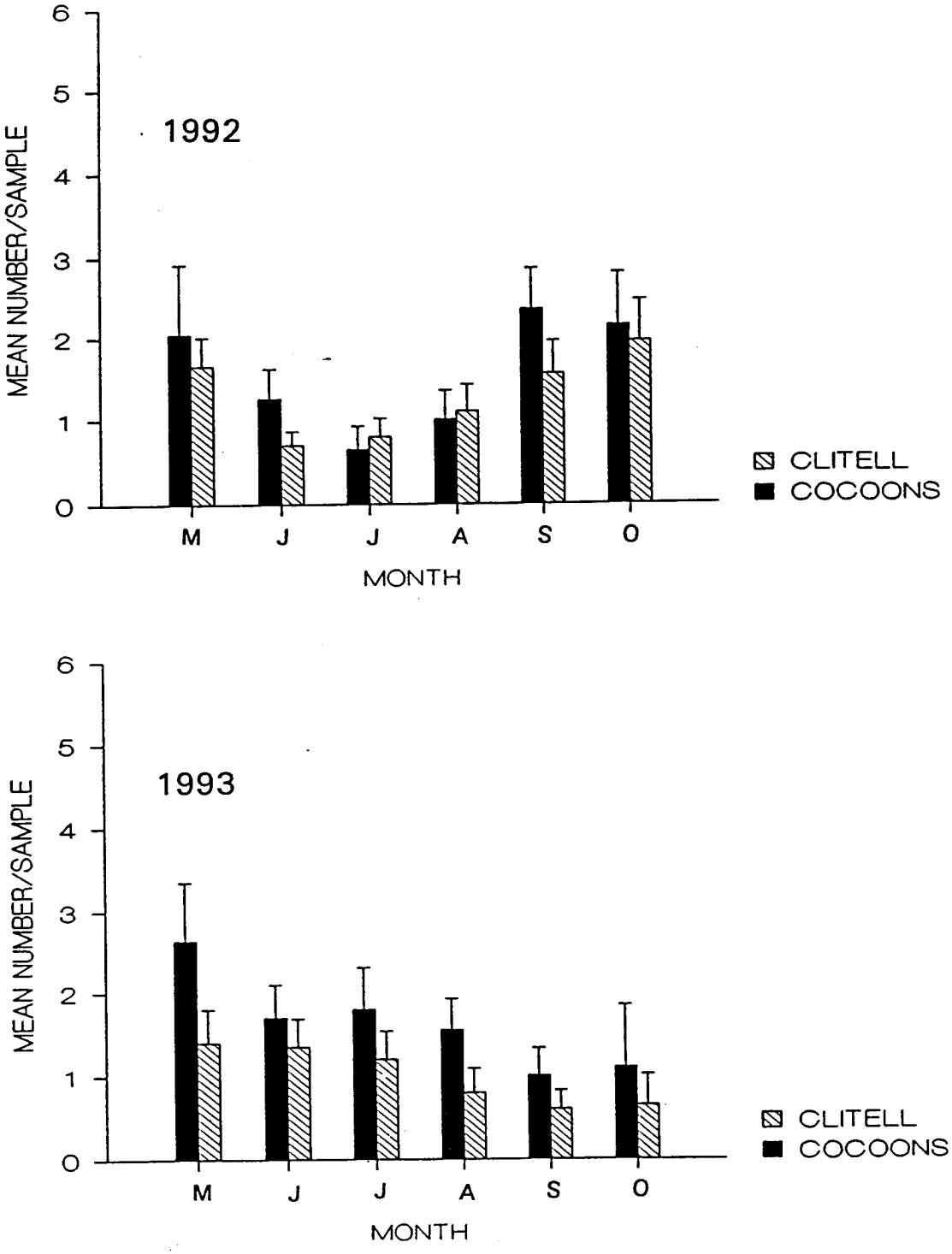
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COCOONS
1993
MEAN NUMBER/SAMPLE
0
1
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M
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A
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MONTH
CLITELL
COCOONS

Fig. 84 cont'd.

and cocoon numbers and decreased responsiveness to soil moisture fluctuations. However, mathematical quantification of reproductive events in terms of their dependence on abiotic variables proved difficult. Data obtained by point-sampling lack the precision needed to quantify processes, such as the rate at which adults regenerate their clitellum given prior and current consitions. Results of available analyses are presented below.

### 4.3.2. Statistical analyses

The main response variables (clitellate density, clitellate proportions, and cocoon density) were tested as follows:

For each parameter, a pre-ELF regression model was developed based on 1984 through 1986 data. The validity of the model was ascertained by testing residuals of the 1984-86 regressions against those of a second (1987-88) pre-ELF regression. All models proved valid, allowing testing of entire pre-ELF sets (1984-88) versus entire ELF sets (1989-93), and versus single operational years.

A condensed overview of results is given in **Table 35**. In all three response variables, the explanatory power of independent variables decreased during operational years. Among single operational years, 1990 was found to be discrepant from pre-ELF models in the case of clitellate and cocoon densities, but not for clitellate proportions. A test of regression residuals obtained for each 5-year period showed that neither clitellate densities nor proportions differed; cocoon densities also yielded non-significant results ($P < 0.06$, **Table 35**).

Clitellate proportions in particular (**Fig. 82**) were prone to variations over time for which we could not find an appropriate independent variable: i.e., following a period of reduced moisture,

return of worms to the reproductive state was delayed, and the degree to which reproduction resumed varied (but not in direct relation to the degree of soil rehydration or the length of time it had been dry).

**Table 35.** Summary of results of regression analyses of reproductive parameters in Test site *A. tuberculata*. Clitellate proportions were transformed to [ln (p/1-p)]. The last two rows are based on tests of regression residuals, for pre-ELF vs. operational periods, and for the entire pre-ELF period vs. single operational years. CLIT. DENS. and CLIT. PROP. = clitellate densities and proportions respectively; COCOON DENS. = density of new cocoons. **Note: details in Appendix 8.**

| PERIOD | RESPONSE VARIABLES | | |
|---|---|---|---|
| | CLIT.DENS.[a] $R^2$ (P) | CLIT.PROP.[b] $R^2$ (P) | COCOON DENS.[c] $R^2$ (P) |
| 1984-1986 | 0.89 (0.000) | 0.55 (0.000) | 0.84 (0.000) |
| 1987-1988 | 0.73 (0.000) | 0.90 (0.000) | 0.86 (0.000) |
| 1984-1988 | 0.79 (0.000) | 0.71 (0.000) | 0.85 (0.000) |
| 1989-1993 | 0.30 (0.003) | 0.39 (0.000) | 0.52 (0.000) |
| 1984-88 vs. 1989-93 | NS (0.20) | NS (0.48) | NS (0.06) |
| Pre-ELF vs. single ELF years: year | 1990 ONLY (0.000) | NONE SIGNIFICANT | 1990 ONLY (0.000) |

[a] Independent variables: Clitellate density lagged (by one date), A horizon moisture, A horizon temperature, (A horizon temperature)$^2$, and (moisture x temperature).

[b] Independent variables: Clitellate proportions lagged (by one date), A horizon moisture.

[c] Independent variables: Clitellate densities and clitellate densities lagged (by one date).

Comparisons between *A. tuberculata* and its congener *A. turgida* in Control are tenuous, since we do not consider them to be the same species (unlike many European authorities, e.g., Sims and Gerard 1985, or Easton 1983). It is striking, however, that correlations between the two species in terms of reproductive parameters were significant in pre-ELF years, but not in operational years. Two of these parameters are illustrated below. Mean annual percent of adults clitellate (**Fig. 85**), although low moisture affected *A. tuberculata* more than *A. turgida*, were well correlated in 1984-1988 ($R^2 = 0.87$, $P < 0.01$, $N = 5$); in 1989-1993, $R^2$ dropped to 0.43. Mean abundance of new cocoons (**Fig. 86**) yielded more extreme results: $R^2$ for 1984-1988 = 0.87, $R^2$ for 1989-1993 = 0.00.

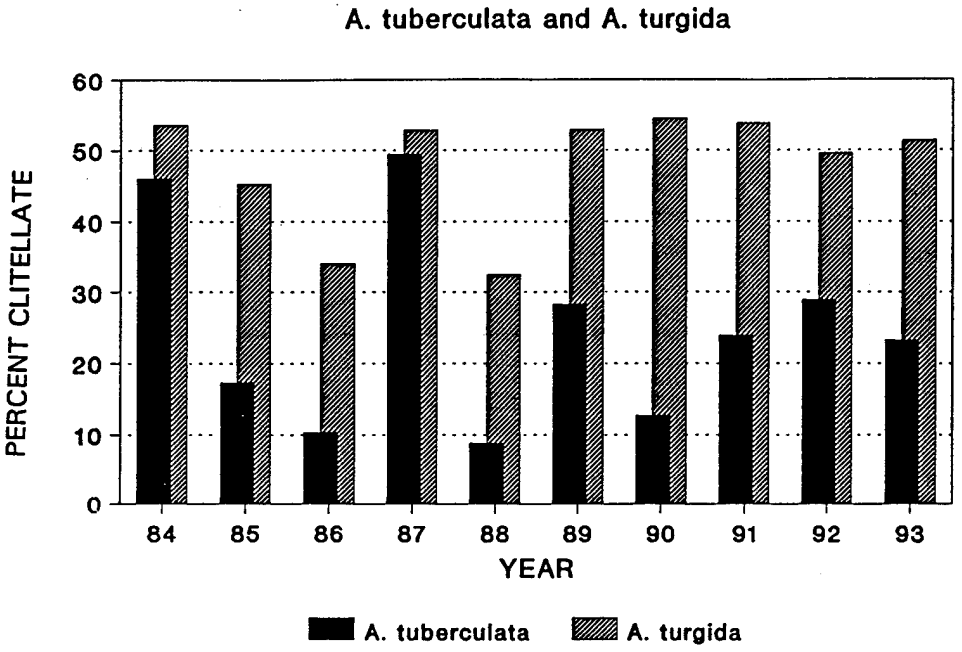


Fig. 85. Mean annual percent of all adults in the clitellate state, *A. tuberculata* (Test site) vs. *A. turgida* (Control site), 1984 to 1993.

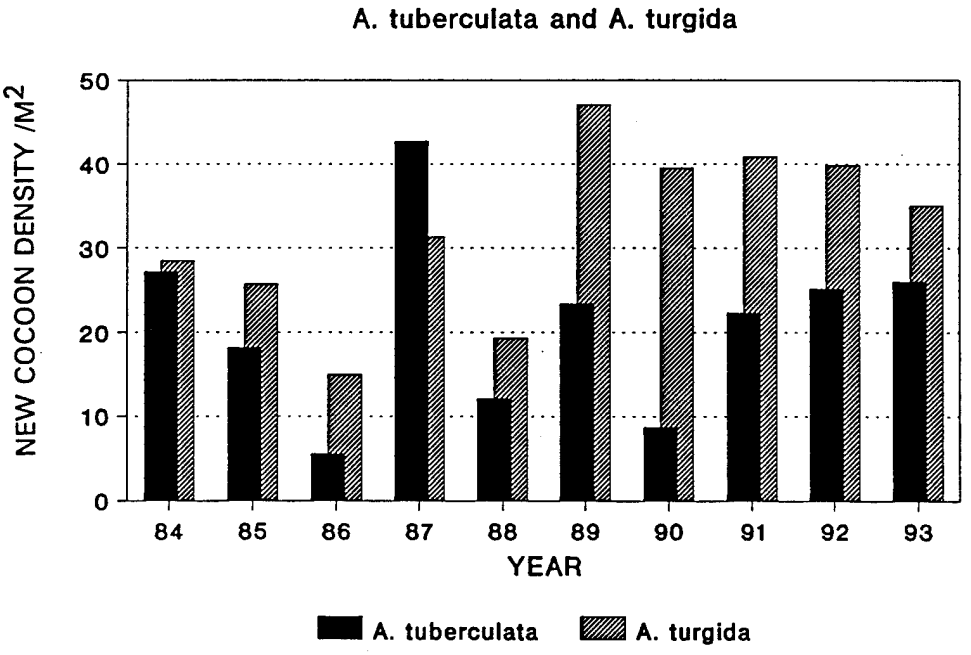


Fig. 86. Mean annual density of new cocoons, *A. tuberculata* (Test site) vs. *A. turgida* (Control site), 1984-1993.

### 4.3.3. Cocoon production rates

Rates of cocoon production (Methods 1 and 2 based on numbers, Method 3 based on mass, ref. page 138 ) were quite variable between years, and tended to be slightly elevated during operational years (**Figs. 87-89**). Summarized by pre-ELF and operational periods, overall mean cocoon production rates were significantly higher in 1989-1993, for all methods of calculation (**Table 36**).

We had thought earlier that increased cocoon production rates represented a possible ELF effect. Comparison of *A. tuberculata* and *A. turgida*, however, raises some doubts. Mean annual cocoon : clitellate ratios were equally variable in *A. turgida*, and tended to be higher during operational years (**Figs. 90-92**). No significant correlation existed between annual mean rates in the two species. We were also unable to tease out any predictive environmental factors which may have affected cocoon production rates. Deviations between species (potentially beginning with antenna activation), such as were observed for other parameters (**Fig. 86**) were not detectable.

Although rates of cocoon production in *A. turgida* during 1989-1993 were significantly increased based only on Method 3 (mass-related calculation) (**Table 37**), the fact that the direction of change over time was the same in both species is noteworthy. It suggests that factors unrelated to antenna activation may have been operative. For instance, uneven rainfall distribution and the severity and duration of soil moisture fluctuations were much less pronounced in 1989-93 than during pre-ELF years.

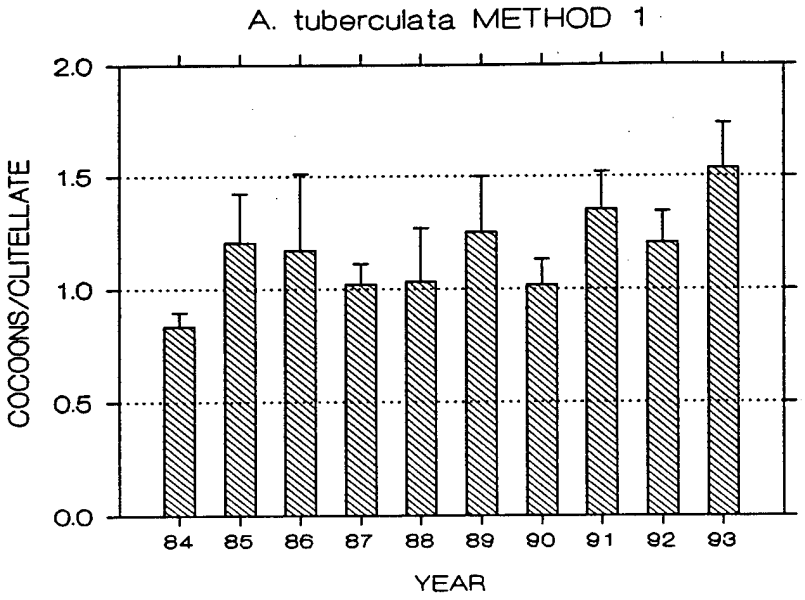


Fig. 87. Annual mean (± SE) cocoon production rates of *A. tuberculata* (Test site), Method 1 (N cocoons / average N clitellates).

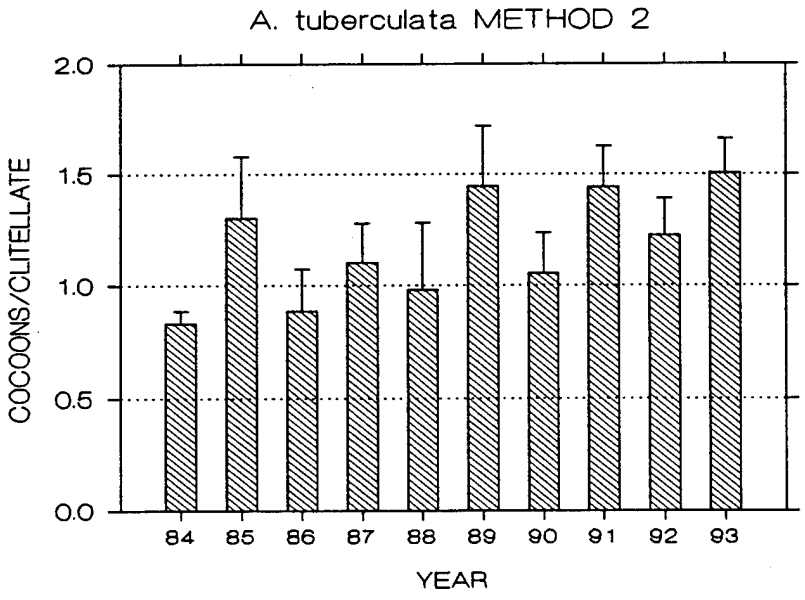


Fig. 88. Annual mean (± SE) cocoon production rates of *A. tuberculata* (Test site), Method 2 (N cocoons /N clitellates).

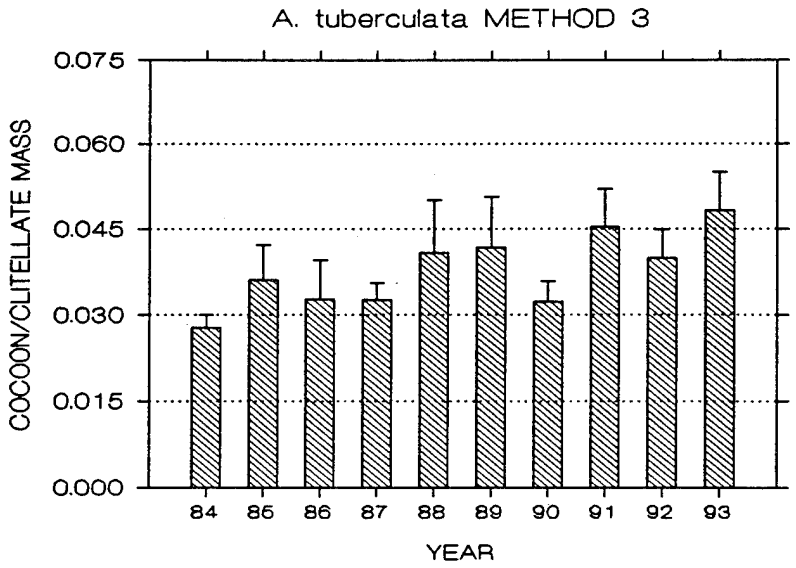


Fig. 89. Annual mean (± SE) cocoon production rates of *A. tuberculata* (Test site), Method 3: (total cocoon mass / average clitellate mass).

**Table 36.** Mean cocoon production rates of *A. tuberculata* during pre-ELF and operational periods in the Test site. Only dates on which ≥ 3 clitellates were present were used, resulting in variable N. P values based on t test results.

| BASIC STATISTICS /METHOD | | PERIOD | | P< |
|---|---|---|---|---|
| | | 1984-1988 | 1989-1993 | |
| METHOD 1 | Mean | 1.0320 | 1.2787 | 0.05 |
| | SD | 0.4919 | 0.5976 | |
| | N | 42 | 55 | |
| METHOD 2 | Mean | 1.0092 | 1.3419 | 0.01 |
| | SD | 0.5489 | 0.6203 | |
| | N | 44 | 53 | |
| METHOD 3 | Mean | 0.0337 | 0.0416 | 0.04 |
| | SD | 0.0179 | 0.0211 | |
| | N | 52 | 55 | |

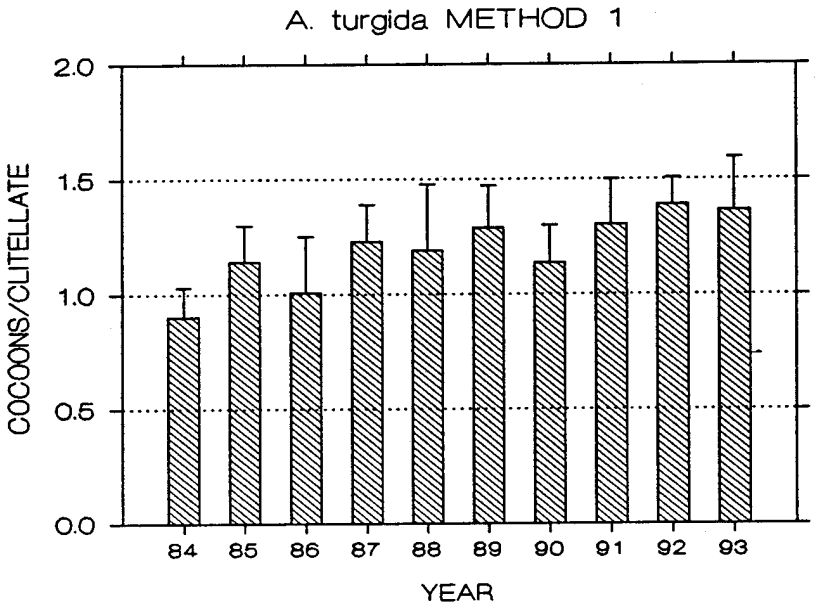


Fig. 90. Annual mean (± SE) cocoon production rates of *A. turgida* in the Control site, 1984 to 1993; rates calculated by Method 1 (N cocoons / average N clitellates).

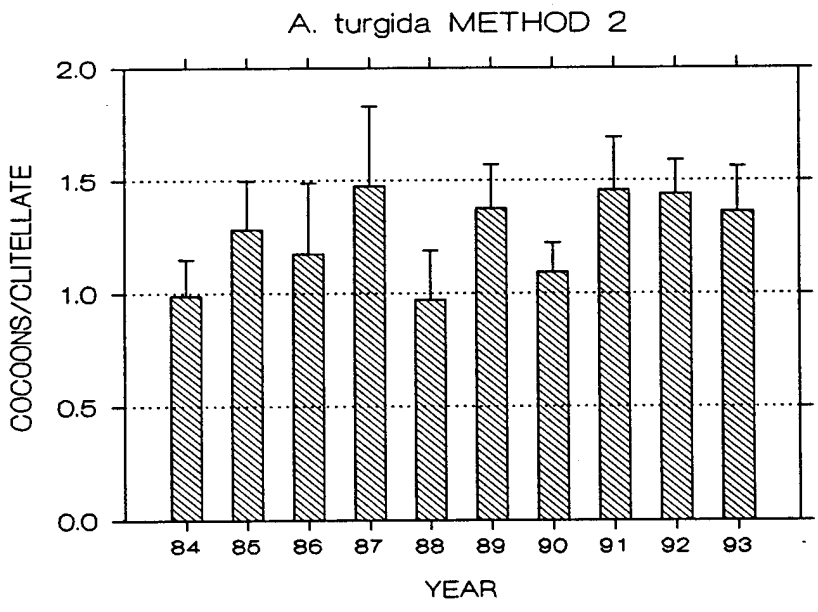


Fig. 91. Annual mean (± SE) cocoon production rates of *A. turgida* in the Control site, 1984 to 1993; rates calculated by Method 2 (N cocoons / N clitellates).

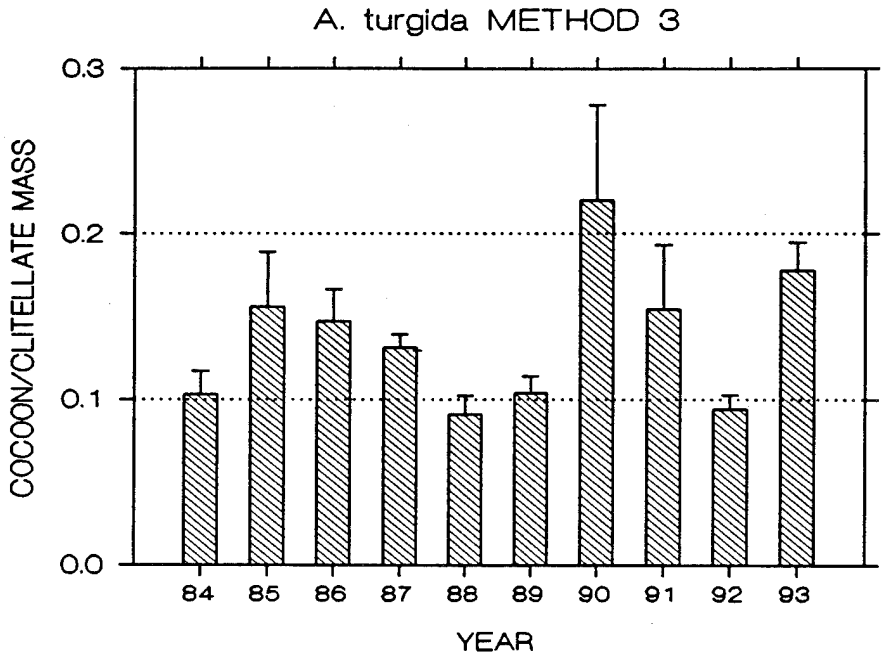


Fig. 92. Annual mean (± SE) cocoon production rates of *A. turgida* in the Control site, 1984 to 1993; rates calculated by Method 3 (total cocoon mass / average clitellate mass).

**Table 37.** Mean cocoon production rates of *A. turgida* in the Control site during pre-ELF and operational periods; P values based on t test results.

| BASIC STATISTICS /METHOD | | PERIOD | | P< |
|---|---|---|---|---|
| | | 1984-1988 | 1989-1993 | |
| METHOD 1 | Mean | 1.1001 | 1.2944 | 0.10 |
| | SD | 0.5662 | 0.5962 | |
| | N | 49 | 55 | |
| METHOD 2 | Mean | 1.1766 | 1.3448 | 0.40 |
| | SD | 0.7310 | 0.6124 | |
| | N | 49 | 55 | |
| METHOD 3 | Mean | 0.1255 | 0.1500 | 0.01 |
| | SD | 0.0667 | 0.0130 | |
| | N | 55 | 55 | |

### 4.4. Population density and structure

Biweekly density estimates (**Fig. 93** and **Appendix 9**) showed a strong dependency of total population abundance on immature abundance. Seasonal fluctuations were very pronounced, and could only be explained as effects of several interacting factors such as: the time of maximum cocoon production during the preceding or current year (determining time of emergence) (Rundgren 1977); or edaphic conditions at the time when recruits were ready to hatch (drought can delay emergence) (James 1992). We did not observe consistent mid-summer density decreases documented by others (Nowak 1975; Tomlin *et al.* 1992).

Although data on population structure do not lend themselves to rigorous analyses, they provide an overview of developmental patterns of *A. tuberculata*, and of their annual variability; a descriptive summary is provided in **Fig. 94**. Small immatures tended to increase in numbers the year following high cocoon production (e.g., 1984-85, 1987-88, 1989-90). Intermediate-sized immatures tended to peak 1 to 2 years later. Between-year fluctuations virtually disappeared in the large immature and adult classes, indicating that a relatively long life span played a role in smoothing out population dynamics over the long term.

A frequently observed phenomenon was the delay between cocoon production and appearance of small immatures. As an example, the 1987 and 1988 seasons are illustrated in **Fig. 95**. New cocoon densities were maximal in July - September of 1987. Hatchlings began to increase in numbers in the second half of the 1987 season, but did not reach highest densities until 1988 (at a time when the 1988 cocoon production was severely depressed by drought). There was thus a delay of a few months, and up to a year (due to the intervening winter) between maximum cocoon production and emergence of the corresponding cohort of recruits (**Fig. 95**). Delayed

emergence and delayed growth of hatchlings during the dry year 1988 probably also affected population structure (Rundgren 1977).

Variable reproduction and growth patterns were also reflected in mean immature:adult ratios. They ranged from approximately 2.5 to 3.7, and differed significantly between successive years on three occasions (1985 ratios higher than 1984, $P < 0.001$; 1987 lower than 1986 , $P < 0.001$; and 1991 ratios lower than 1990, $P < 0.01$). In general, lower ratios were linked to high rates of recruitment 2 to 3 years previously, suggesting that attainment of adulthood requires close to 3 years.

Finally, one may examine immature frequencies with respect to potential differences between *A. tuberculata* and *A. turgida* (**Fig. 96**). Correlation between annual mean immature frequencies was significant in 1984-1988 ($R^2 = 0.82$, $P < 0.01$), but no longer existed in the operational period ($R^2 = 0.05$).

It is possible that discrepancies were caused by differential maturation rates. For instance, low *A. turgida* immature frequencies in 1990 could have been the result of an influx of adults stemming from the 1987 cocoon cohort; a corresponding influx of *A. tuberculata* adults did not depress immature frequencies until 1991 (combined with reduced numbers of small immatures from the 1990 cocoon cohort, **Fig. 84**). It is surprising, however, that similar discrepancies did not occur during pre-ELF years (which, in turn, reflected reproduction and growth patterns **prior to** 1984). Lacking reliable data useable as independent, predictive variables, these results cannot be examined beyond the descriptive stage.

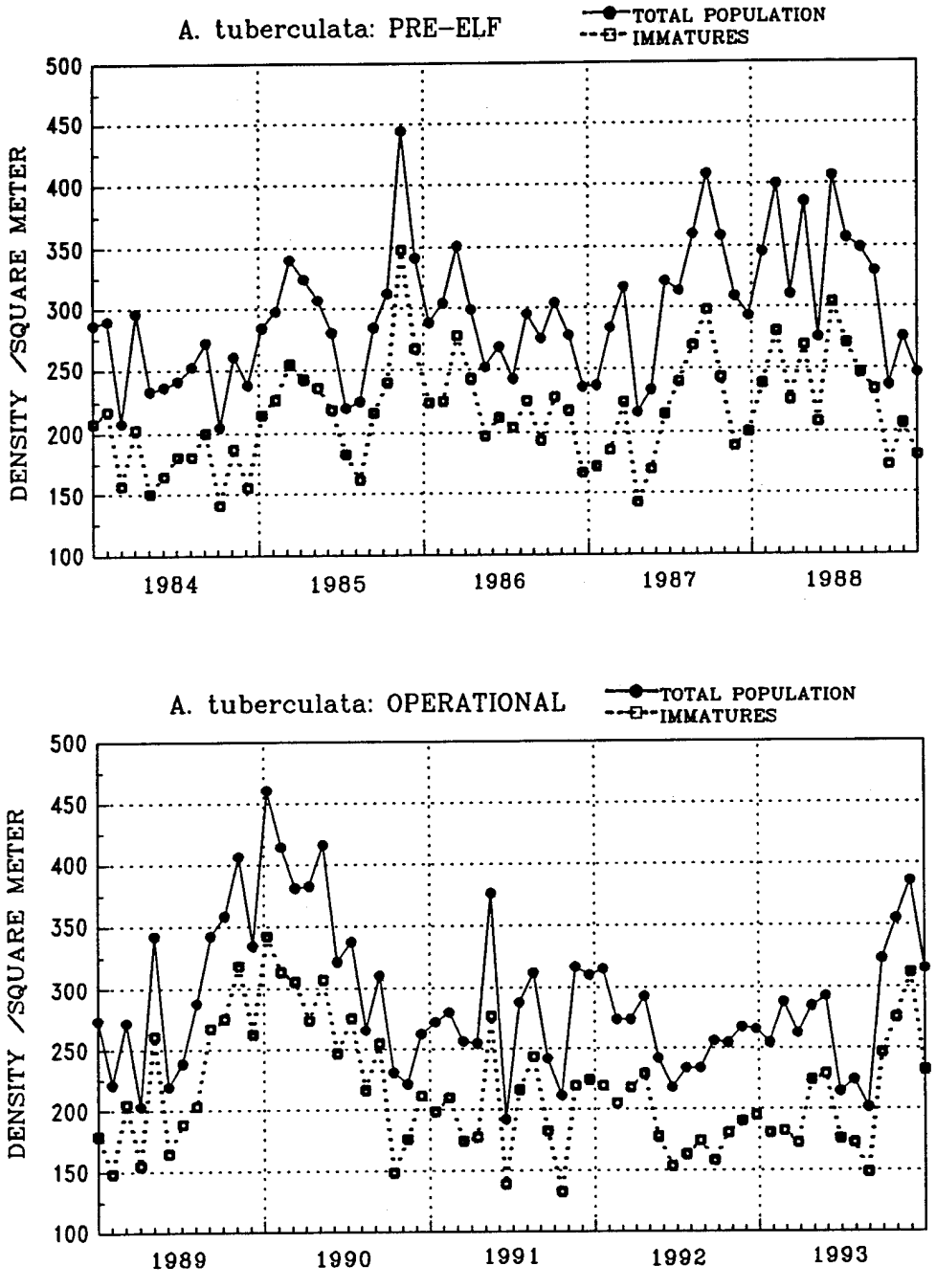


Fig. 93. Mean biweekly density /$m^2$ of *A. tuberculata* in the Test site, for the total population and for immatures during pre-ELF and operational years (see also **Appendix 9**).

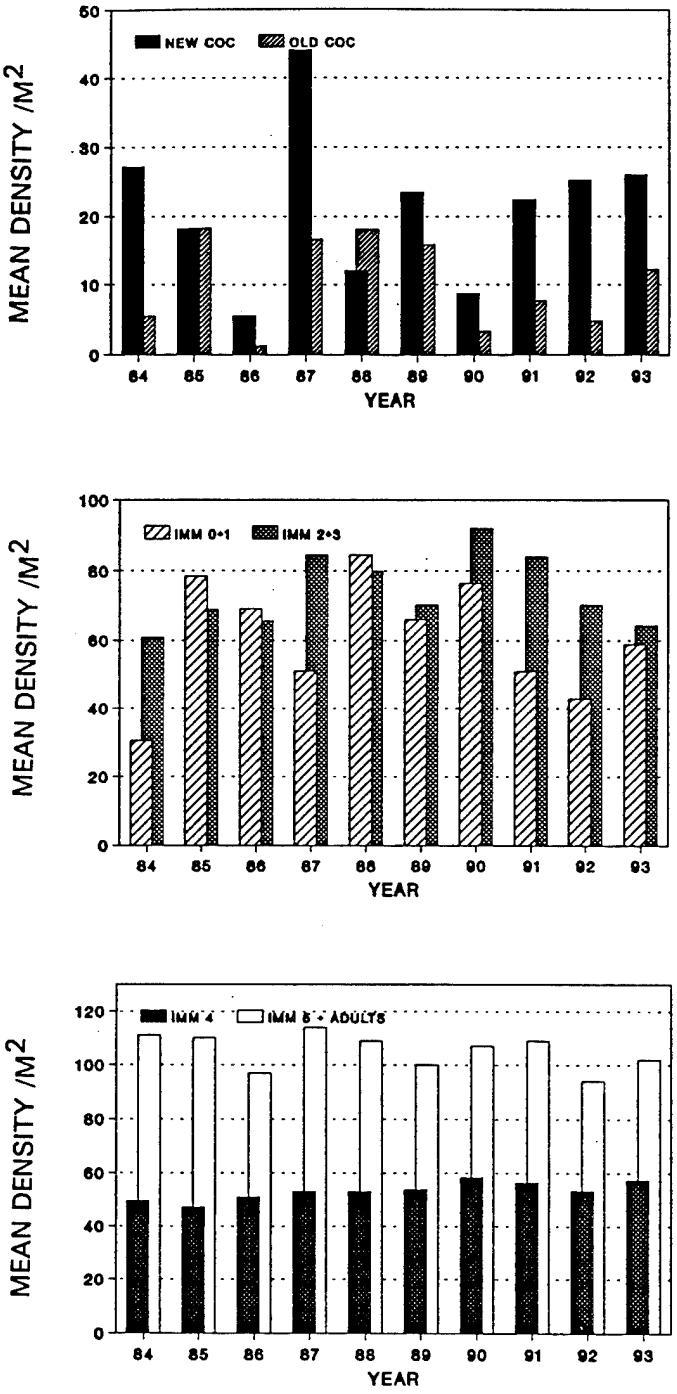


Fig. 94. Mean annual density of developmental classes of *A. tuberculata* in the Test site, 1984-1993. IMM 0+1, ≤45 mg; IMM 2+3, 45.1-180 mg; IMM 4, 180.1-360 mg; IMM 5 and adults, >360 mg.

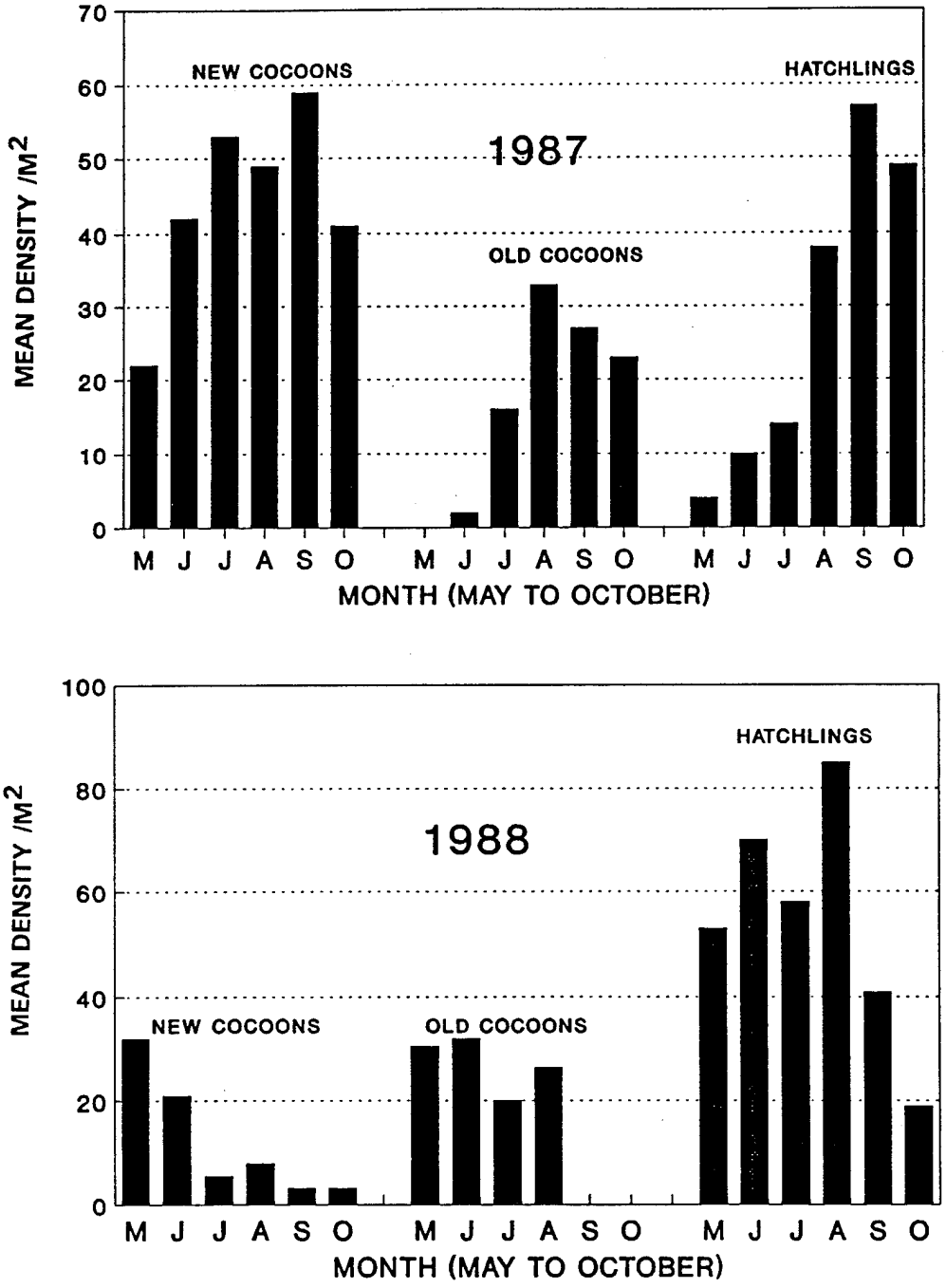


Fig. 95. Mean monthly densities (N = 20 or 24 samples /month) of new cocoons, old cocoons, and hatchlings of *A. tuberculata* in the Test site, 1987 and 1988.

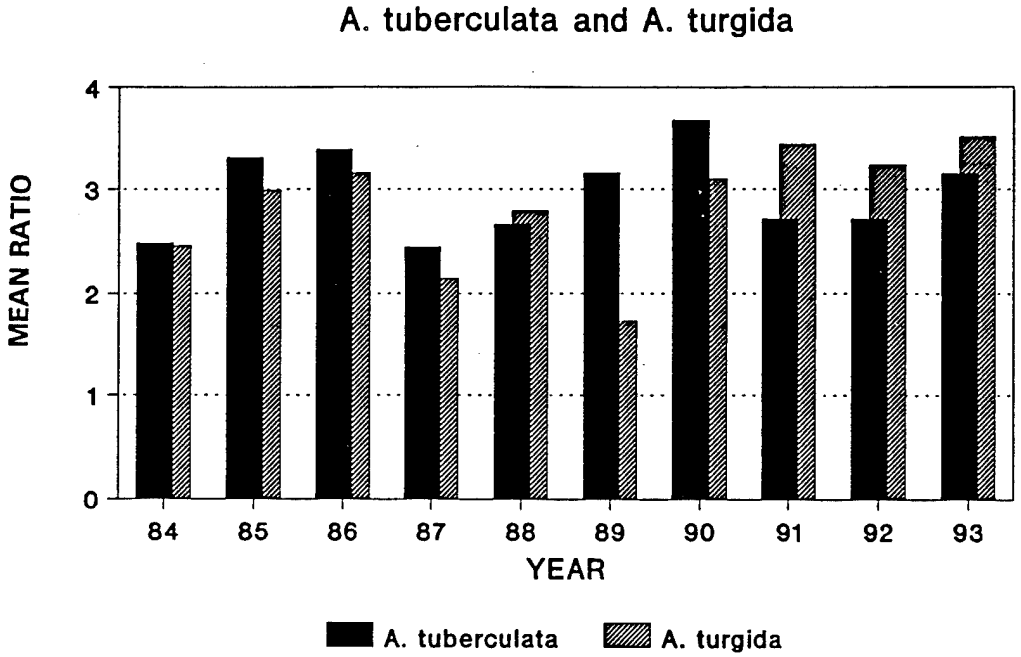


Fig. 96. Mean annual immature/adult ratios for *A. tuberculata* (Test site) and *A. turgida* (Control site), 1984 to 1993 (N = 10 to 13 dates /year).

## C. SUMMARY AND DISCUSSION

Several population attributes or patterns documented here confirm or expand on results reported in the extensive literature on European lumbricids. Species associations in our sites corresponded closely to those found in deciduous forests in various parts of Europe (Bouché 1972, 1977; summaries in Nordström and Rundgren 1973, Satchell 1983, Lee 1985). Individual constituents of Test and Control communities did not deviate behaviorally from expected responses to edaphic conditions as reflected in vertical distribution patterns (Snider and Snider 1988, 1994). The ecologically "intermediate" (Bouché 1977) *L. rubellus*, restricted to A and litter horizons, was here shown to prefer the litter stratum to a greater degree when immature.

The endogeic *A. tuberculata* exhibited seasonal variations in depth distribution, clearly in response to A horizon moisture. In agreement with Rundgren (1975, 1977) and Nordström (1975), adults migrated downward more readily than immatures. In neither of these species were effects of EM fields on vertical distribution detectable.

The most salient points of discussion for this report concern reproductive parameters.

Individual cocoon mass of *L. rubellus* and *A. tuberculata* (as well as of other species not discussed here) showed a wide range, the largest weighing 3 to 4 times as much as the smallest. Such ranges are not unusual (Christensen and Mather 1990; Pedersen and Bjerre 1991). Potential causes for between-year variation in cocoon mass are difficult to detect in field-derived data. In *L. rubellus*, highest mean adult mass in 1989 coincided with highest mean cocoon mass, but over all years the relationship was marginally significant ($P = 0.1$). In *A. tuberculata*, reduced cocoon mass coincided with drought years. In other species, soil moisture was found to be negatively correlated with cocoon mass (Evans and Guild 1948; Reinecke and Venter 1987). Parent adult mass is known to be positively correlated to cocoon mass (Phillipson and Bolton 1977; Lofs-Holmin 1983). The same species living in different soils can produce distinctly different cocoon sizes, related to adult size, which in turn reflects site conditions (Christensen and Mather 1990). Within one site (our Test site), over several years, additional mechanisms may have been operative; e.g., population structure in terms of age and size of adults at first reproduction, or longevity and therefore size of adults as affected by edaphic conditions.

Neither in *L. rubellus* nor in *A. tuberculata* did antenna activation detectably affect adult or cocoon mass.

For *L. rubellus*, we were unable to develop predictive models for reproductive performance

based on pre-ELF data. Our only conclusion can be that given all available information, no EM field effects were detectable.

In *A. tuberculata*, raw data summaries strongly portrayed depressed reproduction in late 1989 through 1990 . Results of regression analyses suggested EM field effects during operational years, as evidenced by lowered $R^2$ **(Table 35)**. Differences between the two 5-year periods, however, were only marginally (cocoon density) or not at all significant (clitellate density and clitellate proportions). Among single operational years, however, 1990 stood out as the year most discrepant from pre-ELF years **(Table 35)**.

Our conclusions (keeping in mind tentative comparisons between *A. tuberculata* and *A. turgida*), are as folllows:

a) an EM field effect on *A. tuberculata* did occur during the first two seasons of antenna operation, resulting in decreased numbers of reproductive worms and cocoons; the effect was transient, however, and no longer detectable in 1991-1993.

b) higher rates of cocoon production during operational years were statistically significant. However, in view of concurrent increases in *A. turgida*, this may simply reflect an effect of several consecutive years of non-limiting moisture conditions. Cocoon production tends to increase with temperature (Butt 1991), so that rates would tend to be highest in mid-season. Low soil moisture curtailed reproduction during the warmest time of the year in 1986 and 1988 (two of five pre-ELF years). Higher mean cocoon production rates in 1989-1993 may have been the result of relatively uninterrupted reproductive activity during the warmest months of all five operational years.

# VI. EARTHWORM ISOLATION EXPERIMENTS

## A. METHODS

*Aporrectodea tuberculata* adults were incubated in cylindrical fiberglass mesh bags (20 cm diameter) embedded in the soil to a depth of approximately 20 cm. Bags were filled with dried, sieved, and re-moistened soil consisting of 70% A horizon and 30% B horizon material, manually compressed and settled by addition of water during the filling process. Earthworms were added to each bag and covered with wet leaf litter in order to eliminate moisture stress during the time they burrowed into the soil. Bags were retrieved at monthly intervals, and earthworms and cocoons were recovered by a combination of handsorting and washing after removing a 150 ml sample of soil from the center of each bag for gravimetric moisture determination. Earthworms were weighed individually (except for 1991) and were returned to the field 24 hours after retrieval. Cocoons were preserved in 10% formalin and weighed 1 to 2 weeks later.

The 1991 season was used to develop the techniques and to document its potential flaws and variations (details in Snider 1994). Below, the characteristics of four observation series, differing with respect to methods and earthworm collection sites ("provenance") are summarized. Each series or group was duplicated in the Test and the Control site. Series are identified by earthworm provenance site and year of initiation of observations (not total duration of observation).

**1. Test 1991 series:**

**Provenance of earthworms: Test site, spring 1991**
**Observation period: May 1991 - October 1993**
**Previous EM exposure history: exposed since May 1989**
Incubation in Test bags = continued exposure to EM fields
Incubation in Control bags = removal from exposure to EM fields
Provenance of soil used for incubation: Test site
Replication / site: 10 bags (May - June 1991, 15 worms / bag); reduced to five bags (30 worms / bag) thereafter

**2. Merriman 1991 series:**

**Provenance of earthworms: Merriman Rd. site (deciduous forest), spring 1991**
**Observation period: May 1991 - October 1991**
**Previous EM exposure history: never exposed**
Incubation in Test bags = first exposure to EM fields
Incubation in Control bags = continued non-exposure
Provenance of soil used for incubation: Test site
Replication / site: 10 bags (May - June 1991, 15 worms / bag); reduced to five bags (30 worms / bag) thereafter

**3. Fire Tower 1992 series:**

**Provenance of earthworms: Fire Tower site (deciduous forest), spring 1992**
**Observation period: May 1992 - October 1993**
**Previous EM exposure history: never exposed**
Incubation in Test bags = first exposure to EM fields
Incubation in Control bags = continued non-exposure
Provenance of soil used for incubation: Fire Tower site
Replication / site: 10 bags (30 worms / bag)

**4. Test 1993 series:**

**Provenance of earthworms: Test site, spring 1993**
**Observation period: May 1993 - October 1993**
**Previous EM exposure history: exposed since May 1989**
Incubation in Test bags = continued exposure to EM fields
Incubation in Control bags = removal from exposure
Provenance of soil used for incubation: Test site
Replication / site: 5 bags (30 worms / bag)

During the three years in which isolation experiments were performed, changes in protocols, omitting details, can be summarized as follows:

**1. Distribution of earthworms:**

In 1991 (Test 1991 and Merriman Rd. 1991 series), each group of earthworms was returned to its bag of origin on each sampling date. Beginning in May 1992, earthworms were re-distributed randomly to replicate bags such that each bag received approximately equal numbers of clitellate and non-reproductive adults. Each incubation period thus began with approximately equal stage structure in each bag. The procedure alleviated problems of autocorrelation and allowed use of parametric statistics.

**2. Earthworm body mass:**

Complete voiding of earthworms' intestines when placed on wet paper towels in the laboratory takes up to 5 days, during which time they are removed from EM field exposure. Although "gut-voided" mass data are more precise than and are preferrable to "gut-full" weights, the long period of removal from EM fields was not justifiable. In early 1991, we attempted to obtain a correction factor which would allow estimation of gut-voided mass from gut-full data by regression. However, mass changes were so variable between individuals (due to combined effects of weight loss by voiding and weight gain by rehydration) that the relationship was not quantifiable. Weighing of worms was thus discontinued for the remainder of the 1991 season.

In 1992 and 1993, we resumed weighing of individual worms from all series (gut-full mass) within 20 minutes of their removal from mesh bags. Analysis of 1991 data yielded no evidence of consistent between-site differences in terms of mass changes after voiding. We concluded that despite some error inherent in gut-full estimates, we would be able to detect potential differences

in body mass, especially since soil moisture inside bags was assessed concurrently.

In all Provenance series, field-collected earthworms were randomly divided into two groups destined for incubation in Test and Control sites. They were allowed to void their intestines prior to initial weighing. Mean initial body mass did not differ significantly between Test and Control groups in any of the series. We thereby confirmed that separation of worms into groups was indeed random, ensuring equal starting points for subsequent assessment of potential differences in mass changes.

Since earthworm body mass was not monitored in 1991, mass-related response variables are available for 1992 and 1993 only (body mass, and cocoon production rates Method 3, which is based on mass ratios).

**3. Moisture and temperature in mesh bags:**

In 1991, bags were left undisturbed between samplings. Beginning in 1992, periodic temperature readings were taken in Test and Control bags by means of a YSI telethermometer. Temperature differences between sites were small ($\pm$ 0.2 to 0.5 $^{o}$C) and not consistently lower or higher in either site.

Beginning in 1992, three additional bags were installed in each site and provided with TDR (Time Domain Reflectometry) moisture sensors. Based on regression ($R^2$ = 0.84, N = 87) it was determined that TDR readings of approx. 20% corresponded to approximately 18% moisture (gravimetric). Whenever TDR readings in any one of the six bags fell below 20%, approximately 3 - 4 l water were gradually added to each bag in both sites.

## B. RESULTS

### 1. Electric fields

Each year, electric fields within and immediately adjacent to each bag were measured by directional field probes designed and calibrated by IIT Research Institute (details in Haradem et al. 1989). In 1991, after initial installation of mesh bags, average field intensities within bags were reduced to 47% of ambient fields in both sites (**Table 38**). Repeated use of the same holes which housed mesh bags apparently resulted in better contact between mesh bags and their contents and the surrounding soil, since mean field intensities in 1992 and 1993 increased in both sites, and approximately 70% of ambient electric field intensity was present inside the bags. On average, field intensities inside Control bags were 250 to 360 times lower than those in Test bags (**Table 38**).

**Table 38.** Mean (± SD) electric field intensities (mV/m) within mesh bags in Test and Control sites, 1991-1993. Percent field reduction = mean of individual ratios of (mV/m within bag)/(mV/m next to bag) x 100. Each value based on N = 20 measurements.

| | TEST SITE | | | CONTROL SITE | | |
|---|---|---|---|---|---|---|
| | 1991 | 1992 | 1993 | 1991 | 1992 | 1993 |
| mV/m within bags | | | | | | |
| mean | 24.0 | 46.0 | 45.0 | 0.09 | 0.14 | 0.12 |
| SD | 6.7 | 10.6 | 11.6 | 0.04 | 0.04 | 0.03 |
| % field reduction | | | | | | |
| mean | 47.0 | 72.0 | 73.0 | 47.0 | 77.0 | 64.0 |
| SD | 12.0 | 11.4 | 13.8 | 9.4 | 9.6 | 12.6 |

**2. Moisture**

All mesh bags were treated equally in terms of periodic addition of water in 1992 and 1993. Drainage conditions in the immediate surroundings of each bag probably influenced bag-specific soil moisture, and differences between sites in terms of drainage patterns as well as (occasional) rainfall events were probably influential in moisture differences between sites.

Mean moisture estimates cannot document moisture conditions as they changed over the short term (i.e., between monthly samplings). They did reflect general seasonal conditions, and indicated that:

a) Differences between Test and Control bags were not always consistent between years (within series) or between series (within years). For instance, moisture in Test 1991 series bags buried in Control tended to be higher than in the Test site, though not in all years or on all dates (**Fig. 97**). In Fire Tower series bags (**Fig. 98**), soil moisture was somewhat higher in Test site bags in 1992 as well as 1993, similar to the site relationships observed in Test 1993 series bags (**Fig. 99**).

b) The watering regime used in 1992 and 1993 was not entirely successful. In August 1993 in particular, moistures in all Provenance series fell to $\leq$ 15%, despite repeated addition of water prior to the August 25 sampling date. Only whole-scale irrigation of the entire area (logistically impossible) could have alleviated the pronounced seasonal changes in soil moisture. However, judging by data obtained for body mass and reproductive performance, seasonal moisture minima were not low enough to curtail earthworm activity (ref. following sections).

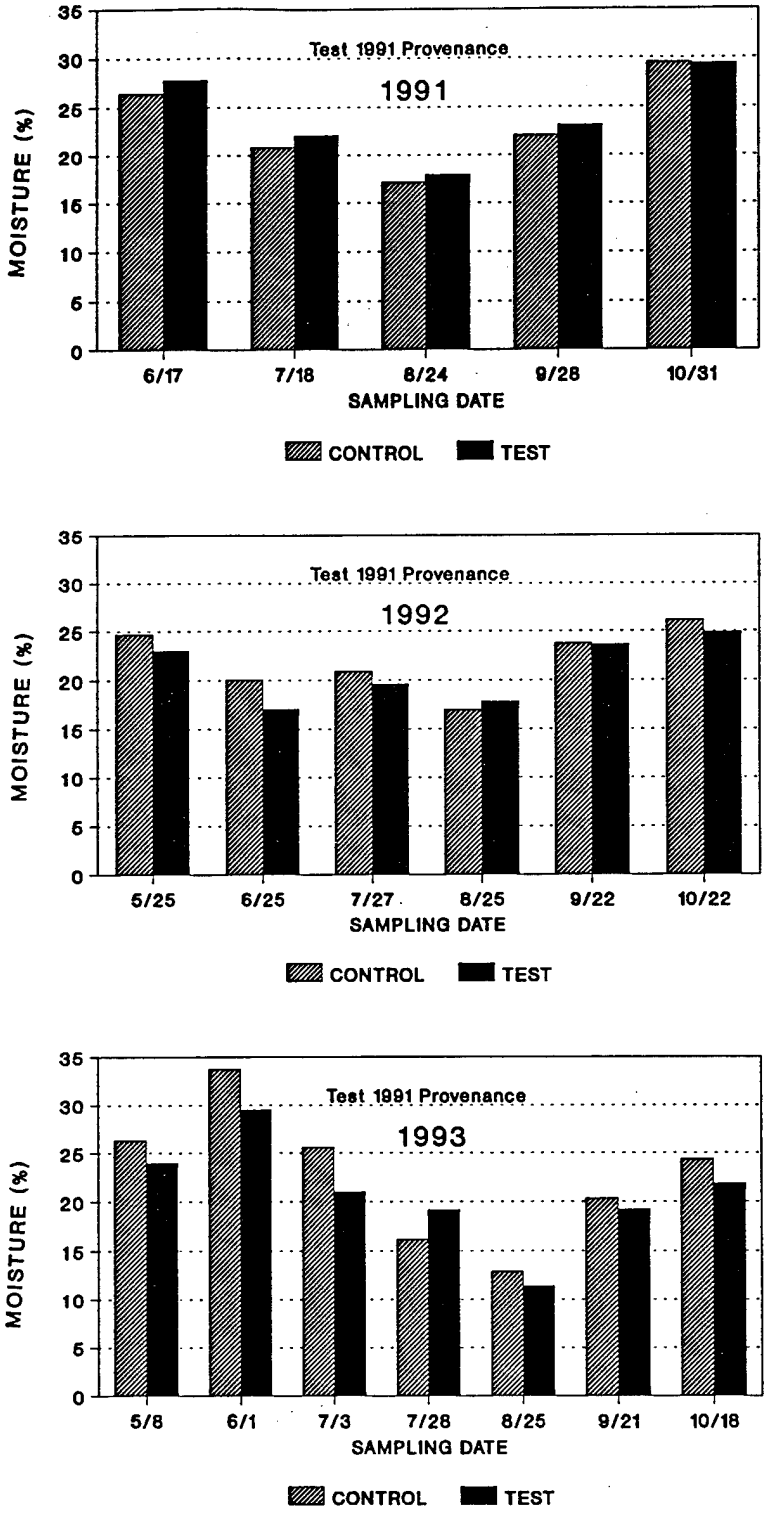


Fig. 97. Mean soil moisture (gravimetric) in wormbags on each sampling date, Test 1991 Provenance series (N = 5 bags per site beginning 8/24/91).

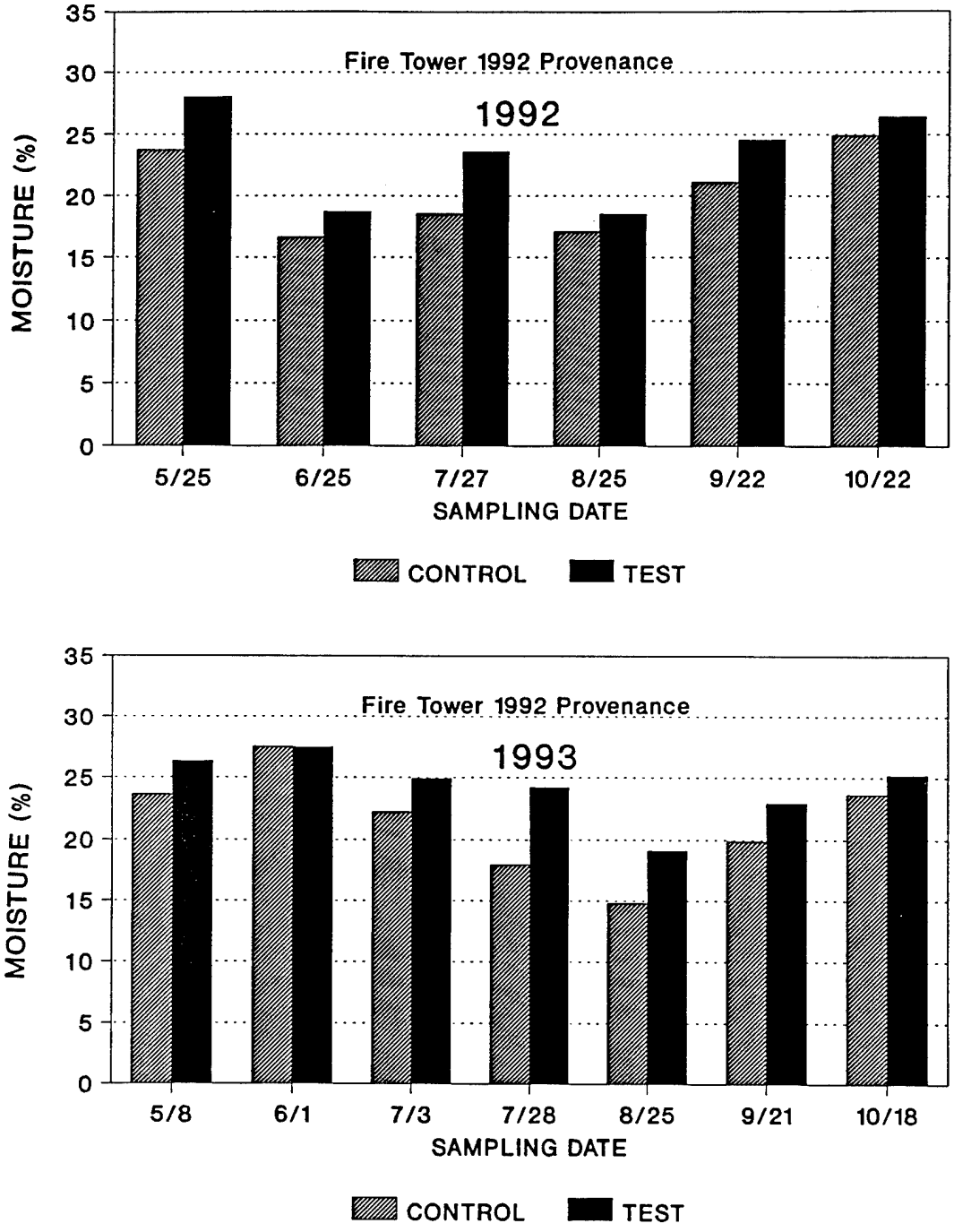


Fig. 98. Mean soil moisture (gravimetric) in wormbags on each sampling date, Fire Tower 1992 Provenance series (N = 10 bags per site).

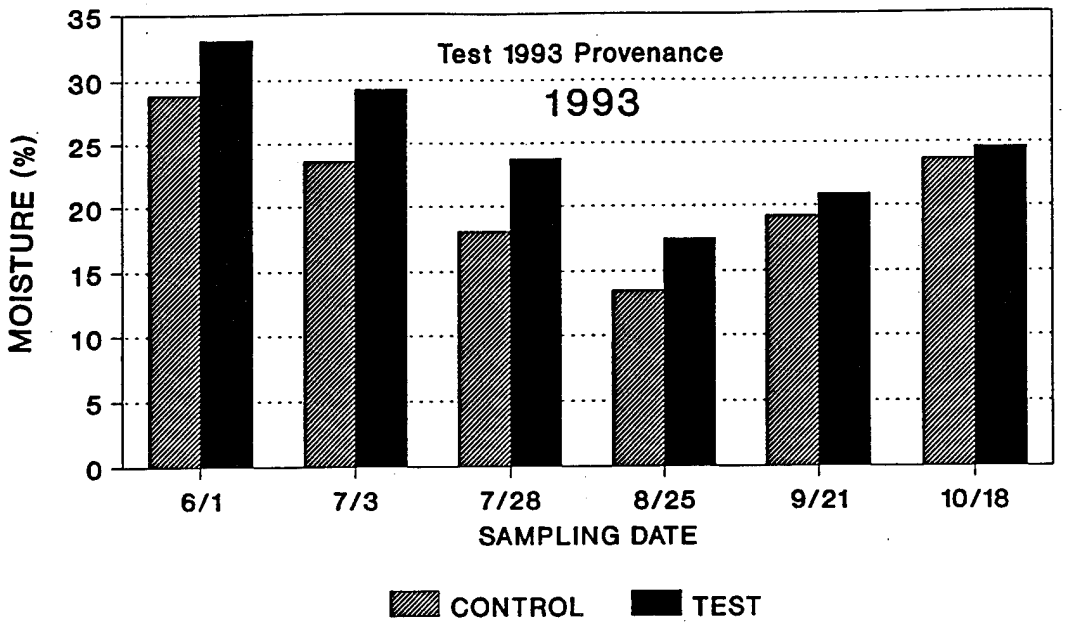


Fig. 99. Mean soil moisture (gravimetric) in wormbags on each sampling date, Test 1993 Provenance series (N = 5 bags per site).

### 3. Test 1991 Provenance series

#### 3.1. Earthworm body mass and cocoon mass

Mean body mass of clitellate adults did not differ significantly between Test and Control groups in 1992 and 1993 (**Table 39**). Mean mass of all individuals taken together (reproductive and non-reproductive) (**Fig. 100**) was significantly higher in the Control group ($P < 0.000$), possibly due to somewhat higher moisture in wormbag soil on several dates.

Mean mass of cocoons (approx. 20 - 25 mg, **Fig. 101**) did not differ significantly between sites throughout the three years of observation. The number of cocoons produced (means /bag are shown in **Fig. 102**) were higher in Control, the most notable exceptions occurring at the end of the 1992 season.

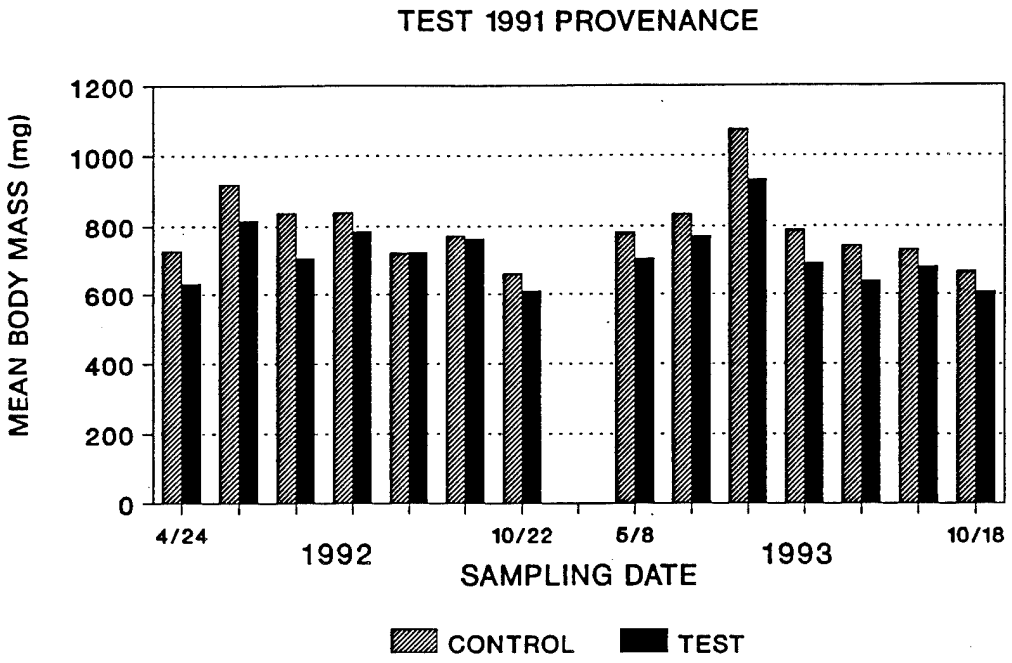


Fig. 100. Mean body mass (mg) per date of earthworms (developmental stages combined) in the Test 1991 Provenance series (N worms /date /site ≤ 150, decreasing gradually over time).

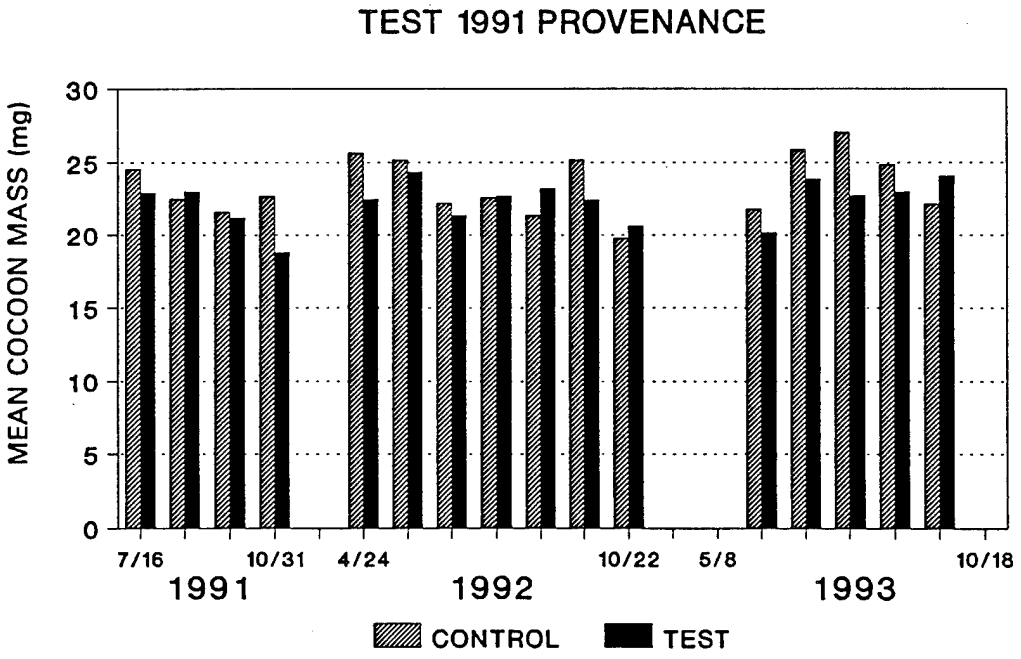


Fig. 101. Mean mass of cocoons (mg) per date, in the Test 1991 Provenance series (N cocoons /date /site variable , range 5 to 94; no data shown for dates where N <5).

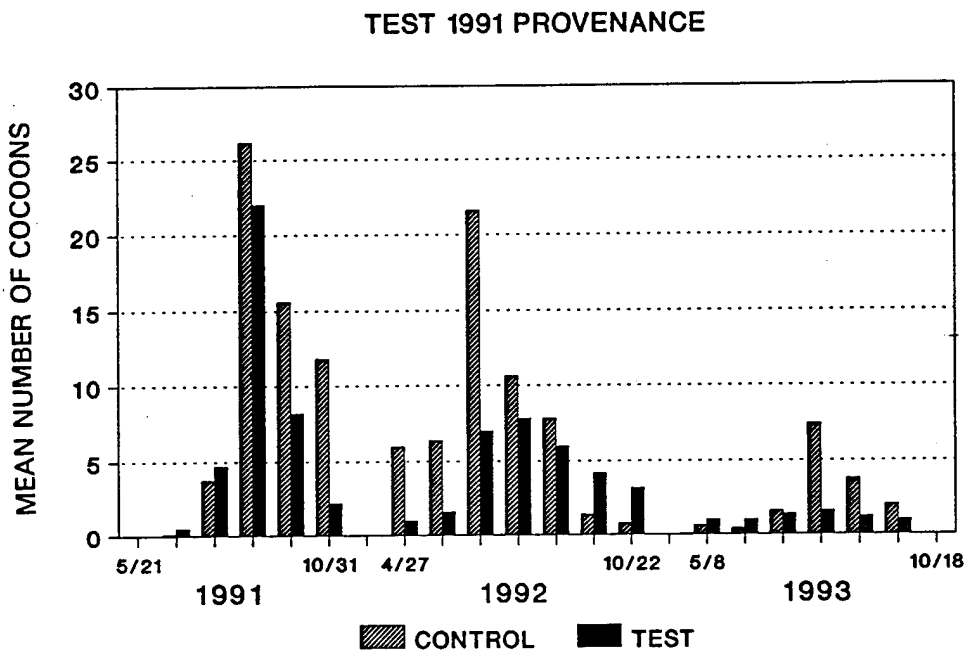


Fig. 102. Mean number of cocoons present in Test and Control bags (N = 5 /site), Test 1991 Provenance series.

### 3.2. Proportion of adults clitellate

In 1991 (when worms were not redistributed randomly on each date), only pairwise comparisons could be made due to serial correlation within bags over time. Worms incubated in Control exhibited higher proportions of clitellates, significantly so in September and October (t tests, $P \leq 0.005$). Analysis of variance was possible for 1992 and 1993 data. ANOVA of each year's data separately showed that the generally greater proportion of clitellates in Control bags (**Fig. 103**) was highly significant ($P < 0.000$), and that site x date interactions were also significant, particularly in 1992 ($P \leq 0.000$) (**Table 39**), when clitellate proportions in Test bags peaked one month after those in Control (**Fig. 103**).

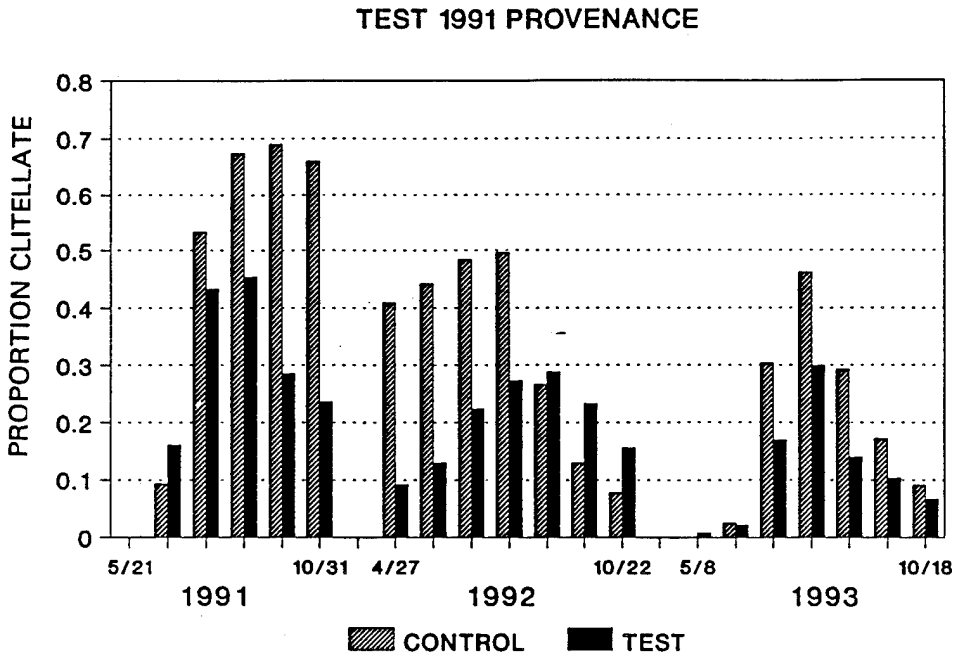


Fig. 103. Mean proportion of all adults in the clitellate state on each sampling date, Test 1991 Provenance series. Note: each group of worms was returned to their bag of origin in 1991; thereafter, worms were randomly redistributed to replicate bags on each date.

### 3.3. Cocoon production rates

As discussed in Section V, ratios of cocoons : clitellates can be a useful parameter for assessing earthworm reproductive performance. We chose two basic calculation methods: **Method 1**, which relates numbers of cocoons to "average" number of clitellates during each incubation period (**Fig. 104**); and **Method 3**, which yields ratios of total mass of cocoons produced to average mass of clitellates during each incubation period (**Fig. 105**).

ANOVA of cocoon production rates based on numbers (**Fig. 104**) yielded no significant between-site differences (**Table 39**). Analysis of mass-based data (**Fig. 105**) showed that production rates were higher in the Test site in 1992 ($P < 0.04$), but that differences were not significant in 1993.

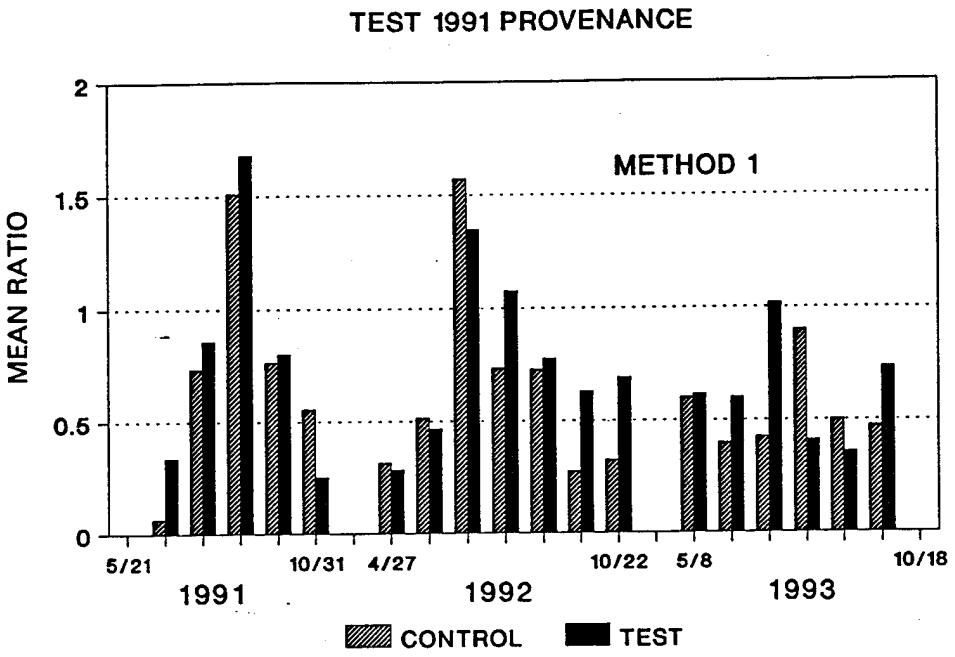


Fig. 104. Mean rates of cocoon production per date, Test 1991 Provenance series; Method 1 based on (total number of cocoons / average number of clitellates) at end of incubation period.

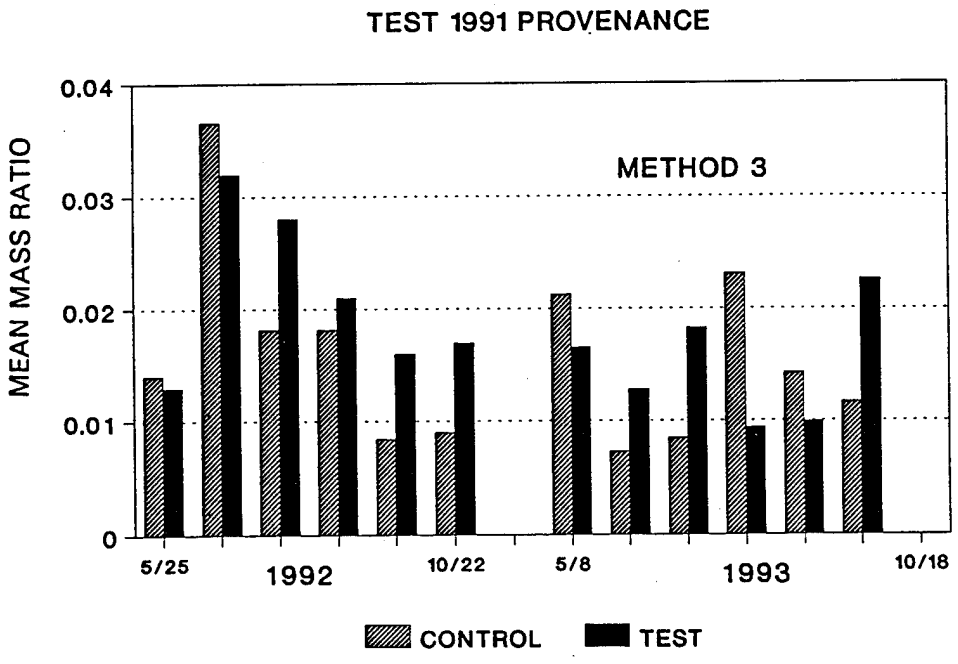


Fig. 105. Mean rates of cocoon production per date, Test 1991 Provenance series; Method 3 based on (total cocoon mass at end of period / average clitellate mass during period).

### 4. Merriman 1991 Provenance series

The Merriman 1991 series differed from all others in that the soil used as incubation medium stemmed from the Test site (it was logistically impossible to retrieve the large quantities of soil needed from the remote Merriman site); i.e., it was not the "native" soil in which the worms had been living. Resulting data, although consistent within themselves, were discrepant from the concurrently run Test 1991 series, for reasons which were not clear. Mean weights of cocoons, for instance, were significantly lower than those in the Test 1991 series, indicating that substrate conditions may have been suboptimal for the Merriman group of *A. tuberculata*. The series was therefore discontinued at the end of 1991. A detailed presentation and discussion of results can be found in Snider (1994).

Statistical analyses were limited to pair-wise comparison of means, due to serial correlation over time within each bag (as in the first year of observation in the Test 1991 series). Either Student's t tests or Lohrding's q tests were used, depending on preliminary tests of equality of variances and coefficients of variation.

#### 4.1. Cocoon mass and numbers

Date-specific tests showed that cocoons from Control bags had less average mass than Test cocoons on 8/24 (**Fig. 106**), differences on all other dates being not significant. Overall means for the entire year did not differ significantly between sites (Test mean $\pm$ SD = 19.9 $\pm$ 3.7, N = 96; Control mean $\pm$ SD = 18.8 $\pm$ 3.6, N = 102).

The number of cocoons per date tended to be slightly higher in Control bags (**Fig. 107**), but none of the date means differed significantly between sites.

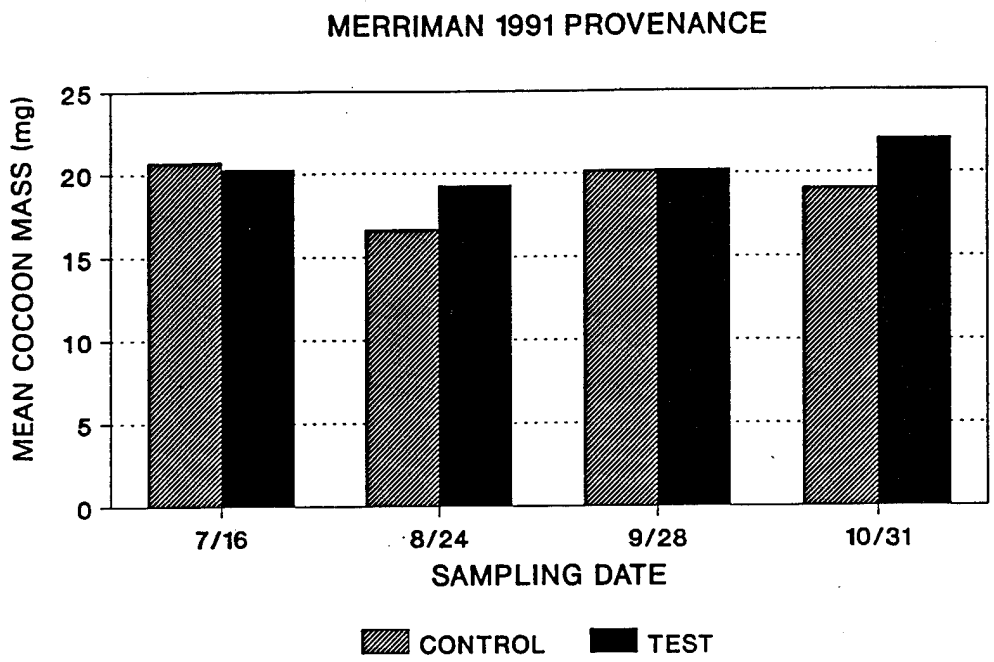


Fig. 106. Mean mass of cocoons /date in the Merriman 1991 Provenance series during 1991 (N variable, range 8 - 46).

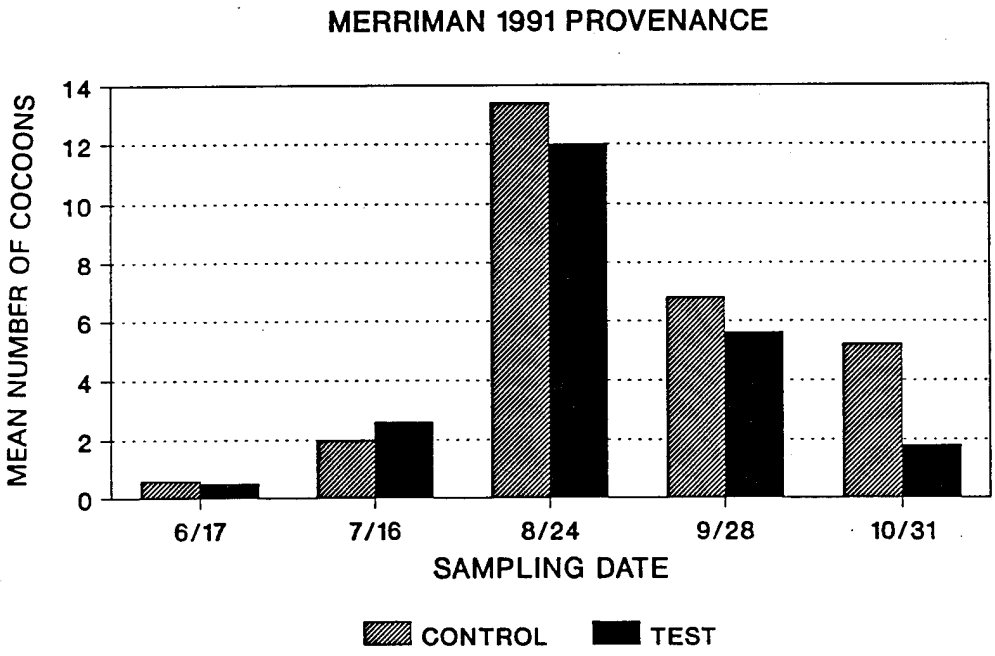


Fig. 107. Mean number of cocoons /date during 1991, Merriman 1991 Provenance series; N = 10 on the first two dates, N = 5 bags thereafter.

### 4.2. Proportion of adults clitellate

Following approximately equal clitellate proportions in both sites through 7/16, a higher proportion of adults were clitellate in Control bags on the last three sampling dates (**Fig. 108**). None of the means differed significantly between sites, however. The general pattern (higher numbers of clitellates in Control during the second half of the season) was reminiscent of that observed in the Test 1991 series during 1991 (**Fig. 103**).

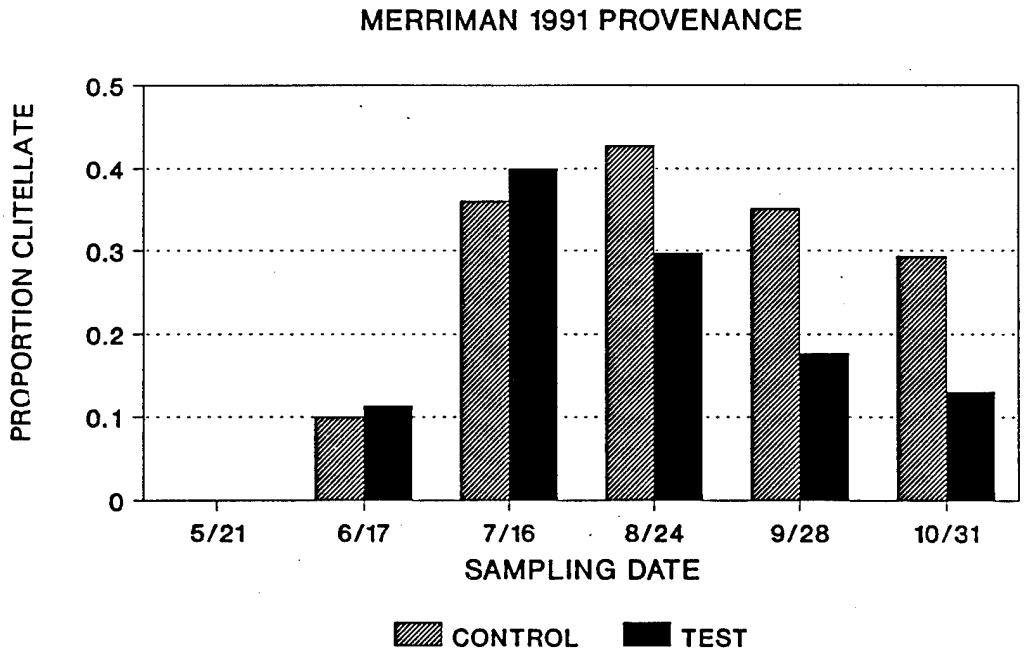


Fig. 108. Mean proportion of adults clitellate during 1991, Merriman 1991 Provenance series; 5/21 = initial date of incubation, no clitellates present. N = 10 bags through 7/16, N = 5 bags thereafter.

### 4.3. Cocoon production rates

Cocoon production rates based on numbers of cocoons and clitellates (**Fig. 109**) did not differ significantly between sites on any date. The trend toward highest rates occurring in mid-summer mirrored that observed in other Provenance series, but rates in the Merriman series were generally lower than, for instance, those in the Test 1991 series (**Fig. 104**).

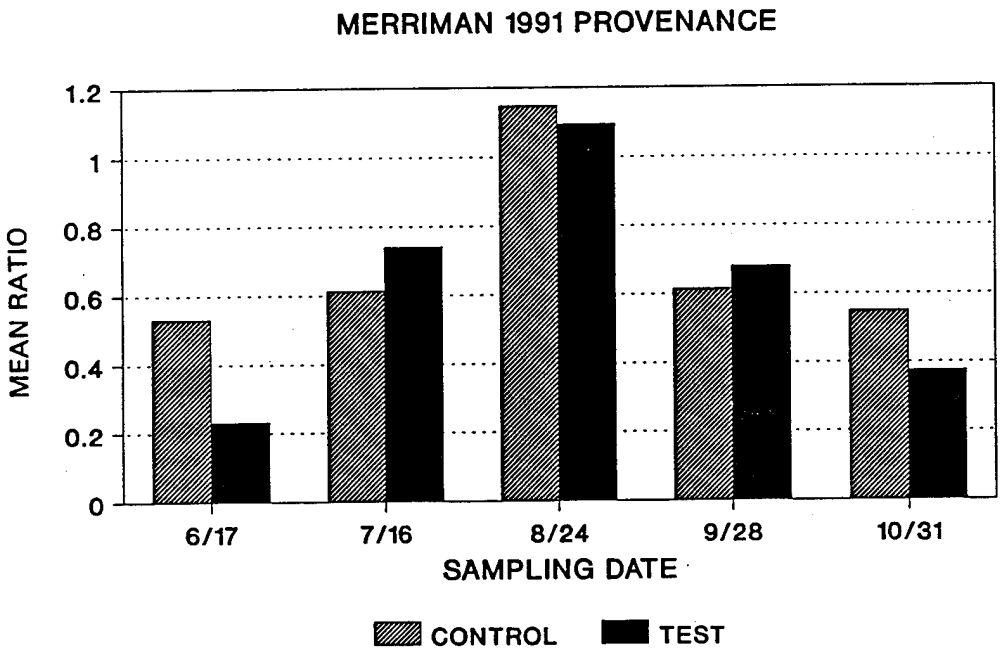


Fig. 109. Mean cocoon production rates during 1991, Merriman 1991 Provenance series, Method 1 (number of cocoons / average number of clitellates); N = 10 through 7/16, N = 5 bags thereafter.

### 5. Test 1993 Provenance series

### 5.1. Earthworm body mass and cocoon mass

Neither mean clitellate body mass, nor mean mass of all worms combined (**Fig. 110**) differed significantly between sites during the single experimental year of 1993. Average cocoon mass

/date proved to be somewhat higher at the Test site (P = 0.04), mainly because of an unusual number of relatively small cocoons in Control bags on May 31 (**Fig. 111**). Site-specific mean cocoon mass for the entire year did not differ significantly between Test and Control (Control mean ± SD = 21.6 ± 3.92 mg, N = 114 cocoons; Test mean ± SD = 22.3 ± 3.73 mg, N = 113 cocoons). No consistent between-site differences were detected with respect to average numbers of cocoons produced over time (**Fig. 112**).

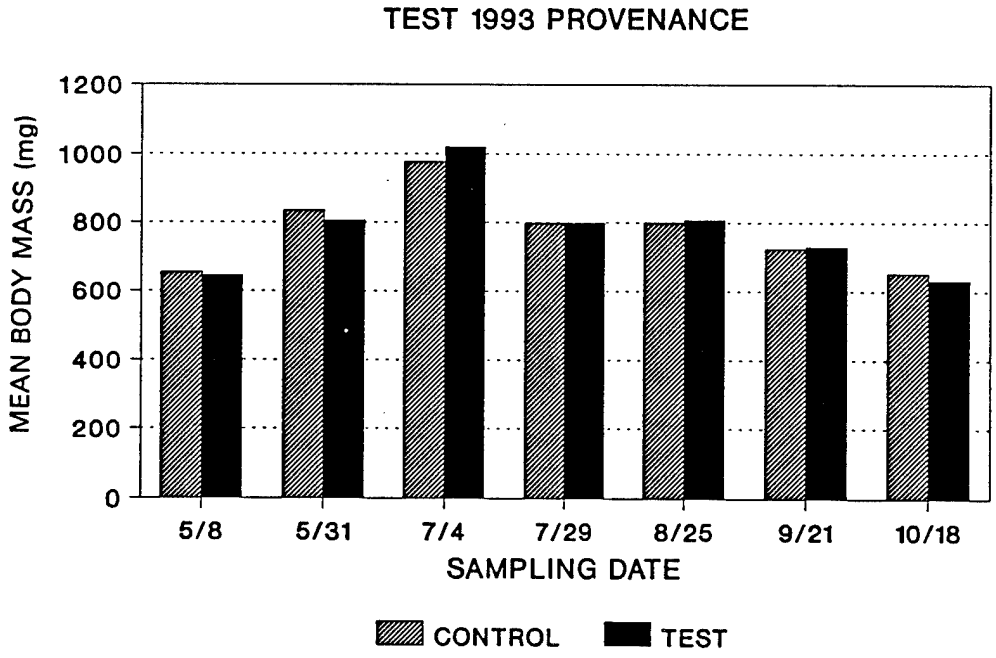


Fig. 110. Mean body mass of earthworms (developmental stages combined) in the Test 1993 Provenance series.

### 5.2. Proportion of adults clitellate

ANOVA of clitellate proportions over time (**Fig. 113**) showed that clitellate proportions did not differ significantly between sites.

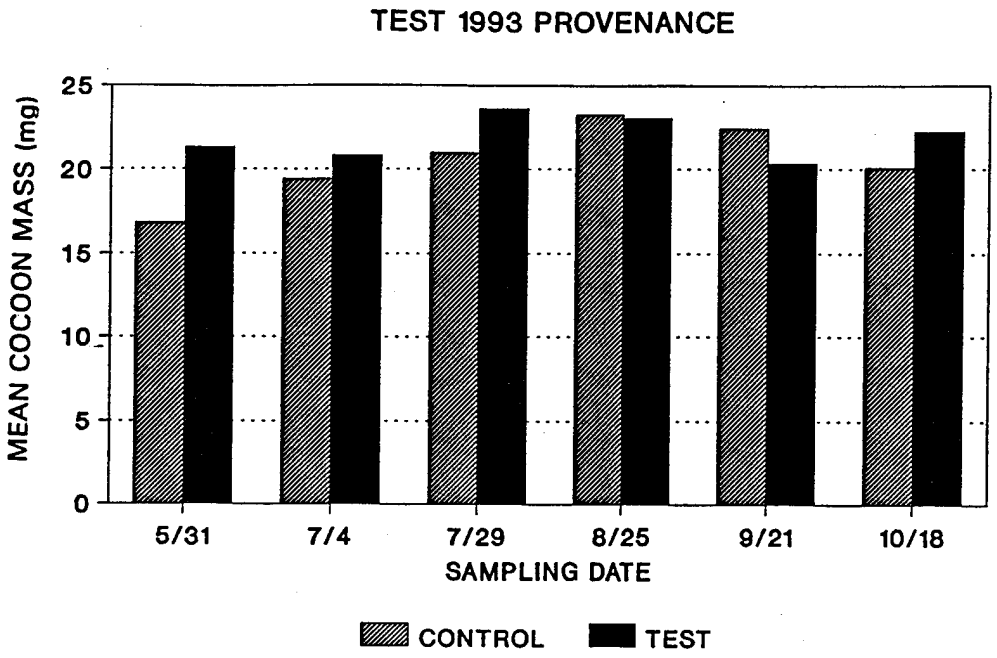


Fig. 111. Mean mass of cocoons (mg) produced by Test 1993 Provenance earthworms on each date in 1993; N cocoons /date variable (range 3 - 39).

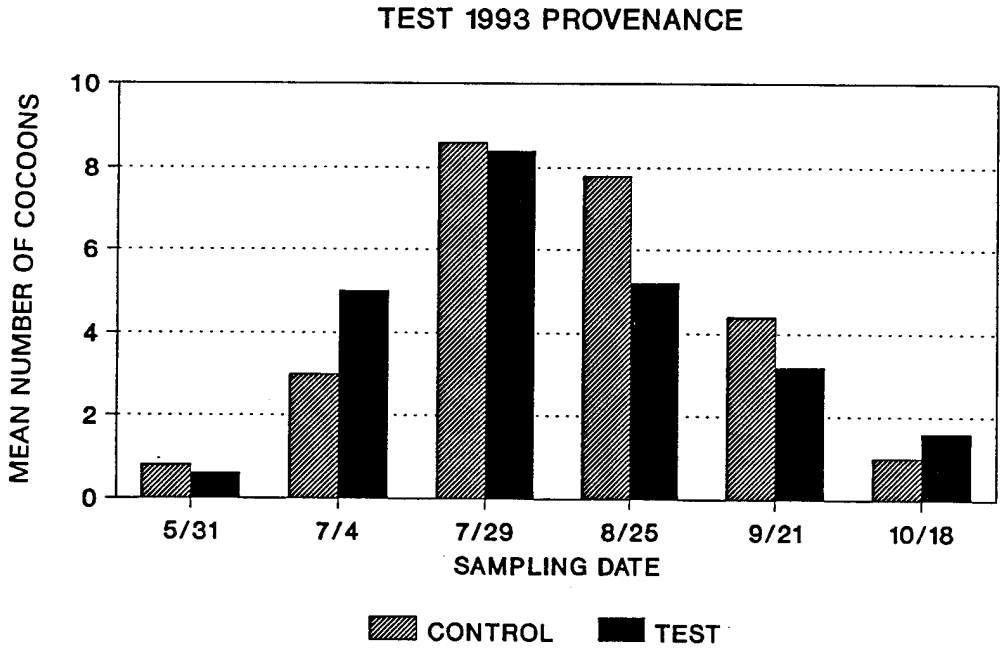


Fig. 112. Average number of cocoons produced by Test 1993 Provenance earthworms on each date in 1993; N = 5 bags /site.

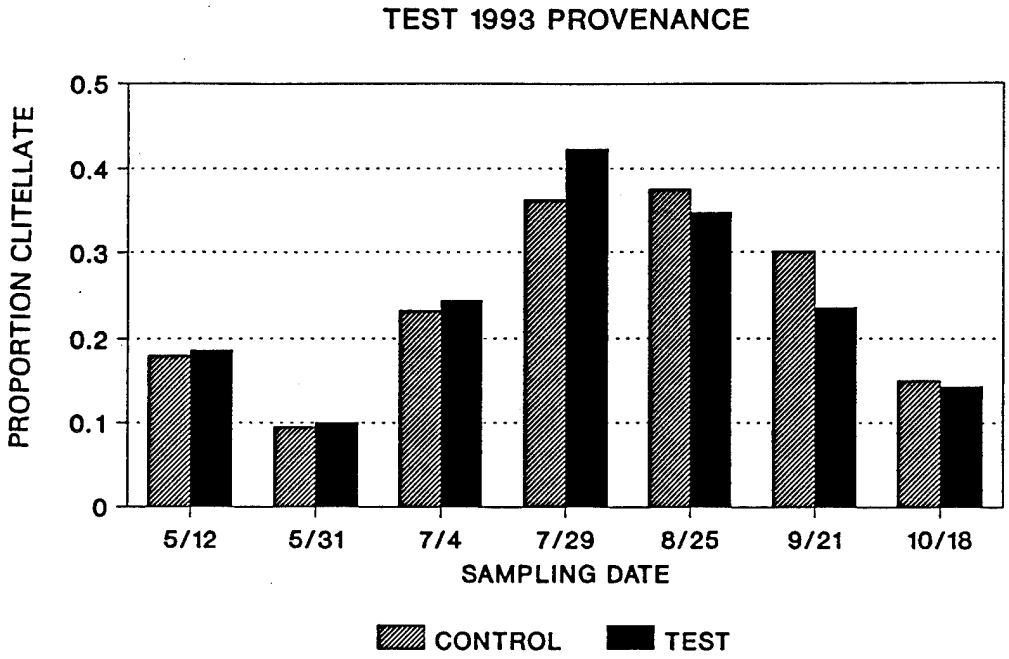


Fig. 113. Average proportion (of all worms) in the clitellate state on each date in 1993, Test 1993 Provenance series; N = 5 bags /site.

### 5.3. Cocoon production rates

Despite seemingly large differences in cocoon production rates between sites on some dates (**Figs. 114** and **115** illustrate numbers-based and mass-based rates respectively), results of ANOVA showed that, overall, these differences were not significant.

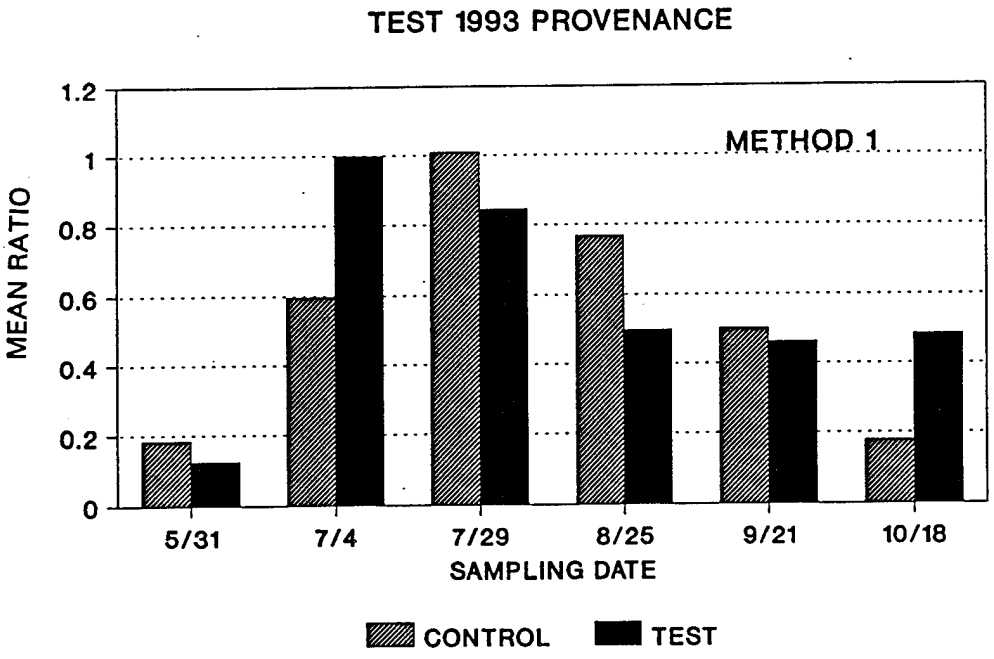


Fig. 114. Mean rates of cocoon production in 1993, Test 1993 Provenance series; Method 1 based on (numbers of cocoons / average number of clitellates) on each date; N = 5 bags /site.

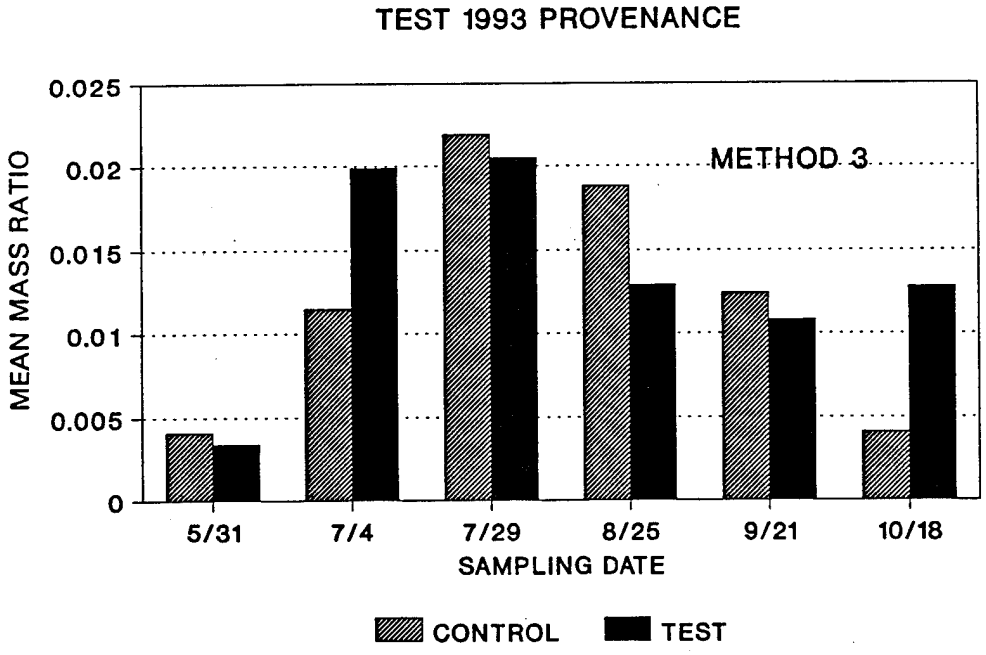


Fig. 115. Mean rates of cocoon production in 1993, Test 1993 Provenance series; Method 3 based on (total mass of cocoons / average mass of clitellates); N = 5 bags /site.

## 6. Fire Tower 1992 Provenance series

### 6.1. Earthworm body mass and cocoon mass

Mean body mass of clitellates as well as mean mass of all worms (developmental states combined) (**Fig. 116**) were consistently higher in Test groups throughout 1992 and 1993 (ANOVA, $P < 0.000$). It is unlikely that generally higher moisture in Test bags (**Fig. 98**) produced such consistent differences over all dates. In the Test 1993 Provenance series, for instance, no body mass differences were detectable, although the soil in these bags also tended to be moister in Test than in Control (**Fig. 99**).

Average mass of cocoons (**Fig. 117**) differed between sites in 1993 ( ANOVA of date-specific data, $P = 0.04$. However, annual mean mass (all dates combined) did not differ between sites; rather, a significant mass decrease from 1992 to 1993 occurred within each site (**Table 39**), probably as a result of increasing age and generally decreasing body mass of adults.

**Table 39.** Mean annual mass ($\pm$ SD, N in parentheses) of cocoons produced in the Fire Tower 1992 series in Test and Control sites, 1992 and 1993.

| SITE | YEAR | |
|---|---|---|
| | **1992** | **1993** |
| CONTROL | $24.88 \pm 3.90^{a}$ (659) | $23.97 \pm 4.39^{a}$ (312) |
| TEST | $25.24 \pm 4.01^{b}$ (884) | $24.20 \pm 4.34^{b}$ (552) |

**a** = means differ at $P < 0.01$
**b** = means differ at $P < 0.001$

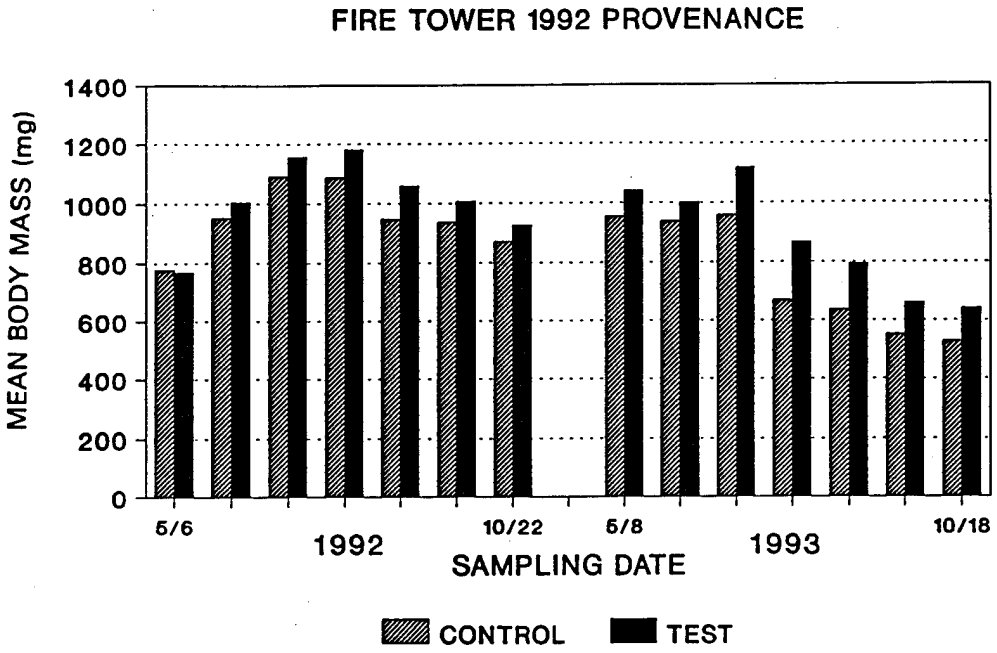


Fig. 116. Mean body mass (mg) of earthworms (all developmental states combined) per date, in the Fire Tower 1992 Provenance series; N /date /site variable, approx. 300 in 1992, gradually decreasing thereafter.

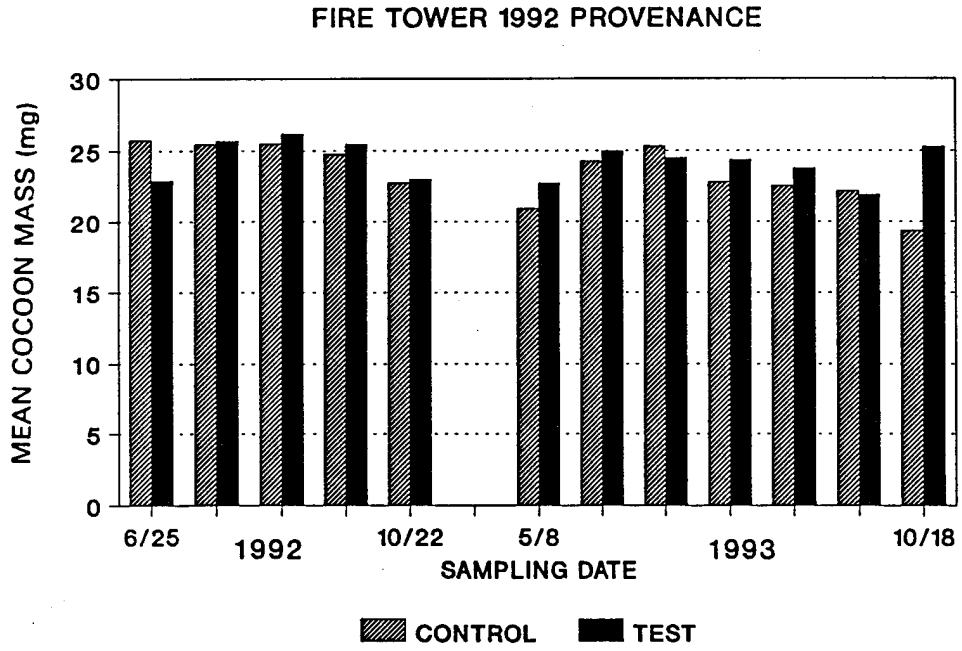


Fig. 117. Mean mass of cocoons (mg) per date, Fire Tower 1992 Provenance series; N /date /site variable (range 3 to 260).

Earthworms at the Test site produced higher numbers of cocoons than those in the Control site, during 1992 as well as 1993 (**Fig. 118**).

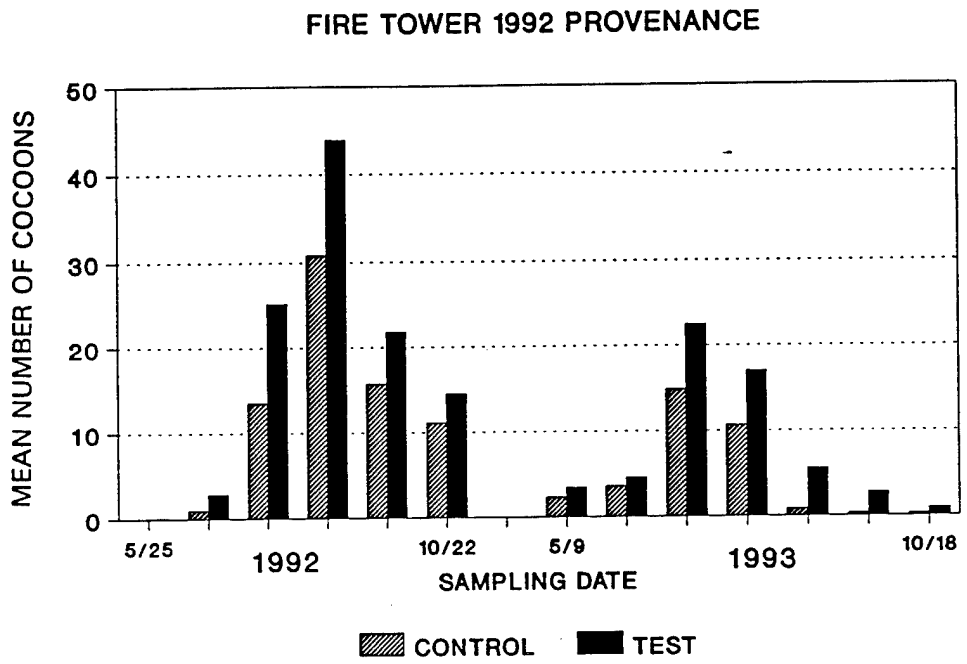


Fig. 118. Mean number of cocoons produced per date, Fire Tower 1992 Provenance series; N = 10 bags / site /date.

### 6.2. Proportion of adults clitellate

On most dates in 1992 and 1993, the proportion of individuals in the reproductive state was higher in Test than in Control groups (**Fig. 119**). Data from 1992 could not be transformed to meet the requirements for ANOVA; however, single dates could be compared by either t-tests or Lohrding's q-tests, depending on the magnitude of variances. Mean clitellate proportions were indeed significantly higher in Test in June, July and August, but did not differ significantly on the last two sampling dates of the year. ANOVA of 1993 data showed that, despite higher mean

proportions of clitellates at the Control site in May ($P < 0.01$ on 5/31/93), overall proportions were higher in the Test site ($P < 0.000$).

The validity of using individual bags as the sample unit could be questioned, because the redistribution scheme employed in 1992 and 1993 (ref. p. 179) disrupted the continuity of each replicate (A. El-Shaarawi, pers. comm.). Data were therefore subjected to a second analysis, ignoring bag replicates, and using only date-specific totals from each site. In this regression model, ln (moisture), ln (moisture$^2$), differences between ln (moisture), and dates were the variates taken into account. Results for 1992 through 1993 data again indicated that clitellate proportions were significantly higher in Test groups ($P < 0.01$) (A. El-Shaarawi, pers. comm.).

### 6.3. Cocoon production rates

Again, we selected Methods 1 and 3 for a summary presentation of results. Based on numbers (**Fig. 120**) as well as on mass estimates (**Fig. 121**), rates of cocoon production were consistently much higher in the Test group than in the Control group over both years (ANOVA, $P < 0.000$). As was the case with clitellate proportions (above), a second analytical design was used to check these results, using numbers-based Method 1 data: in this case, the regression model included ln (moisture) and ln (clitellate numbers), and used date-specific totals rather than bag-specific numbers. Cocoon production rates were again shown to be significantly higher at the Test site ($P < 0.01$) (A. El-Shaarawi, pers. comm.).

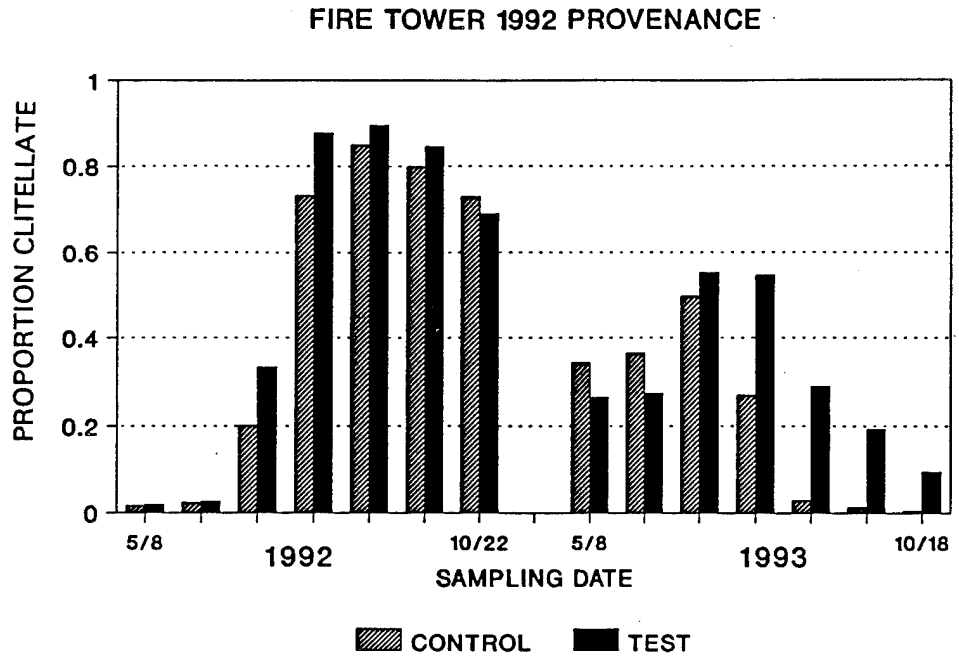


Fig. 119. Mean proportion (of all adults) in the clitellate state on each date, Fire Tower 1992 series; N = 10 bags /site /date.

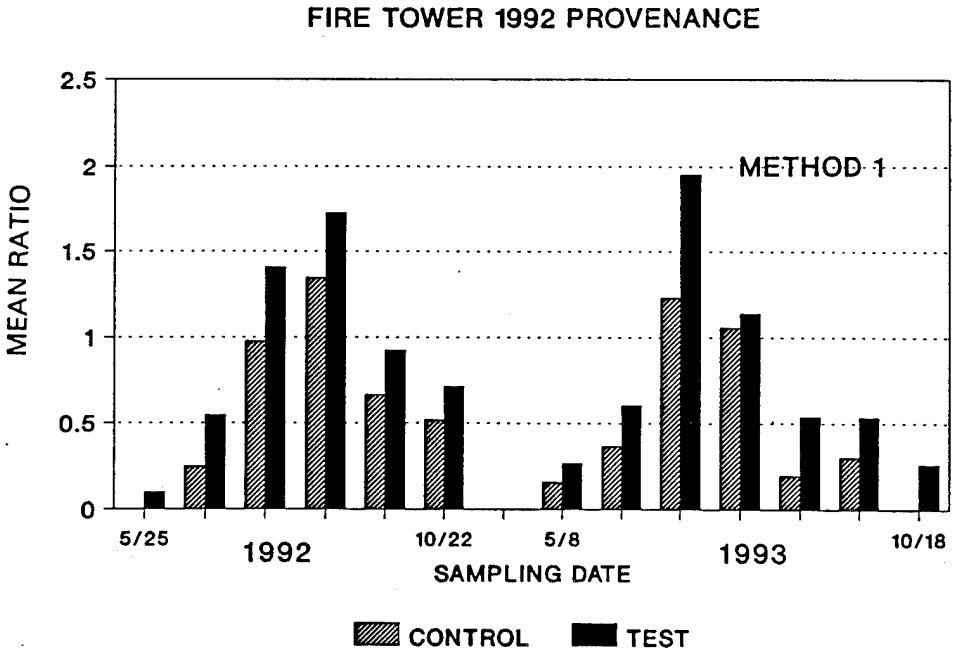


Fig. 120. Mean cocoon production rates in the Fire Tower 1992 Provenance series; Method 1 based on (number of cocoons / average number of clitellates); N = 10 bags /site /date. Rates not calculated if < 3 bags contained cocoons (Control 5/25/92 and 10/18/93).

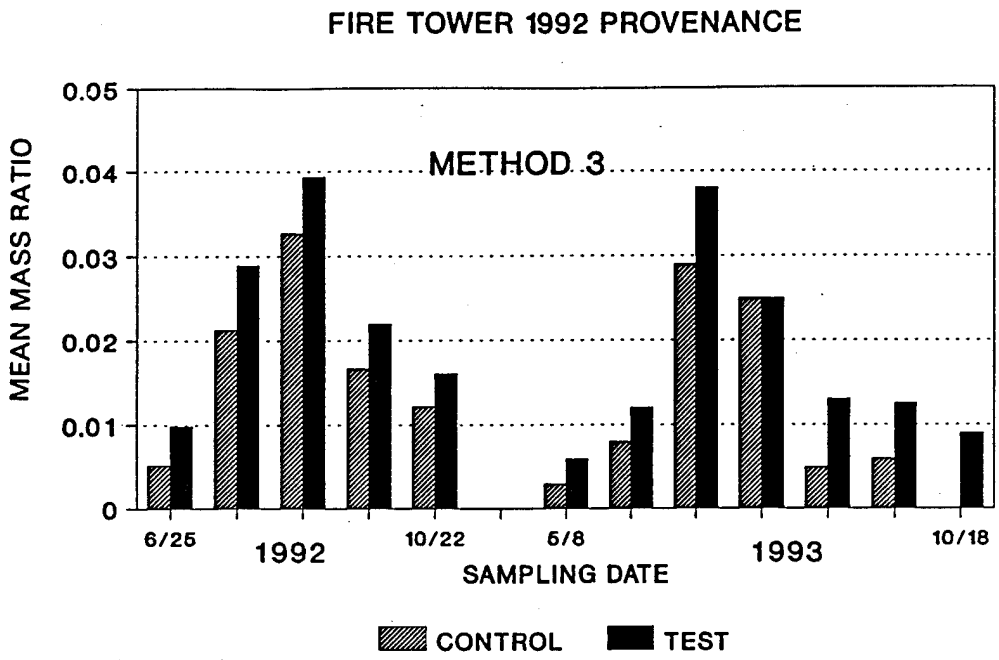


Fig. 121. Mean cocoon production rates in the Fire Tower 1992 Provenance series; Method 3 based on (total mass of cocoons / average mass of clitellates); N = 10 bags /site /date. Rates not calculated if < 3 bags contained cocoons and/or clitellates.

## C. SUMMARY AND DISCUSSION

We here focus on Test and Fire Tower Provenance series. Results of the Merriman 1991 series were limited to one season and three response variables, and the reproductive performance of these groups of *A. tuberculata* appeared to be unusual, for reasons which were not quantifiable (refer to Snider 1994 for details). A summary of statistical results for all series is is provided in **Table 40**.

**Test 1991 and 1993 series:**

At the beginning of field-incubation, Test 1991 series worms were non-reproductive (aclitellate and posclitellate) adults which had been collected in the Test site and had thus been exposed to EM fields for 2 years. They exhibited significant responses to removal from EM influence (=

incubation in Control site bags), particularly with respect to increased clitellate proportions relative to their counterparts in Test site bags (**Fig. 103, Table 40**). In 1992, a temporal shift took place, individuals in Control site bags reaching a reproductive peak sooner than those incubated in the Test site (**Fig. 103**). No such shift was apparent in 1993; it is possible that effects of senescence were then becoming more pronounced and more random, since these worms were in their third (known) year of adulthood, and their chronological age was not known. There were essentially no major differences in cocoon production rates, except for higher ratios in Test site groups in 1992 ($P < 0.04$ for mass-based ratios).

It is striking that the Test 1993 series duplicated none of the significant results obtained for the Test 1991 series (**Table 40**). The 1993 series worms had been exposed to EM fields for 4 years prior to incubation. Continued exposure in Test bags or removal from exposure in Control bags produced very similar reproductive patterns, with a single exception concerning higher mean cocoon mass in Test.

We find that failure to confirm 1991 series results was most probably a consequence of the duration of exposure to EM fields with respect to the development of individuals.

Many earthworms can mature in approximately 1 year (Evans and Guild 1948; Satchell 1967), although periods of low temperature or drought lengthen development time considerably. In our Test site, we estimated that approximately 3 years were needed for *A. tuberculata* to reach adulthood, somewhat longer than *A. caliginosa* in Polish pastures (Nowak 1975). Total lifespans

**Table 40.** Summary of statistical results of earthworm isolation experiments. Years (in series which were observed for more than one season) and dates for which a given result was obtained are indicated in parentheses. NA = Not Applicable (no worm mass data available).

| RESPONSE VARIABLE | PROVENANCE SERIES | | | |
|---|---|---|---|---|
| | TEST 1991 | TEST 1993 | MERRIMAN 1991 | FIRE TOWER 1992 |
| Body mass (clitellates) | NA (91)<br>NS (92-93) | NS | NA | **P ≤ 0.003**<br>**Test higher** (92-93) |
| Body mass (all worms) | NA (91)<br>**P < 0.000**<br>**Control higher** (92-93) | NS | NA | **P ≤ 0.000**<br>**Test higher** (92-93) |
| Cocoon mass | NS (91-92-93) | **P < 0.04**<br>**Test higher** | **P < 0.001 ****<br>**Test higher**<br>(August 24 only) | NS (92)<br>**P < 0.04**<br>**Test higher** (93) |
| Proportion clitellate | **P < 0.000**<br>**Control higher** (92-93)<br>**P ≤ 0.005 ****<br>**Control higher**<br>(Sept-Oct 91 only) | NS | NS | **P < 0.01 ***<br>**Test higher** (92-93)<br>**P ≤ 0.05 ****<br>**Test higher**<br>(June-July-Aug 92)<br>**P < 0.000**<br>**Test higher (93)** |
| Cocoon/clitellate ratios Method 1 (numbers-based) | NS (91-92-93) | NS | NS | **P < 0.01 ***<br>**Test higher** (92-93)<br>**P < 0.000**<br>**Test higher** (92-93) |
| Cocoon/clitellate ratios Method 3 (mass-based) | NA (91)<br>**P < 0.04**<br>**Test higher** (92)<br>NS (93) | NS | NA | **P < 0.000**<br>**Test higher** (92-93) |

* indicates results of analyses by regression (ref. p. 201);
** indicates date-specific pairwise comparisons of means (t tests or Lohrding's q tests, depending on equality of variances or coefficients of variation); all other results obtained by ANOVA.

are often thought to be short in the field (Satchell 1967), although Phillipson and Bolton (1977) estimated that large individuals of *Aporrectodea rosea* were 5 to 6 years old. We know from isolation experiments that *A. tuberculata* can survive for at least 3 years **after** reaching adulthood: 30 to 50% of the original Test 1991 series individuals were still alive in October 1993. Animals injured during sampling had not been replaced since May 1992, so that actual survial rates were slightly higher. Some effects of senescence were evident in declining cocoon production and clitellate proportions in 1993 (**Fig. 103**), but not in body mass (**Fig. 100**).

We estimate that adult earthworms collected for the Test 1991 Provenance series had been medium- to large-sized immatures at the time of antenna activation in May 1989; some may even have been adults. Worms collected for the Test 1993 series were most likely to have hatched during or shortly before the first year of antenna operation; i.e., they were exposed to EM fields during most or all of their development to maturity. Lack of response to **removal** from EM influence (= incubation in Control site bags) would then indicate some form of "habituation", or would indicate that they had gone beyond the initial, short-lived effects of exposure. We have found no pertinent information in the published literature to substantiate these explanations.

**Fire Tower 1992 series:**

In this series (never exposed to EM fields prior to the beginning of observations), Test groups out-performed Control groups with respect to all response variables tested (**Table 40**). One may argue that soil moisture was consistently higher in Test site bags (**Fig. 98**), which could well result in higher body mass and reproductive activity there (Gerard 1967; Nordström 1975; Grant 1955). However, our ANOVA results were substantiated by regression analyses which included moisture differences in their design (ref. p. 201). In this series, therefore, first exposure to EM

fields appeared to stimulate reproductive activity when compared to continued non-exposure.

The question remains: do data from isolation experiments explain data obtained for the *A. tuberculata* population at large?

What we observed in the field population at the Test site were reduced numbers and proportions of clitellates, and increased cocoon production rates, mainly during the second year of antenna operation, 1990. Clitellate numbers and proportions returned to approximately "normal" levels (approximating pre-ELF averages and seasonal patterns) during the third year of exposure.

The Test 1991 wormbag series supported the first of these observations (clitellate proportions increased when worms were removed from EM influence). The Test 1993 series confirmed that EM effects tended to be short-lived (after 4 years of exposure, removal from EM influence had no effect). The Fire Tower 1992 series, however, did not substantiate field observations, with the possible exception of increased cocoon production rates in 1992 and 1993 following first exposure of worms to EM fields.

It is possible that subtle, transient EM field effects on *A. tuberculata* reproduction did occur for 1 to 2 years after antenna activation. The extent of this effect may in part be dependent on dose-response relations, on the chronological age of individuals at the time of first exposure, and both the degree and duration of the effect may vary for different response variables. For instance, lower-than-ambient EM field intensities in mesh bags may have had a role in stimulating reproduction in the Fire Tower 1992 series. In the field population, such stimulation was expressed only in higher cocoon production rates. Reduced clitellate numbers in the field population may have been the result of higher ambient EM field intensities. Given available data,

and the lack of pertinent information in the literature, we cannot carry conclusions any further.

## VII. LITTER INPUTS

### A. METHODS

Litter traps (50 x 50 cm) were made of fiberglass screening (2 mm mesh) encased by 15 cm high wooden frames. They were positioned 50 cm above the forest floor, in permanent locations in the same corner of each quadrat. Trap contents (minus woody debris) were collected at monthly intervals from spring to early fall, and at weekly intervals during the main period of abscission. Litter samples were sorted into categories: maple, basswood, others (mainly leaves of *Populus* spp. and shrubs), oven-dried at 60 $^{o}$C and weighed.

Replication consisted of 20 traps /site, one in each of the 20 quadrats used for faunal sampling. Data are available for 1984-88 (pre-ELF) and 1989-92 (operational).

### B. RESULTS

#### 1. Annual and seasonal patterns

Mean annual litter inputs by the main tree components and all species together are listed in **Table 41**. In general, the magnitude of between-year and between-site variations did not appear to be influenced by antenna activation. "Other" species typically contributed more litter mass in Control than in Test, in all years.

The tight synchronicity of abscission patterns in Test and Control sites was clearly evident and is illustrated in **Figs. 122-124**. Maple leaffall was typically unimodal, while basswood abscission tended to be bimodal to varying degrees. Although not evident in **Figs. 122-124**, some variation in the timing of peak leaffall was observed in all species, peak inputs occurring between late September and mid-October (variable between years, but synchronous in both sites).

**Table 41.** Annual leaf litter inputs (g dry /$m^2$, means ± SE) in Test and Control sites; N = 20 traps /site.

| YEAR/SITE | MAPLE | BASSWOOD | OTHER | TOTAL |
|---|---|---|---|---|
| 1984 T | 175.3 ± 14.5 | 56.9 ± 11.1 | 26.8 ± 9.1 | 259.2 ± 8.8 |
| C | 179.0 ± 9.0 | 56.1 ± 8.4 | 29.8 ± 6.7 | 264.9 ± 7.4 |
| 1985 T | 203.5 ± 14.3 | 64.7 ± 12.3 | 17.4 ± 4.0 | 285.6 ± 7.3 |
| C | 198.6 ± 8.6 | 57.6 ± 7.8 | 32.4 ± 6.2 | 288.6 ± 4.9 |
| 1986 T | 176.0 ± 13.2 | 64.0 ± 13.2 | 11.6 ± 1.9 | 251.6 ± 7.2 |
| C | 189.1 ± 11.5 | 62.1 ± 9.5 | 32.3 ± 6.3 | 284.2 ± 9.8 |
| 1987 T | 160.9 ± 14.5 | 58.7 ± 10.9 | 10.9 ± 2.0 | 231.2 ± 9.1 |
| C | 180.0 ± 12.6 | 62.8 ± 8.2 | 31.2 ± 8.3 | 274.3 ± 8.6 |
| 1988 T | 191.2 ± 15.2 | 69.4 ± 13.2 | 14.7 ± 2.0 | 275.6 ± 9.6 |
| C | 198.0 ± 10.5 | 63.6 ± 8.0 | 39.1 ± 7.3 | 300.7 ± 9.9 |
| 1989 T | 180.1 ± 12.6 | 73.8 ± 12.6 | 15.4 ± 2.3 | 269.3 ± 6.7 |
| C | 161.7 ± 9.0 | 64.5 ± 14.4 | 31.7 ± 5.5 | 257.9 ± 9.7 |
| 1990 T | 169.0 ± 10.6 | 62.4 ± 10.9 | 15.0 ± 2.8 | 246.4 ± 5.2 |
| C | 171.8 ± 7.7 | 58.2 ± 5.6 | 31.2 ± 4.9 | 261.3 ± 6.5 |
| 1991 T | 166.6 ± 12.6 | 78.2 ± 14.4 | 16.2 ± 3.0 | 261.0 ± 9.9 |
| C | 186.6 ± 8.7 | 76.8 ± 10.8 | 33.1 ± 6.0 | 296.5 ± 8.4 |
| 1992 T | 159.3 ± 8.9 | 74.5 ± 9.7 | 16.2 ± 3.1 | 250.0 ± 7.4 |
| C | 176.2 ± 7.4 | 68.8 ± 7.8 | 31.9 ± 5.0 | 277.0 ± 9.8 |

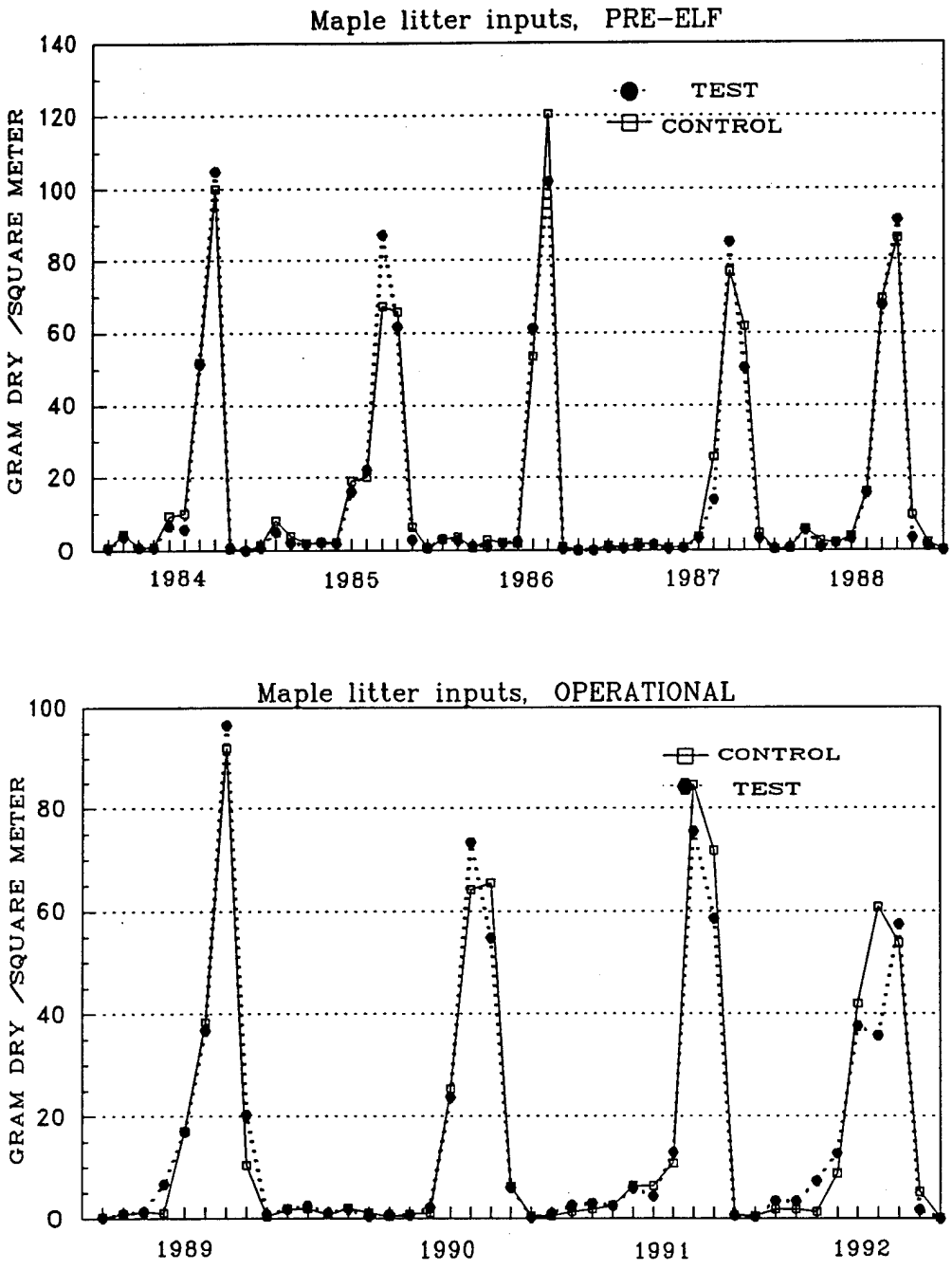


Fig. 122. Mean maple litter inputs (g dry /$m^2$) per date during pre-ELF and operational years in Test and Control sites.

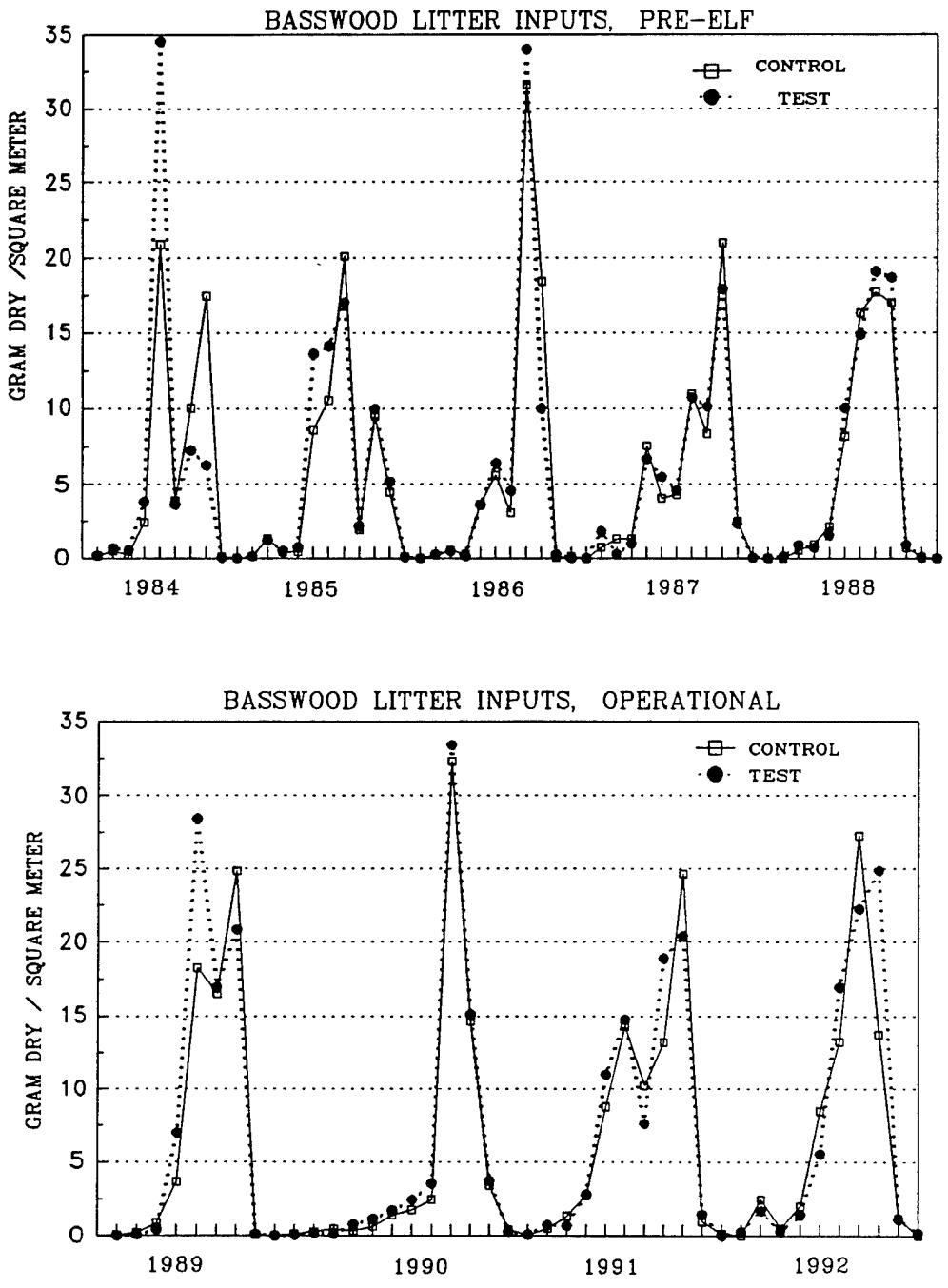


Fig. 123. Mean basswood litter inputs (g dry /$m^2$) per date during pre-ELF and operational years in Test and Control sites.

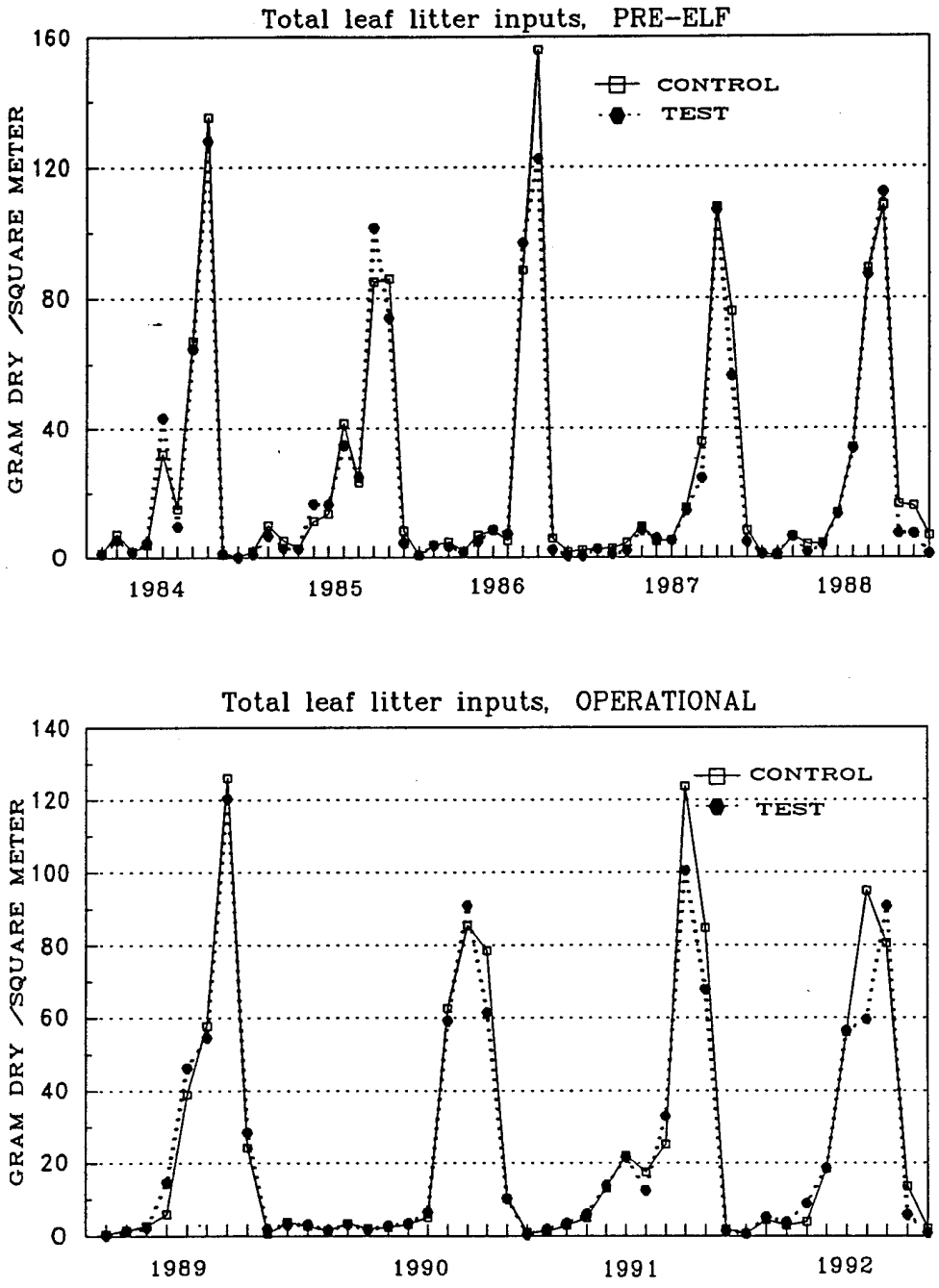


Fig. 124. Mean total (all species combined) inputs of leaf litter per date during pre-ELF and operational years in Test and Control sites.

**2. Statistical analyses**

ANOVA was used to test for differences between sites, between pre-ELF and operational periods, and for ELF x site interactions. For maple and total litter inputs, none of these factors were significant (**Table 42**). In the case of basswood, differences between pre-ELF and operational periods were significant, but ELF x site interactions were not. These results simply documented that in **both** sites, basswood litterfall had increased during the 1989-92 period (**Table 41**).

**Table 42.** ANOVA table for litter inputs in Test and Control sites, with ELF = pre-ELF vs. operational periods, and TOTAL = all species combined.

| RESP. VARIABLE | SOURCE | SS | DF | MS | F | P |
|---|---|---|---|---|---|---|
| MAPLE | ELF | 37.168 | 1 | 37.168 | 0.639 | 0.424 |
| | Site | 14.670 | 1 | 14.670 | 0.252 | 0.616 |
| | ELF x site | 0.008 | 1 | 0.008 | 0.000 | 0.991 |
| | Error | 223138 | 3836 | 58.170 | | |
| BASSWOOD | ELF | 51.972 | 1 | 51.972 | 5.684 | 0.017 |
| | Site | 7.530 | 1 | 7.530 | 0.823 | 0.364 |
| | ELF x site | 1.025 | 1 | 1.025 | 0.112 | 0.738 |
| | Error | 35074 | 3836 | 9.144 | | |
| TOTAL | ELF | 3.312 | 1 | 3.312 | 0.036 | 0.849 |
| | Site | 182.438 | 1 | 182.438 | 2.008 | 0.157 |
| | ELF x site | 2.071 | 1 | 2.071 | 0.023 | 0.880 |
| | Error | 348553 | 3836 | 90.864 | | |

## C. SUMMARY AND DISCUSSION

Leaf litter inputs clearly were not affected by ELF antenna activation. Total annual inputs were approximately 2.5 to 3.0 tons /ha /year in both sites, well within the range of 2.2 to 3.6 tons /ha reported by Chandler (1941), Alway *et al.* (1933), Bray and Gorham (1964) and Maldague (1967) for similar forest stands. Observed between-year variation also fell within the range reported by Bray and Gorham (1964). Reduced inputs following an unusually dry spring and summer (Blandin *et al.* 1980) were not observed in our sites in the two driest years, 1986 and 1988.

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## VIII. LITTER DECOMPOSITION

### A. METHODS

The first studies of maple litter decomposition in 1984 and 1985 involved litterbags (1 mm and 5 mm mesh) and "leafpacks", which consisted of six leaves for which surface area, mass, and position in the pack were known. We have reported these results previously (Snider and Snider 1987) and will not repeat them here, since the methods employed were discontinued.

Beginning in November 1985, we used litterbags made of flexible nylon netting, 15-20 mm mesh size (birdnetting), to enclose samples of maple litter samples of known mass. Wooden clothespins and labels were used to anchor them to the soil surface.

Litter was collected around the periphery of each site just after peak abscission, air-dried, weighed in portions of approx. 10 g, and distributed in litternags over several quadrats (not used for faunal sampling) in each site. Control litter was routinely used in Control bags, and Test litter in Test bags. An additional series of litterbags was cross-exposed (Control litter in Test and vice versa) from November 1990 to November 1991.

Loss of leaf fragments during handling was validated twice and found to be insignificant. Mass loss of air-dried leaves after oven-drying, and % ash of initial litter were quantified for each litterbag series at the time of field placement, so that initial AFDW could be calculated.

Litterbags were placed in the field in November and sampled at approximately monthly intervals from May to November of the following year. Continued sampling into the second year (after a second winter) was found to yield imprecise data due to problems with invasion of bags by herbs and seedlings. Samples were oven-dried at 80 $^{o}$C, weighed, ground, and two subsamples (approx. 1 g each) were ashed four hours at 600 $^{o}$C. Results are based on AFDW.

**Available litterbag "series":**
Series I: November 1985 - November 1986
Series II: November 1988 - November 1989
Series III: November 1989 - November 1990
Series IV: November 1990 - November 1991
Series V: November 1991 - November 1992
Series VI: November 1992 - October 1993
Exchange series: November 1990 - November 1991

Available data were thus unbalanced with respect to pre-ELF vs. operational periods: series I and series II are considered pre-operational (although the antenna was activated in May 1989, mass loss had been occurring throughout the preceding 7 months). Series III through VI were operational series.

## B. RESULTS AND ANALYSES

For each litterbag series, mean percent of initial mass remaining is illustrated in **Fig. 125**. Some differences between sites were observed: with the exception of series I and V, litter tended to decay to a greater degree in the Test site.

Data for individual samples were converted to differences (subtracted from the mean percent remaining on the previous date), and were analyzed by ANOVA; series I and II represented the pre-ELF period, series III through VI the operational period. Site effects were not significant during pre-ELF years, but were significant at $P = 0.02$ during operational years. Neither series nor site x series interactions, however, were significant (**Table 43**). ANOVA of pre-ELF vs. operational periods also showed that the most important factor, site x ELF interaction, was not significant, i.e., that between-period variability was synchronous in Test and Control.

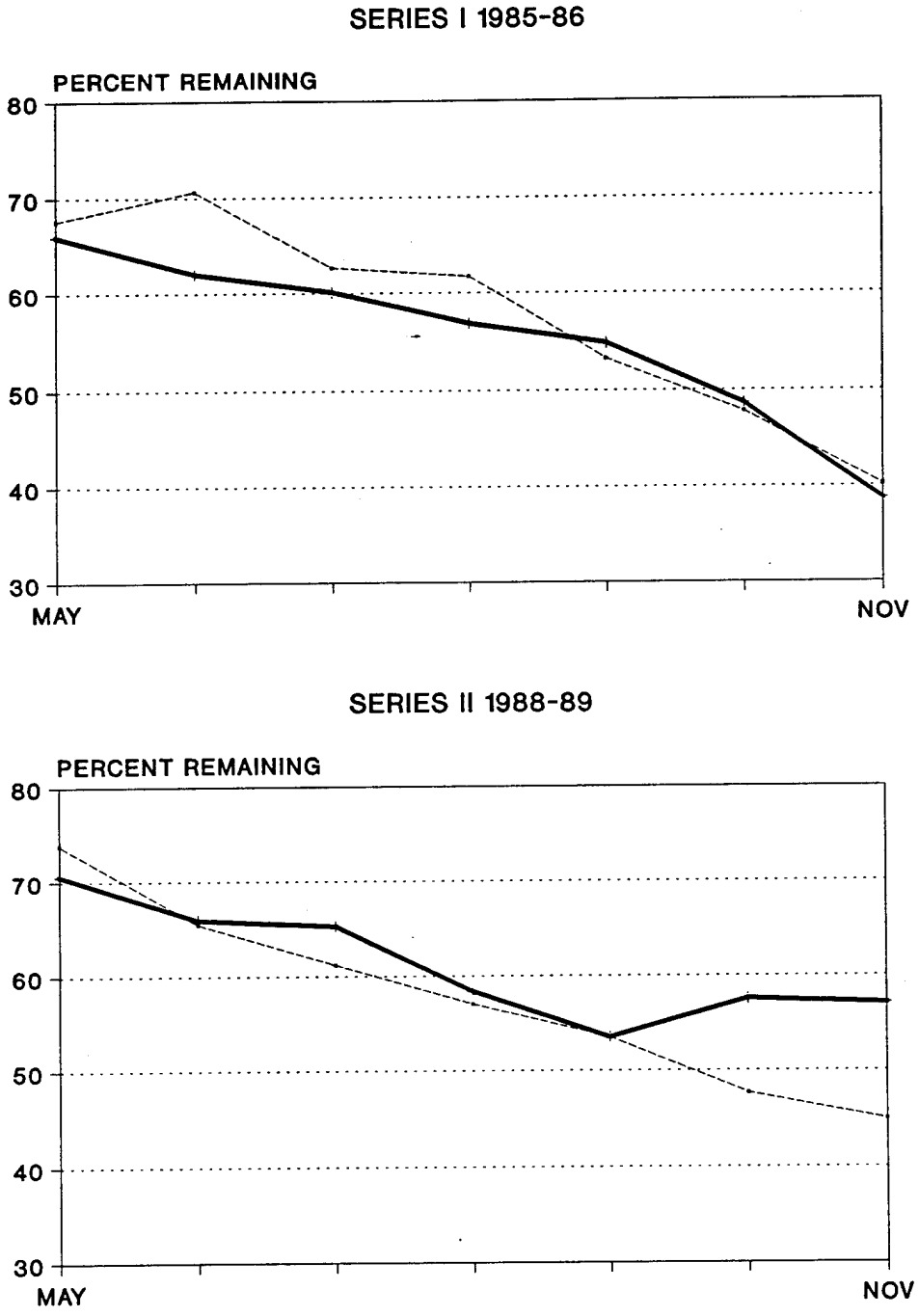
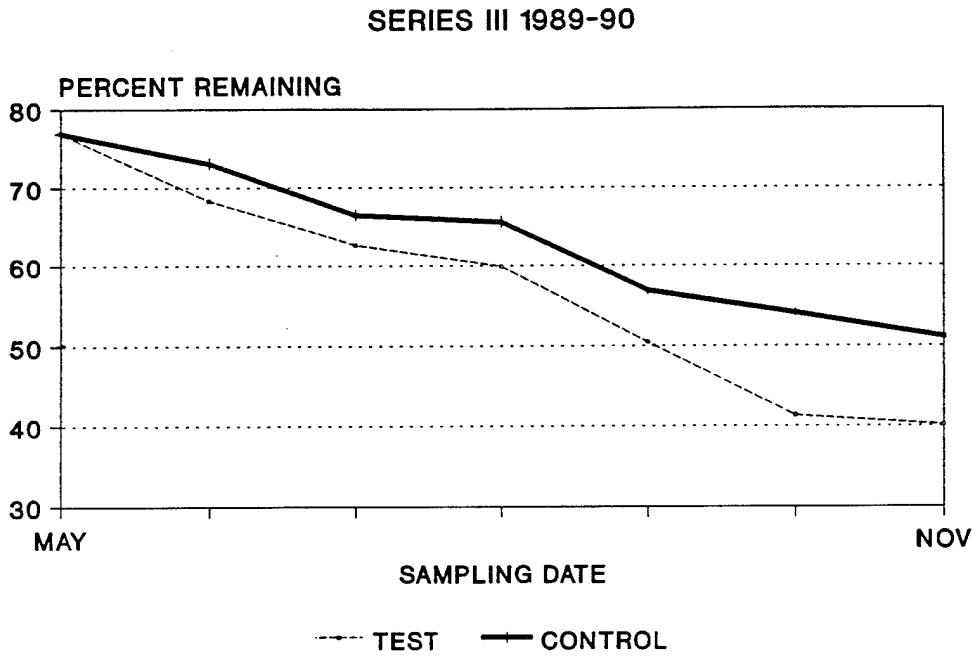



Fig. 125. Mean mass remaining (AFDW) of maple litter incubated in litterbags in Test and Control sites; N samples /date = 10 or 12, variable with SERIES, which are identified by number and year.



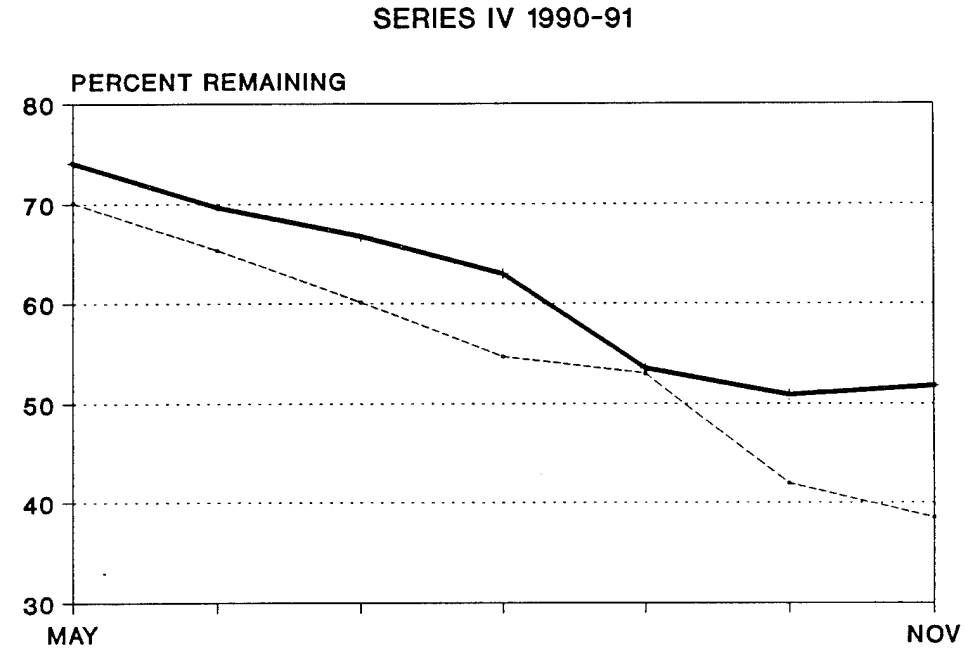




Fig. 125. continued.

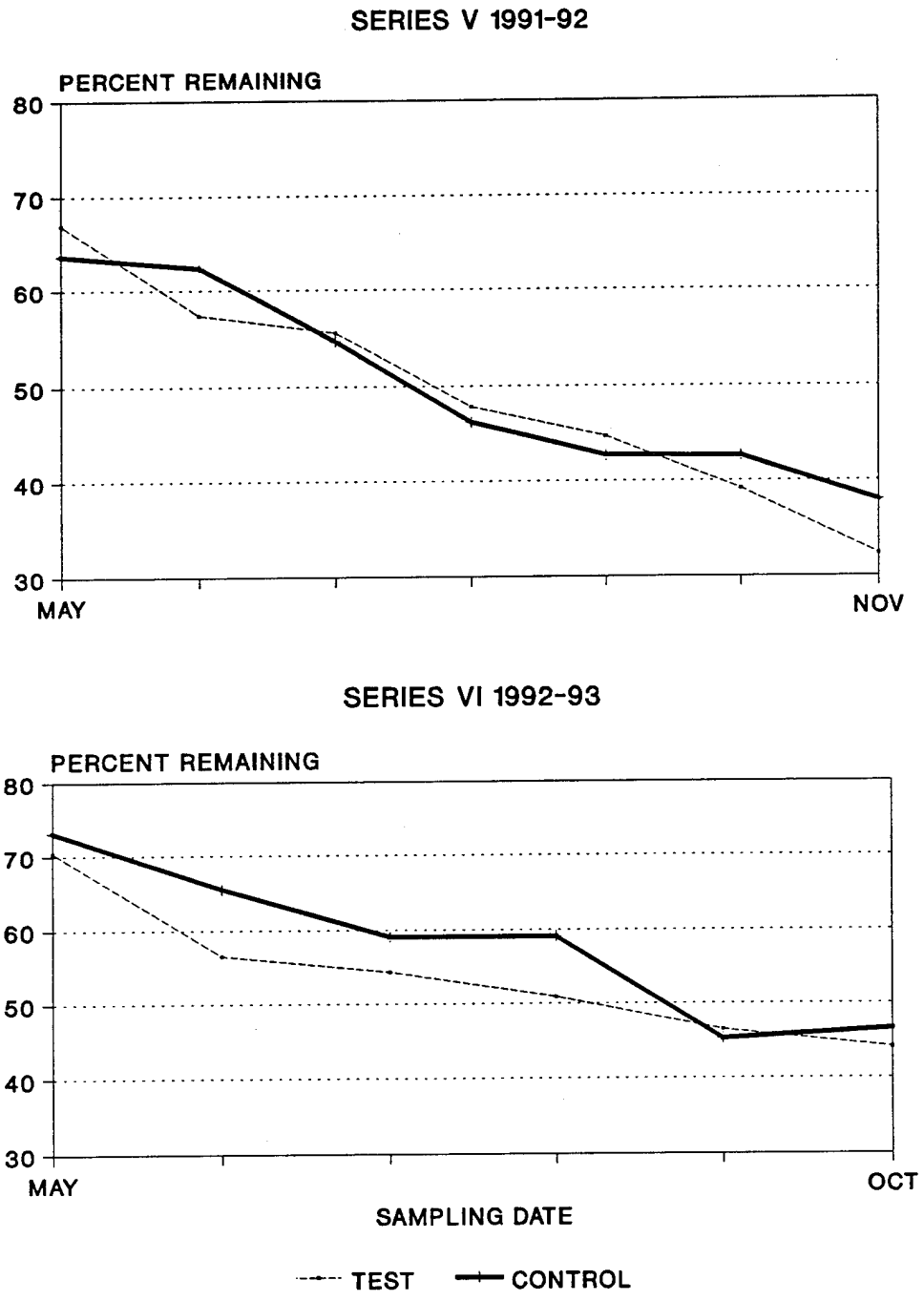



Fig. 125. continued.

**Table 43.** ANOVA table for percent remaining mass (based on AFDW of $bag_i$ minus mean AFDW remaining on the previous date); SERIES = litterbag series; ELF = pre-ELF and operational periods (series I and II vs, series III through VI). **Summaries of raw data are shown in Appendix 10.**

| SERIES | SOURCE | SS | DF | MS | F | P |
|---|---|---|---|---|---|---|
| I+II | Site | 100.31 | 1 | 100.31 | 1.909 | 0.168 |
| | Series | 65.25 | 1 | 65.25 | 1.242 | 0.266 |
| | Site x series | 96.85 | 1 | 96.85 | 1.843 | 0.176 |
| | Error | 12401.70 | 236 | 52.55 | | |
| III-VI | Site | 195.16 | 1 | 195.16 | 5.1343 | 0.024 |
| | Series | 64.38 | 3 | 64.38 | 0.565 | 0.639 |
| | Site x series | 64.14 | 3 | 64.14 | 0.563 | 0.640 |
| | Error | 20678.16 | 544 | 38.01 | | |
| I+II vs. III-VI | Site | 269.62 | 1 | 269.62 | 6.367 | 0.012 |
| | ELF | 162.17 | 1 | 162.17 | 3.830 | 0.051 |
| | Site x ELF | 0.09 | 1 | 0.09 | 0.002 | 0.963 |
| | Error | 33370.48 | 788 | 42.35 | | |

Differences between years, in terms of estimated turnover times, occurred in both sites, althoughto a much greater degree in Control where they ranged from approximately 1 year to 1.77 years (**Table 44**). Although the direction of between-year changes was similar in both sites, correlation was weak ($R^2 = 0.48$).

**Table 44.** Estimated turnover times (1/k) for litterbag series I through VI (identified by the year during which samples were taken).

| | SERIES (YEAR) | | | | | |
|---|---|---|---|---|---|---|
| SITE | I (86) | II (89) | III (90) | IV (91) | V (92) | VI (93) |
| CONTROL | 0.963 | 1.767 | 1.485 | 1.475 | 1.002 | 1.253 |
| TEST | 1.003 | 1.237 | 1.089 | 1.016 | 1.014 | 1.167 |

We did, however, find good correlation between biomass of decomposer earthworms and variations in turnover times. Mean annual mass of [*D. octaedra* + *Lumbricus* spp] in Control, and mean annual mass of [*D. octaedra* + *L. rubellus* immatures] were significantly correlated with turnover times (**Fig. 126**).

Results of the Exchange series, sampled during 1991 (**Fig. 127**) allowed the following conclusions:

a) provenance site of litter was not a factor influencing decay rates: Test litter incubated in Control decomposed at approximately the same rate as Control litter incubated in Control; and Control litter incubated in Test decomposed at approximately the same rate as Test litter incubated in Test (**Table 45** and **Figs. 125** and **127**);

b) by corollary, decay rates were site- and year-specific, most likely as a result of fluctuations in decomposer populations, as discussed above.

## C. SUMMARY AND DISCUSSION

Analyses of variance (**Table 43**) clearly showed that variations in litter breakdown rates were not affected by antenna activation (i.e., site x ELF effects were not significant). Decomposition rates did differ between years and groups of years (pre-ELF vs. operational series). To a large degree, differences were explainable by fluctuations in epigeic earthworm biomass.

In Test, *L. rubellus* immatures contributed > 75% of worm biomass in all years, *D. octaedra* playing a minor role due to its consistently low abundance. Relatively stable biomass (range 6.4 to 9.7 g /$m^2$) resulted in relatively little variation in litter turnover times (range 1.0 to 1.24 years).

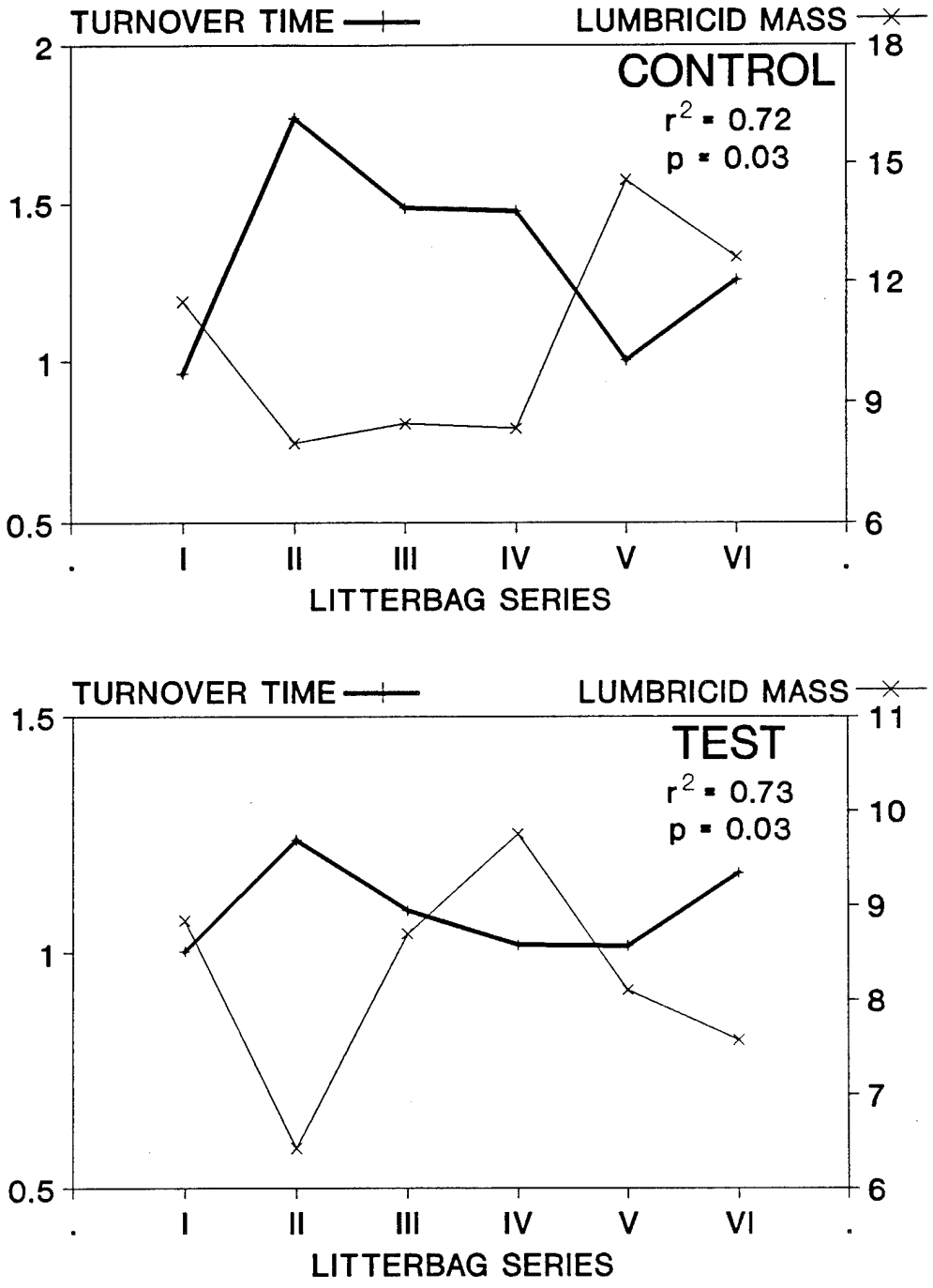



Fig. 126. Turnover times (1/k) and mean annual biomass of litter-feeding lumbricids in Test and Control, litterbag series I through VI.

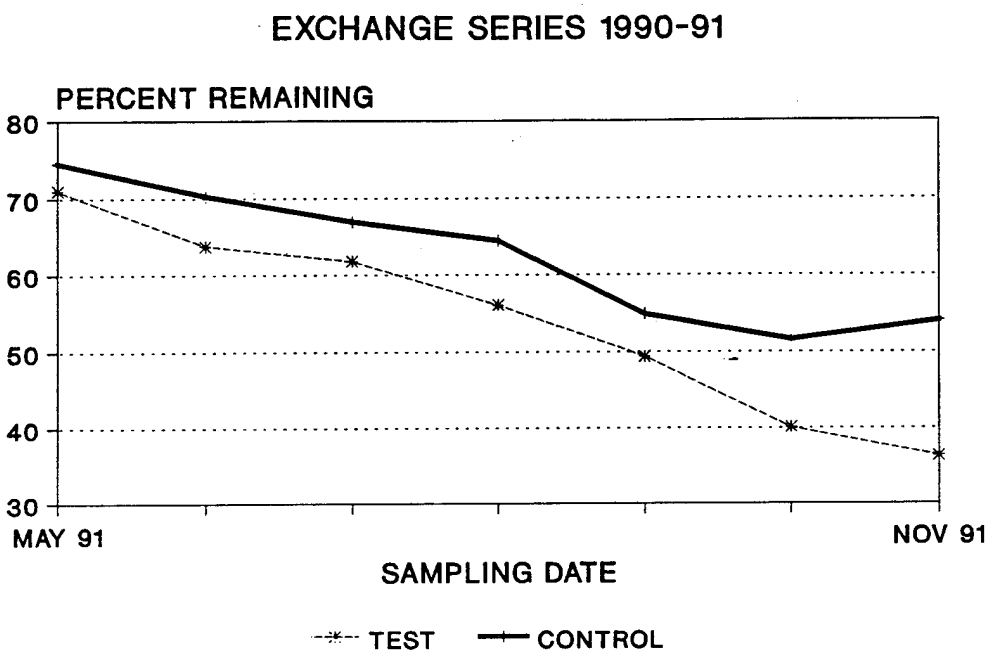



Fig. 127. Mean mass remaining (AFDW) in Exchange series litterbags during 1991.

**Table 45.** Turnover time (1/k) for litterbag series IV and for the Exchange series, both placed in the field in November 1990 and sampled from May to November 1991.

| SERIES / SITE | 1/k |
|---|---|
| IV TEST | 1.016 |
| EXCHANGE TEST | 0.957 |
| IV CONTROL | 1.475 |
| EXCHANGE CONTROL | 1.574 |

In Control, worm biomass fluctuated more drastically (range 8.0 to 14.6 g /$m^2$); *D. octaedra* constituted more variable proportions of this biomass (range 47 to 83%). A wider range of turnover times (0.96 to 1.77 years) were the result.

Many authors have related organic matter breakdown to lumbricid activity (summary in Lee, 1985). Recently, Hendroksen (1990) and Daniel (1991) have shown a direct, positive effect of *Lumbricus* spp. on litter disappearance. In microcosm experiments by Haimi and Huhta (1990), *D. octaedra* and *L. rubellus* clearly enhanced mass loss of birch litter, but relationships with worm biomass were unclear due to variable mortality of worms in experimental containers. Our field-derived data allowed correlation between climate-induced biomass fluctuations and litter decay over several years.

In summary, we conclude that:

a) litter breakdown rates were site-specific, independent of provenance of litter (Exchange series), in agreement with Herlitzius and Herlitzius (1977) who related decay to site-specific macrodecomposer populations;

b) variations in turnover times were due mainly to species composition and dynamics of lumbricid decomposers; and

c) no effects of EM fields on litter decay were detectable; if any had become apparent in Test, they would have had to be traced to their primary source (i.e., effects on numbers, biomass or behavior of *L. rubellus*): we were unable, however, to document significant changes in that population (ref. section V).

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**Appendix 1.** Site locations, site configurations, and EM field measurements (excerpted and adapted from Haradem *et al.* (1994).

The location of sites relative to the Michigan ELF antenna are shown in **Fig. 1.1.** Site code numbers in **Fig. 1.1.** are those used by IITRI, who provided engineering support; cross-references of IITRI site numbers, investigators' site designations, and township, range and section numbers are listed in **Table 1.1.** Configuration of Control and Test sites are shown in **Figs. 1.2.** and **1.3.** respectively.

The remaining **Tables 1.2.** through **1.10.** list data for electric field intensities and magnetic flux densities pertaining to our study and laboratory sites, for 60 Hz as well as 76 Hz frequencies.

**Table 1.1.** Cross-reference list of site designations used by IITRI and by investigators, and site locations.

| IITRI Site No. | Investigator's Site Name | Location | | |
|---|---|---|---|---|
| | | Township | Range | Section |
| 3T2 | Test site | T44N | R29W | 25 |
| 3C5 | Control site | T43N | R30W | 11 |
| 3L1 | Laboratory (barn) | T43N | R30W | 32 |
| 3S1 | Merriman Rd. site[a] | T41N | R29W | 21 |
| 3S2 | Fire Tower site[a] | T44N | R30W | 24 |

a = collection sites for earthworms used in Isolation Experiments (see section VI).

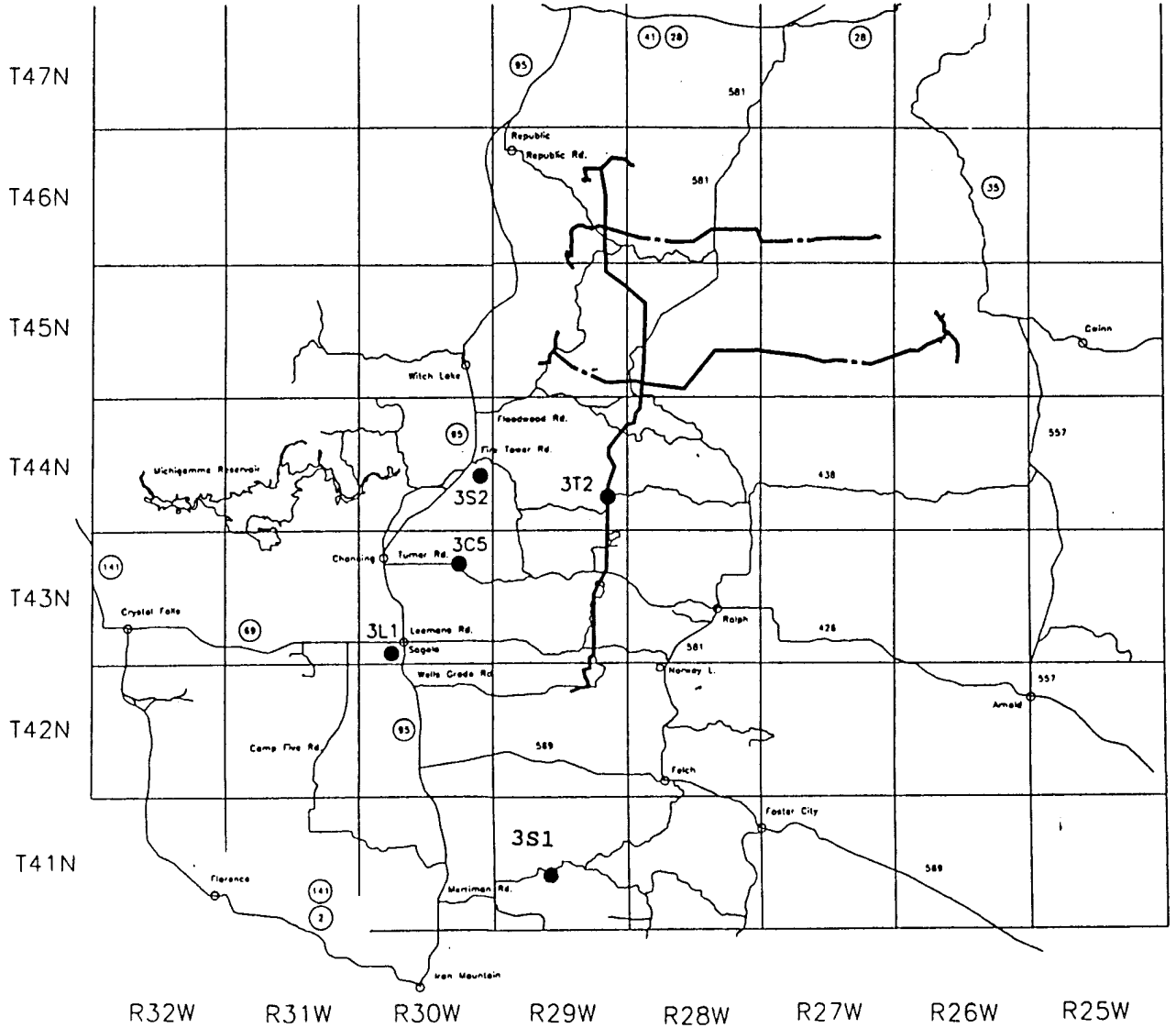


**Fig. 1.1.** Location of study sites relative to NRTF-Republic antenna elements. For code numbers of sites, ref. to Table 1.1.

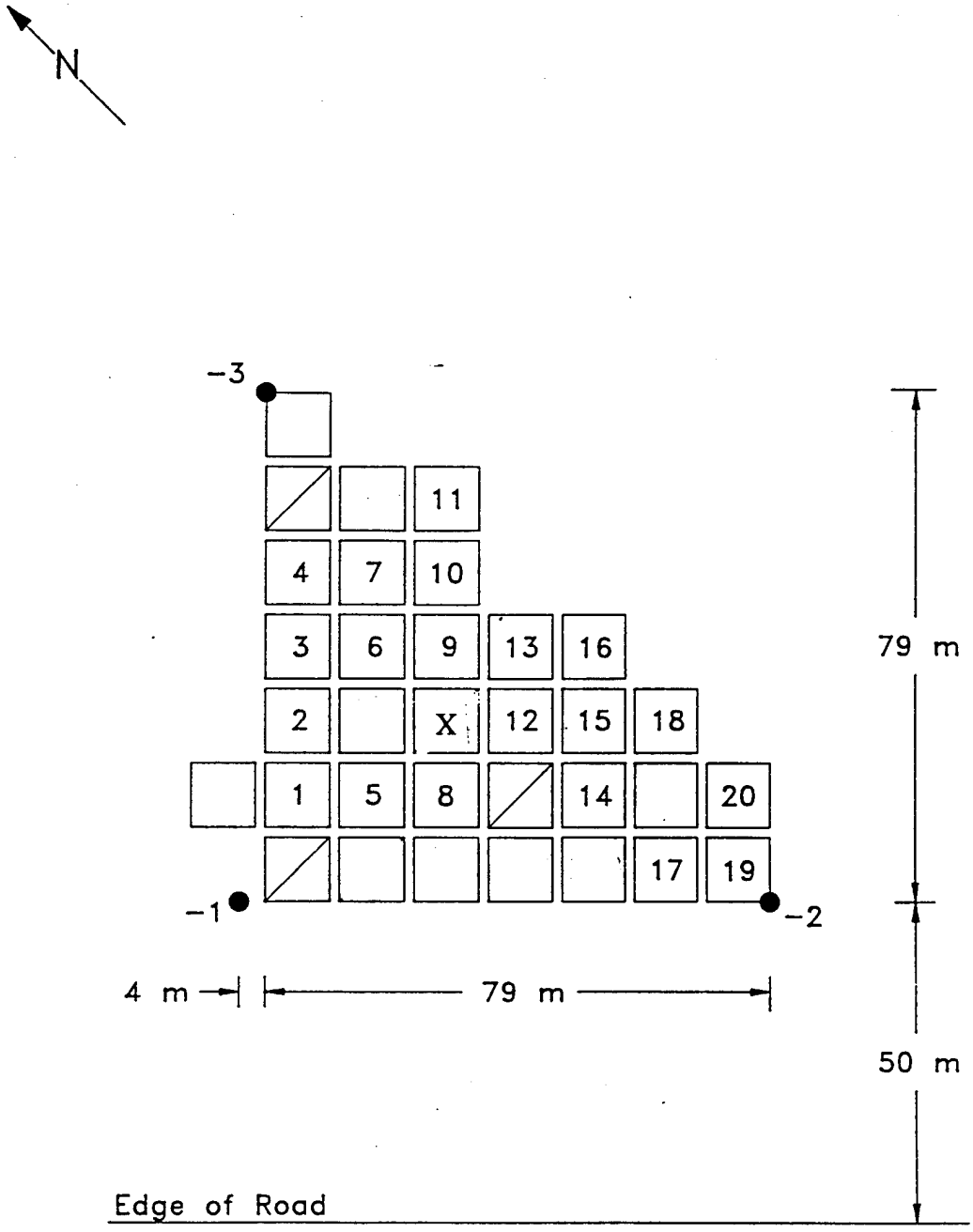


**Fig. 1.2.** Configuration of the Control site: numbered quadrats (each 10 x 10 m) were available for faunal sampling; others were used for litter decomposition studies or environmental monitoring (quadrat marked X) or were unused due to excessive dead wood; points 1, 2 and 3 refer to measurement points for EM field monitoring. Measurement point 1 served for monitoring EM fields in the Earthworm Isolation Experiment area, which was located next to it.

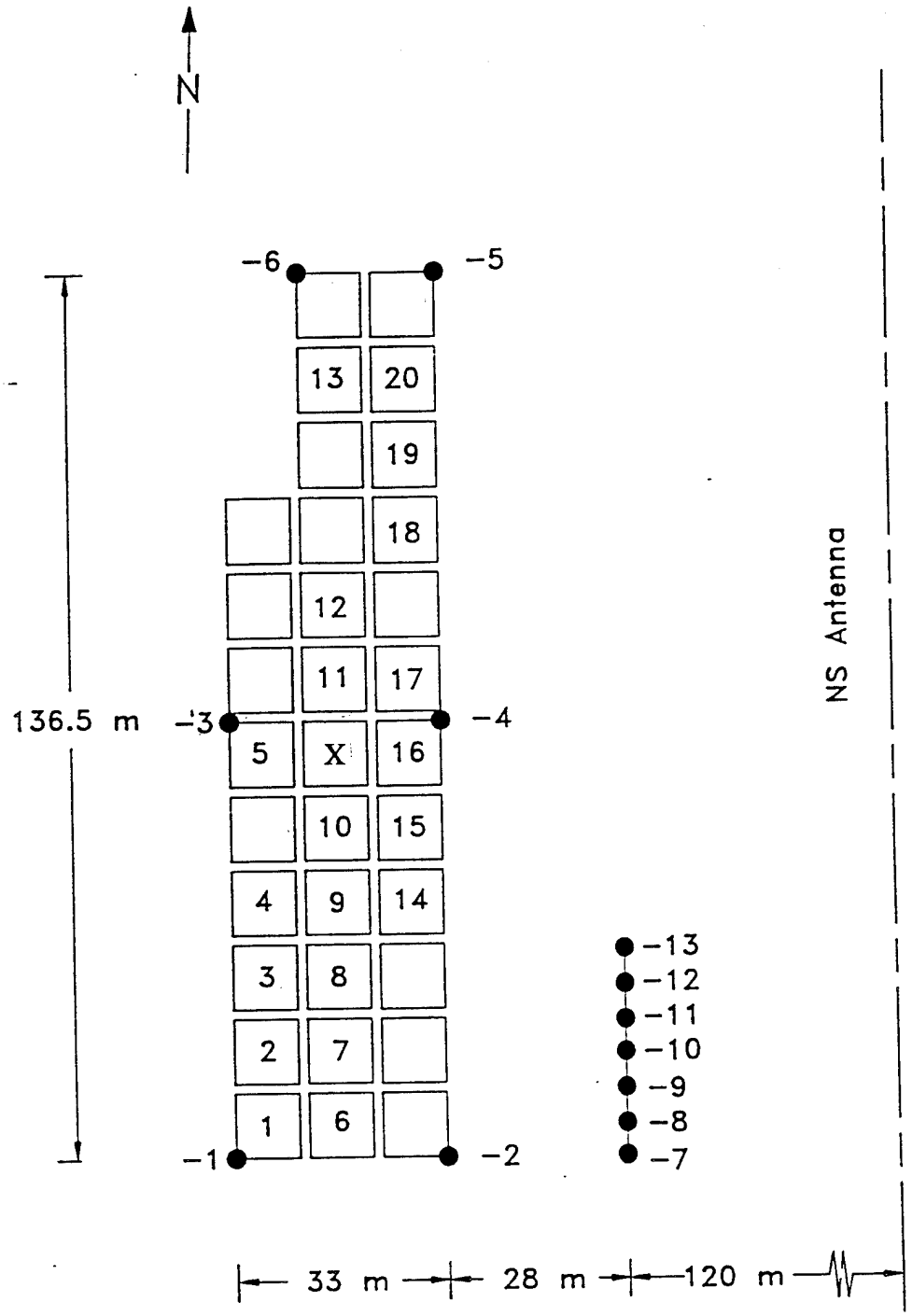


**Fig. 1.3.** Configuration of the Test site: numbered quadrats (each 10 x 10m) were available for faunal sampling; others were used either for litter decomposition studies or environmental monitoring (quadrat marked X), or were unused due to excessive dead wood; points 1 through 6 were measurement points for monitoring EM fields; points 7 through 13 were EM field measurement points located in the Earthworm Isolation Experiment area.

**Table 1.2.** 60 Hz AIR ELECTRIC FIELD INTENSITIES (V/m).

| Site No., Meas. Pt. | 1983[a] | 1984[a] | 1985[a] | 1986[b] | 1987[c] | 1988[c] | 1989[d] | 1990 | 1991 | 1992 | 1993 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 3C5-1 | <0.001 | <0.001 | < | < | < | < | < | <[d] | <[d] | <[d] | <[d] |
| 3C5-2 | - | - | - | < | < | < | < | <[d] | <[d] | <[d] | <[d] |
| 3C5-3 | - | - | - | - | - | - | - | - | <[d] | <[d] | <[d] |
| 3T2-1 | <0.001 | <0.001 | < | < | < | < | <0.001 | <0.001[c] | <[c] | <[b] | <[b] |
| 3T2-2 | - | - | - | < | < | < | < | <0.001[c] | <[c] | <[b] | <[b] |
| 3T2-3 | - | - | - | < | < | < | < | <[c] | <[c] | <[b] | <[b] |
| 3T2-4 | - | - | - | < | < | < | < | <[c] | <[c] | <[b] | <[b] |
| 3T2-5 | - | - | - | < | < | < | < | <[c] | <[c] | <[b] | <[b] |
| 3T2-6 | - | - | - | < | < | < | < | <[c] | <[c] | <[b] | <[b] |
| 3T2-7 | - | - | - | - | - | - | - | - | / | <[b] | <[b] |
| 3T2-8 | - | - | - | - | - | - | - | - | / | / | / |
| 3T2-9 | - | - | - | - | - | - | - | - | / | / | / |
| 3T2-10 | - | - | - | - | - | - | - | - | / | / | / |
| 3T2-11 | - | - | - | - | - | - | - | - | / | / | / |
| 3T2-12 | - | - | - | - | - | - | - | - | / | / | / |
| 3T2-13 | - | - | - | - | - | - | - | - | / | <[b] | <[b] |
| 3S1-1 | - | - | - | - | - | - | - | - | <[c] | / | / |
| 3S2-1 | - | - | - | - | - | - | - | - | <[c] | <[b] | <[b] |

a = antennas not constructed.
b = antennas off, grounded at transmitter.
c = antennas off, connected to transmitter.
d = antennas on, 150 ampere current.

\- = measurement point not established.
< = measurement estimated <0.001 V/m based on earth electric field.
/ = measurement not taken.

**Table 1.3.** 60 Hz EARTH ELECTRIC FIELD INTENSITIES (mV/m).

| Site No., Meas. Pt. | 1983[a] | 1984[a] | 1985[a] | 1986[b] | 1987[c] | 1988[c] | 1989[d] | 1990 | 1991 | 1992 | 1993 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 3C5-1 | 0.063 | 0.018, 0.032 | 0.036 | 0.027 | 0.054 | 0.054 | 0.062 | 0.065[d] | 0.069[d] | 0.044[d] | 0.036[d] |
| 3C5-2 | - | - | - | 0.027 | 0.071 | 0.085 | 0.182 | 0.118[d] | 0.098[d] | 0.086[d] | 0.047[d] |
| 3C5-3 | - | - | - | - | - | - | - | - | 0.120[d] | 0.077[d] | 0.040[d] |
| 3T2-1 | 0.106 | 0.129, 0.27 | 0.194 | 0.045 | 0.042 | 0.091 | 0.055 | 0.042[c] | 0.050[c] | 0.062[b] | 0.21[b] |
| 3T2-2 | - | - | - | 0.068 | 0.049 | 0.093 | 0.049 | 0.043[c] | 0.063[c] | 0.053[b] | 0.068[b] |
| 3T2-3 | - | - | - | 0.038 | 0.043 | 0.084 | 0.035 | 0.047[c] | 0.041[c] | 0.074[b] | 0.051[b] |
| 3T2-4 | - | - | - | 0.045 | 0.039 | 0.087 | 0.068 | 0.040[c] | 0.176[c] | 0.076[b] | 0.051[b] |
| 3T2-5 | - | - | - | 0.044 | 0.045 | 0.084 | 0.053 | 0.047[c] | 0.047[c] | 0.065[b] | 0.050[b] |
| 3T2-6 | - | - | - | 0.048 | 0.033 | 0.087 | 0.041 | 0.042[c] | 0.043[c] | 0.065[b] | 0.042[b] |
| 3T2-7 | - | - | - | - | - | - | - | - | / | 0.073[b] | 0.086[b] |
| 3T2-8 | - | - | - | - | - | - | - | - | / | / | / |
| 3T2-9 | - | - | - | - | - | - | - | - | / | / | / |
| 3T2-10 | - | - | - | - | - | - | - | - | / | / | / |
| 3T2-11 | - | - | - | - | - | - | - | - | / | / | / |
| 3T2-12 | - | - | - | - | - | - | - | - | / | / | / |
| 3T2-13 | - | - | - | - | - | - | - | - | / | 0.055[b] | 0.069[b] |
| 3S1-1 | - | - | - | - | - | - | - | - | 0.62[c] | / | / |
| 3S2-1 | - | - | - | - | - | - | - | - | 0.45[c] | 0.084[b] | 0.31[b] |

a = antennas not constructed.
b = antennas off, grounded at transmitter.
c = antennas off, connected to transmitter.
d = antennas on, 150 ampere current.

- = measurement point not established.
/ = measurement not taken.

## Table 1.4. 60 Hz MAGNETIC FLUX DENSITIES (mG).

| Site No., Meas. Pt. | 1983[a] | 1984[a] | 1985[a] | 1986[b] | 1987[c] | 1988[c] | 1989[d] | 1990 | 1991 | 1992 | 1993 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 3C5-1 | 0.001 | 0.001 | 0.001 | 0.001 | 0.002 | 0.001 | 0.001 | 0.002[d] | 0.002[d] | 0.002[d] | 0.002[d] |
| 3C5-2 | - | - | - | <0.001 | 0.001 | 0.001 | 0.002 | 0.001[d] | 0.001[d] | 0.001[d] | 0.001[d] |
| 3C5-3 | - | - | - | - | - | - | - | - | 0.001[d] | 0.001[d] | 0.001[d] |
| 3T2-1 | <0.001 | <0.001 | 0.001 | 0.005 | 0.002 | 0.004 | 0.001 | 0.003[c] | 0.005[c] | 0.003[b] | 0.006[b] |
| 3T2-2 | - | - | - | 0.006 | 0.003 | 0.006 | 0.002 | 0.004[c] | 0.006[c] | 0.003[b] | 0.008[b] |
| 3T2-3 | - | - | - | 0.004 | 0.003 | 0.003 | 0.001 | 0.003[c] | 0.005[c] | 0.003[b] | 0.006[b] |
| 3T2-4 | - | - | - | 0.005 | 0.003 | 0.005 | 0.002 | 0.004[c] | 0.010[c] | 0.003[b] | 0.007[b] |
| 3T2-5 | - | - | - | 0.005 | 0.003 | 0.004 | 0.002 | 0.004[c] | 0.005[c] | 0.003[b] | 0.007[b] |
| 3T2-6 | - | - | - | 0.004 | 0.003 | 0.003 | 0.001 | 0.004[c] | 0.006[c] | 0.002[b] | 0.006[b] |
| 3T2-7 | - | - | - | - | - | - | - | - | / | 0.004[b] | 0.009[b] |
| 3T2-8 | - | - | - | - | - | - | - | - | / | / | / |
| 3T2-9 | - | - | - | - | - | - | - | - | / | / | / |
| 3T2-10 | - | - | - | - | - | - | - | - | / | / | / |
| 3T2-11 | - | - | - | - | - | - | - | - | / | / | / |
| 3T2-12 | - | - | - | - | - | - | - | - | / | / | / |
| 3T2-13 | - | - | - | - | - | - | - | - | / | 0.004[b] | 0.010[b] |
| 3S1-1 | - | - | - | - | - | - | - | - | 0.006[c] | / | / |
| 3S2-1 | - | - | - | - | - | - | - | - | 0.004[c] | 0.002[b] | 0.003[b] |

a = antennas not constructed.
b = antennas off, grounded at transmitter.
c = antennas off, connected to transmitter.
d = antennas on, 150 ampere current.

- = measurement point not established.
/ = measurement not taken.

**Table 1.5.** 76 Hz AIR ELECTRIC FIELD INTENSITIES (V/m).

| Site No., Meas. Pt. | 1986 NS 4 A | 1986 NEW 6 A | 1986 SEW 6 A | 1986 SEW 10 A, EX | 1987 NS 15 A | 1987 EW 15 A | 1988 NS 75 A | 1988 EW 75 A | 1989 B 150 A | 1990 B 150 A | 1991 B 150 A | 1992 B 150 A | 1993 B 150 A |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3C5-1 | < | < | < | * | < | < | < | < | < | < | < (NS) | < | < |
| 3C5-2 | < | < | < | * | < | < | < | < | < | < | < (NS) | < | < |
| 3C5-3 | - | - | - | - | - | - | - | - | - | - | < (NS) | < | < |
| 3T2-1 | 0.002 | < | < | * | 0.006 | < | 0.031 | 0.003 | 0.064 | 0.056 | 0.067 | 0.059 | 0.059 |
| 3T2-2 | 0.002 | < | < | * | 0.006 | < | 0.024 | 0.003 | 0.070 | 0.068 | 0.064 | 0.062 | 0.075 |
| 3T2-3 | 0.002 | < | < | * | 0.006 | < | 0.028 | 0.003 | 0.048 | 0.067 | 0.061 | 0.061 | 0.061 |
| 3T2-4 | 0.002 | < | < | * | 0.006 | < | 0.026 | 0.003 | 0.055 | 0.061 | 0.054 | 0.059 | 0.060 |
| 3T2-5 | 0.002 | < | < | * | 0.006 | < | 0.029 | 0.005 | 0.061 | 0.056 | 0.097 | 0.065 | 0.075 |
| 3T2-6 | 0.002 | < | < | * | 0.006 | < | 0.027 | 0.002 | 0.048 | 0.055 | 0.053 | 0.050 | 0.074 |
| 3T2-7 | - | - | - | - | - | - | - | - | - | - | / | 0.080 | 0.089 |
| 3T2-8 | - | - | - | - | - | - | - | - | - | - | / | / | / |
| 3T2-9 | - | - | - | - | - | - | - | - | - | - | / | / | / |
| 3T2-10 | - | - | - | - | - | - | - | - | - | - | / | / | / |
| 3T2-11 | - | - | - | - | - | - | - | - | - | - | / | / | / |
| 3T2-12 | - | - | - | - | - | - | - | - | - | - | / | / | / |
| 3T2-13 | - | - | - | - | - | - | - | - | - | - | / | 0.075 | 0.072 |
| 3S1-1 | - | - | - | - | - | - | - | - | - | - | / | / | / |
| 3S2-1 | - | - | - | - | - | - | - | - | - | - | / | / | 0.004 |

NS = north-south antenna.
(NS) = north-south antenna only due to EW shutdown.
EW = east-west antenna.
NEW = northern EW antenna element.
SEW = southern EW antenna element.
B = NS + EW antennas
EX = extrapolated data.

< = measurement estimated <0.001 V/m based on earth electric field.
* = data cannot be extrapolated.
- = measurement point not established.
/ = measurement not taken.

**Table 1.6.** 76 Hz EARTH ELECTRIC FIELD INTENSITIES (mV/m).

| Site No., Meas. Pt. | 1986 NS 4 A | 1986 NEW 6 A | 1986 SEW 6 A | 1986 SEW 10 A, EX | 1987 NS 15 A | 1987 EW 15 A | 1988 NS 75 A | 1988 EW 75 A | 1989 B 150 A | 1990 B 150 A | 1991 B 150 A | 1992 B 150 A | 1993 B 150 A |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3C5-1 | 0.005 | 0.001 | 0.002 | 0.003 | 0.020 | 0.006 | 0.093 | 0.027 | 0.22 | 0.21 | 0.186 (NS) | 0.22 | 0.21 |
| 3C5-2 | 0.009 | 0.001 | 0.003 | 0.005 | 0.034 | 0.009 | 0.170 | 0.021 | 0.38 | 0.29 | 0.31 (NS) | 0.38 | 0.44 |
| 3C5-3 | - | - | - | - | - | - | - | - | - | - | 0.27 (NS) | 0.33 | 0.30 |
| 3T2-1 | 1.33 | 0.057 | 0.188 | 0.31 | 5.4 | 0.54 | 27 | 2.6 | 58 | 55 | 59 | 64 | 63 |
| 3T2-2 | 1.46 | 0.064 | 0.24 | 0.40 | 6.3 | 0.71 | 26 | 3.0 | 60 | 53 | 55 | 59 | 56 |
| 3T2-3 | 1.19 | 0.047 | 0.149 | 0.25 | 5.3 | 0.60 | 27 | 2.7 | 49 | 56 | 58 | 60 | 56 |
| 3T2-4 | 1.47 | 0.060 | 0.20 | 0.33 | 5.6 | 0.47 | 29 | 2.6 | 62 | 50 | 54 | 56 | 64 |
| 3T2-5 | 1.56 | 0.070 | 0.23 | 0.38 | 5.7 | 0.61 | 27 | 2.8 | 52 | 59 | 62 | 62 | 55 |
| 3T2-6 | 1.20 | 0.056 | 0.180 | 0.30 | 5.5 | 0.54 | 27 | 2.4 | 49 | 49 | 55 | 48 | 56 |
| 3T2-7 | - | - | - | - | - | - | - | - | - | - | 74 (NS) | 85 | 83 |
| 3T2-8 | - | - | - | - | - | - | - | - | - | - | 68 (NS) | / | / |
| 3T2-9 | - | - | - | - | - | - | - | - | - | - | 71 (NS) | / | / |
| 3T2-10 | - | - | - | - | - | - | - | - | - | - | 46 (NS) | / | / |
| 3T2-11 | - | - | - | - | - | - | - | - | - | - | 56 (NS) | / | / |
| 3T2-12 | - | - | - | - | - | - | - | - | - | - | 66 (NS) | / | / |
| 3T2-13 | - | - | - | - | - | - | - | - | - | - | 60 (NS) | 66 | 65 |
| 3S1-1 | - | - | - | - | - | - | - | - | - | - | / | / | / |
| 3S2-1 | - | - | - | - | - | - | - | - | - | - | / | 3.9 | 2.6 |

NS = north-south antenna.
(NS) = north-south antenna only due to EW shutdown.
EW = east-west antenna.
NEW = northern EW antenna element.
SEW = southern EW antenna element.
B = NS + EW antennas.
EX = extrapolated data.
\- = measurement point not established.
/ = measurement not taken.

**Table 1.7.** 76 Hz MAGNETIC FLUX DENSITIES (mG).

| Site No., Meas. Pt. | 1986 NS 4 A | 1986 NEW 6 A | 1986 SEW 6 A | 1986 SEW 10 A, EX | 1987 NS 15 A | 1987 EW 15 A | 1988 NS 75 A | 1988 EW 75 A | 1989 B 150 A | 1990 B 150 A | 1991 B 150 A | 1992 B 150 A | 1993 B 150 A |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3C5-1 | <0.001 | <0.001 | <0.001 | * | 0.002 | 0.001 | 0.008 | 0.003 | 0.019 | 0.018 | 0.014 (NS) | 0.020 | 0.018 |
| 3C5-2 | <0.001 | <0.001 | <0.001 | * | 0.002 | 0.001 | 0.007 | 0.002 | 0.017 | 0.017 | 0.014 (NS) | 0.019 | 0.019 |
| 3C5-3 | - | - | - | - | - | - | - | - | - | - | 0.012 (NS) | 0.018 | 0.016 |
| 3T2-1 | 0.048 | 0.001 | 0.001 | 0.002 | 0.187 | 0.003 | 0.88 | 0.012 | 1.84 | 1.81 | 1.73 | 1.86 | 1.80 |
| 3T2-2 | 0.060 | 0.002 | 0.001 | 0.002 | 0.23 | 0.003 | 1.11 | 0.012 | 2.3 | 2.2 | 2.2 | 2.3 | 2.3 |
| 3T2-3 | 0.046 | 0.001 | 0.001 | 0.002 | 0.182 | 0.002 | 0.89 | 0.012 | 1.81 | 1.80 | 1.68 | 1.85 | 1.81 |
| 3T2-4 | 0.055 | 0.002 | 0.001 | 0.002 | 0.23 | 0.003 | 1.08 | 0.012 | 2.3 | 2.2 | 2.3 | 2.3 | 2.2 |
| 3T2-5 | 0.057 | 0.002 | 0.001 | 0.002 | 0.22 | 0.003 | 1.03 | 0.012 | 2.2 | 2.1 | 2.1 | 2.2 | 2.2 |
| 3T2-6 | 0.049 | 0.001 | 0.001 | 0.002 | 0.190 | 0.003 | 0.90 | 0.012 | 1.88 | 1.89 | 1.77 | 1.92 | 1.87 |
| 3T2-7 | - | - | - | - | - | - | - | - | - | - | 2.5 (NS) | 2.9 | 2.8 |
| 3T2-8 | - | - | - | - | - | - | - | - | - | - | 2.5 (NS) | / | / |
| 3T2-9 | - | - | - | - | - | - | - | - | - | - | 2.5 (NS) | / | / |
| 3T2-10 | - | - | - | - | - | - | - | - | - | - | 2.5 (NS) | / | / |
| 3T2-11 | - | - | - | - | - | - | - | - | - | - | 2.6 (NS) | / | / |
| 3T2-12 | - | - | - | - | - | - | - | - | - | - | 2.6 (NS) | / | / |
| 3T2-13 | - | - | - | - | - | - | - | - | - | - | 2.6 (NS) | 2.9 | 2.9 |
| 3S1-1 | - | - | - | - | - | - | - | - | - | - | / | / | / |
| 3S2-1 | - | - | - | - | - | - | - | - | - | - | / | 0.051 | 0.052 |

NS = north-south antenna.
(NS) = north-south antenna only due to EW shutdown.
EW = east-west antenna.
NEW = northern EW antenna element.
SEW = southern EW antenna element.
B = NS + EW antennas.
EX = extrapolated data.
* = data cannot be extrapolated.
- = measurement point not established.
/ = measurement not taken.

**Table 1.8.** 1993 paired site EM field intensity ratios.

| Compared Sites | Air Electric Field | | | | Earth Electric Field | | | | Magnetic Flux Density | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | R1 | R2 | R3 | R4 | R1 | R2 | R3 | R4 | R1 | R2 | R3 | R4 |
| 3T2/3C5 | 59 | 59 | 59 | 1.00 | 125 | 300 | 1170 | 0.89 - 2.4 | 95 | 290 | 900 | 3.0 - 10.0 |

R1: T(76)/C(76)
R2: T(76)/T(60)
R3: T(76)/C(60)
R4: T(60)/C(60)

T(76) = ELF Communications System EM fields at the treatment site.
C(76) = ELF Communications System EM fields at the control site.
T(60) = ambient EM fields at the treatment site.
C(60) = ambient EM fields at the control site.

**Table 1.9.** 60 Hz AIR ELECTRIC FIELD INTENSITIES (V/m) at the laboratory (barn) in Sagola.

| Site No., Meas. Pt. | 1992 | Measurement Notes |
|---|---|---|
| 3L1-1 | 0.003 | Benchtop level |
| 3L1-2 | 0.011 | Ground level |
| 3L1-3 | 1.16 | Atop electronic scale, scale on |

**Table 1.10.** 60 Hz MAGNETIC FLUX DENSITIES (mG) at the laboratory (barn) in Sagola.

| Site No., Meas. Pt. | 1992 | Measurement Notes |
|---|---|---|
| 3L1-1 | 0.012 | Benchtop level |
| 3L1-2 | 0.013 | Ground level |
| 3L1-3 | 38 | Atop electronic scale, scale on |

**Appendix 2.** Average weekly temperature in the A horizon (5 cm depth) obtained in the Control site, 1984 through 1993 (Test data not shown because temperatures were essentially identical in the two sites). Week (WK) 1 = the week beginning May 1 of each year.

| WK | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 | 1993 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 6.8 | 9.6 | 9.9 | 8.8 | 9.4 | 5.2 | 8.0 | 5.7 | 8.6 | 8.5 |
| 2 | 8.7 | 12.8 | 11.0 | 11.3 | 9.7 | 7.3 | 6.7 | 11.9 | 11.3 | 12.3 |
| 3 | 10.0 | 11.3 | 10.8 | 10.6 | 10.5 | 11.7 | 8.2 | 12.4 | 13.4 | 8.4 |
| 4 | 9.0 | 11.5 | 11.8 | 10.9 | 11.7 | 12.1 | 10.2 | 15.8 | 10.5 | 9.2 |
| 5 | 8.5 | 10.9 | 12.8 | 15.1 | 13.9 | 11.4 | 10.6 | 16.3 | 13.4 | 8.4 |
| 6 | 12.1 | 12.3 | 11.6 | 13.4 | 13.4 | 11.2 | 11.3 | 15.6 | 13.8 | 11.3 |
| 7 | 12.9 | 12.0 | 12.0 | 16.4 | 14.4 | 10.9 | 13.8 | 16.5 | 13.8 | 12.6 |
| 8 | 12.8 | 13.0 | 13.3 | 16.8 | 15.8 | 14.7 | 13.0 | 15.7 | 10.8 | 13.9 |
| 9 | 13.8 | 15.0 | 14.4 | 14.6 | 13.3 | 14.7 | 15.1 | 17.8 | 12.2 | 13.1 |
| 10 | 13.8 | 15.6 | 16.0 | 16.3 | 16.7 | 16.5 | 15.3 | 17.3 | 13.8 | 16.0 |
| 11 | 15.7 | 15.5 | 14.7 | 16.3 | 15.9 | 15.2 | 13.9 | 17.0 | 15.3 | 15.0 |
| 12 | 12.0 | 15.7 | 17.6 | 18.6 | 16.2 | 15.6 | 15.2 | 19.7 | 14.4 | 15.4 |
| 13 | 15.0 | 16.1 | 17.4 | 18.1 | 16.8 | 16.3 | 16.1 | 15.4 | 15.2 | 16.6 |
| 14 | 16.7 | 16.0 | 15.8 | 17.3 | 18.1 | 17.2 | 15.2 | 15.8 | 15.2 | 14.5 |
| 15 | 17.0 | 16.7 | 15.3 | 17.1 | 17.9 | 15.2 | 12.8 | 16.6 | 15.2 | 16.0 |
| 16 | 16.2 | 15.3 | 15.7 | 17.5 | 17.4 | 14.7 | 15.1 | 17.5 | 14.5 | 17.3 |
| 17 | 15.7 | 14.6 | 14.1 | 14.7 | 15.1 | 14.8 | 15.6 | 17.8 | 15.7 | 17.4 |
| 18 | 15.3 | 14.9 | 13.6 | 13.7 | 14.5 | 14.6 | 15.6 | 18.9 | 13.4 | 14.7 |
| 19 | 14.0 | 16.2 | 12.1 | 15.0 | 12.6 | 14.9 | 15.1 | 16.0 | 12.8 | 11.8 |
| 20 | 12.8 | 12.4 | 10.4 | 14.0 | 13.1 | 11.9 | 13.2 | 15.9 | 14.4 | 11.6 |
| 21 | 13.4 | 14.7 | 12.1 | 13.0 | 13.3 | 12.7 | 10.8 | 9.9 | 10.7 | 9.9 |
| 22 | 10.1 | 10.4 | 14.0 | 12.7 | 12.1 | 10.4 | 11.2 | 7.8 | 10.3 | 8.2 |
| 23 | 10.8 | 9.8 | 10.8 | 9.3 | 9.1 | 7.8 | 9.9 | 8.1 | 10.7 | 7.4 |
| 24 | 12.7 | 9.3 | 7.8 | 7.6 | 7.9 | 8.3 | 7.2 | 7.6 | 7.6 | 5.6 |
| 25 | 7.6 | 8.7 | 7.6 | 7.6 | 7.7 | 5.7 | 7.1 | 6.3 | 4.8 | 6.5 |

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**Appendix 3.** Moisture of soil and leaf litter.

**Figs. 3.1.** through **3.10.**: Gravimetric moisture estimates (means /date, N = 20) for leaf litter, A horizon and B horizon in Test and Control sites. Shown are data for 12 dates /year, at biweekly intervals from early May to October. Sampling date 13 omitted from those years in which a late October sampling was possible.

Figures are arranged sequentially, from 1984 (**Fig. 3.1.**) through 1993 (**Fig. 3.10.**).

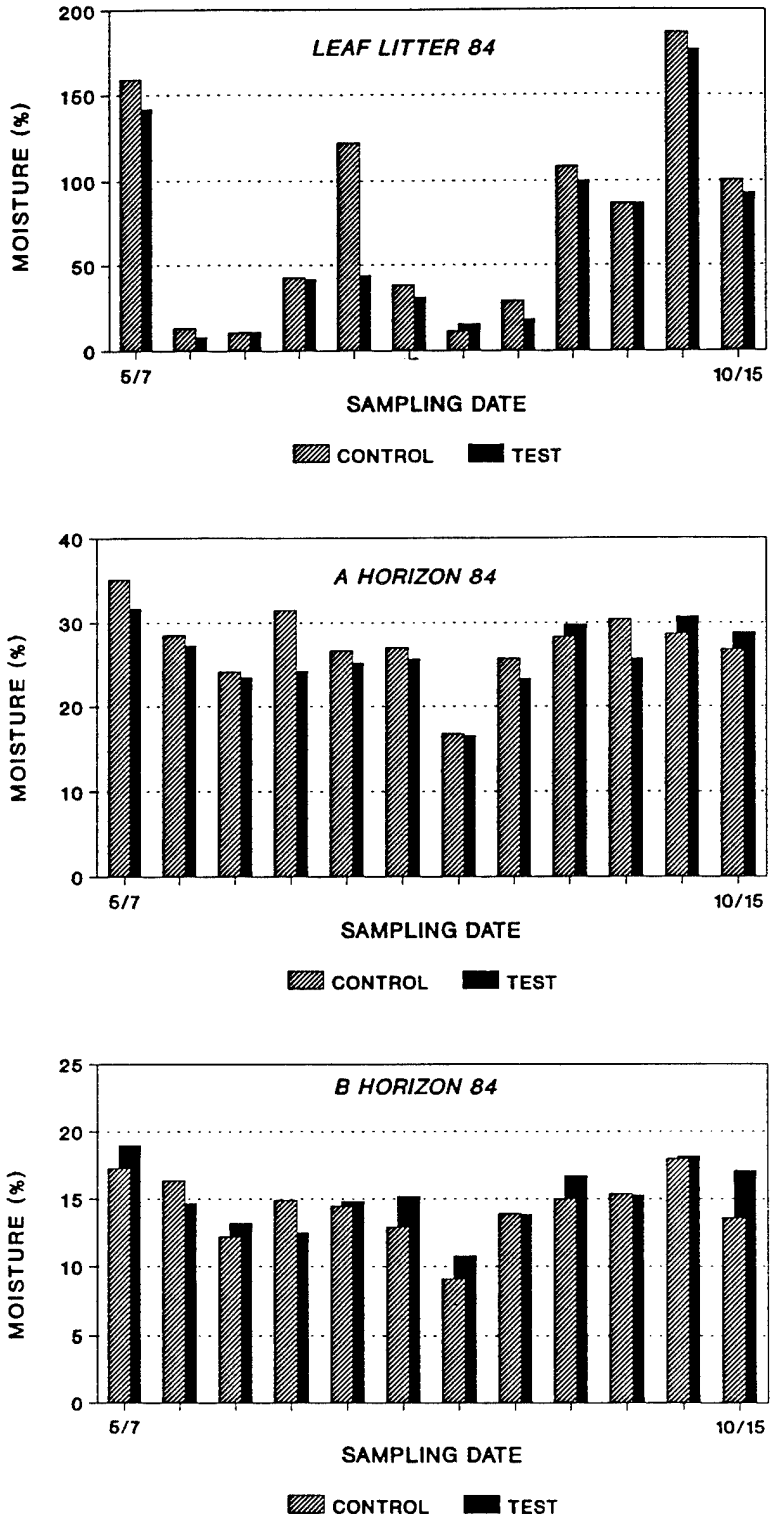


Fig. 3.1. Litter and soil moisture at biweekly intervals, 1984.

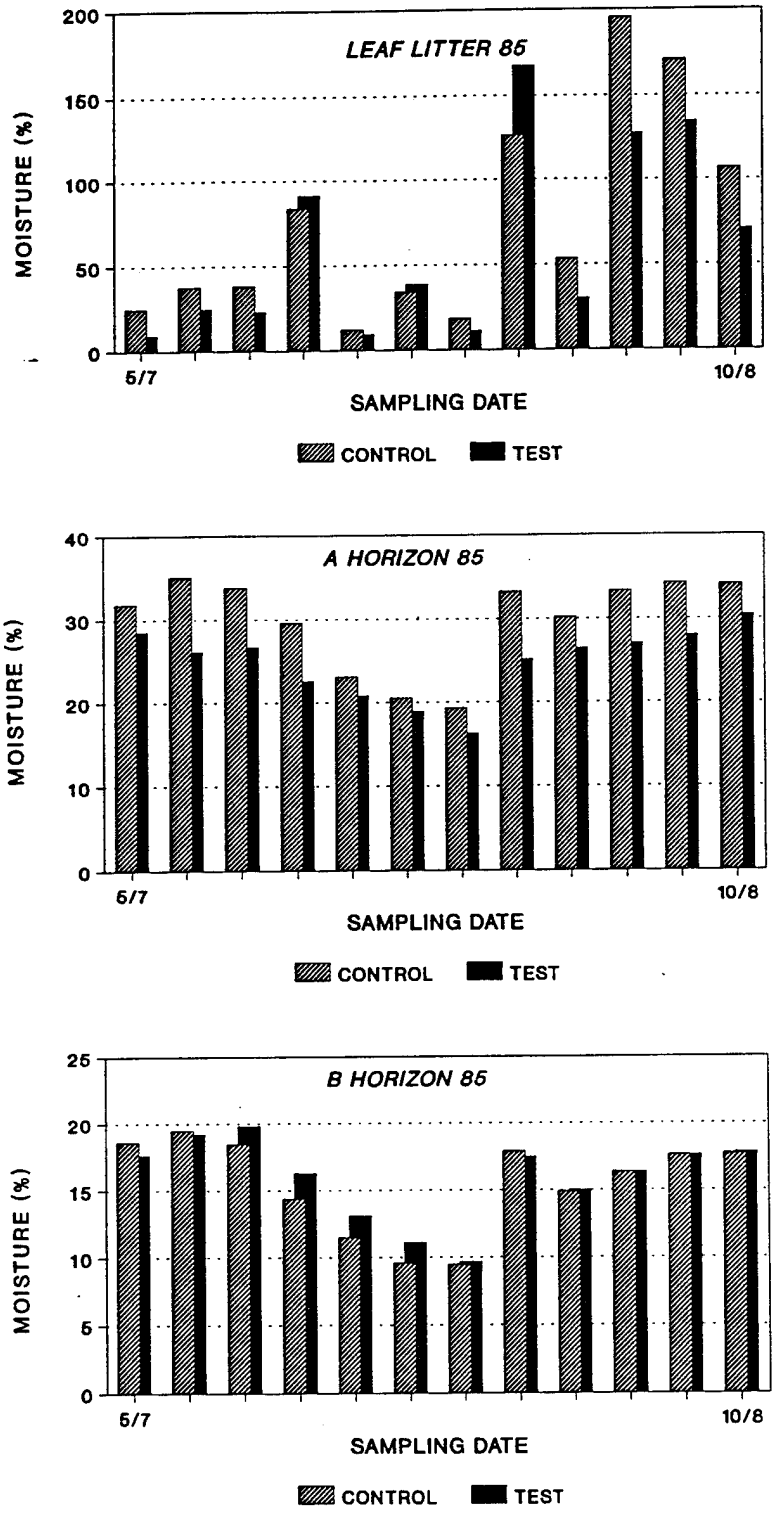


Fig. 3.2. Litter and soil moisture at biweekly intervals, 1985.

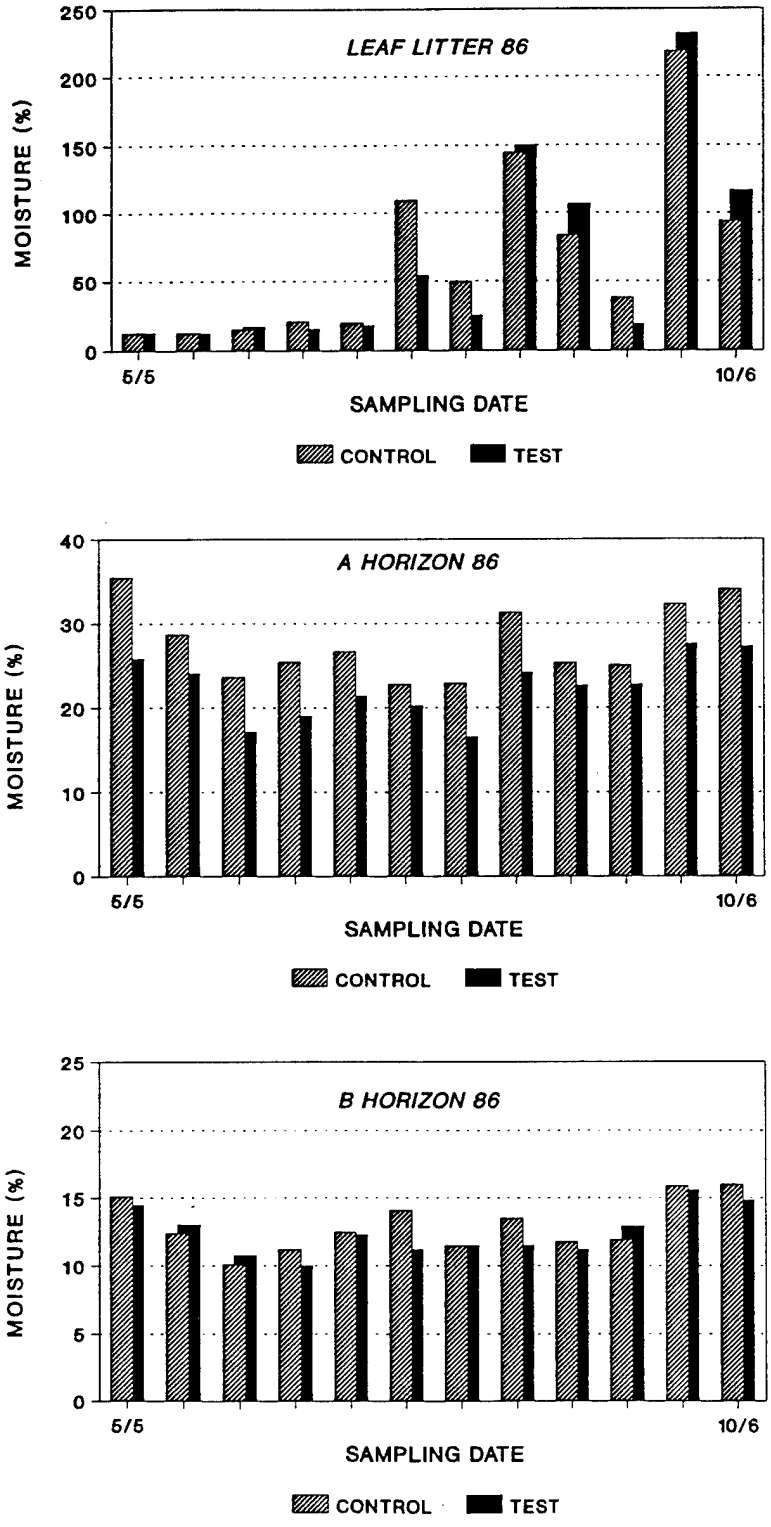


Fig. 3.3. Litter and soil moisture at biweekly intervals, 1986.

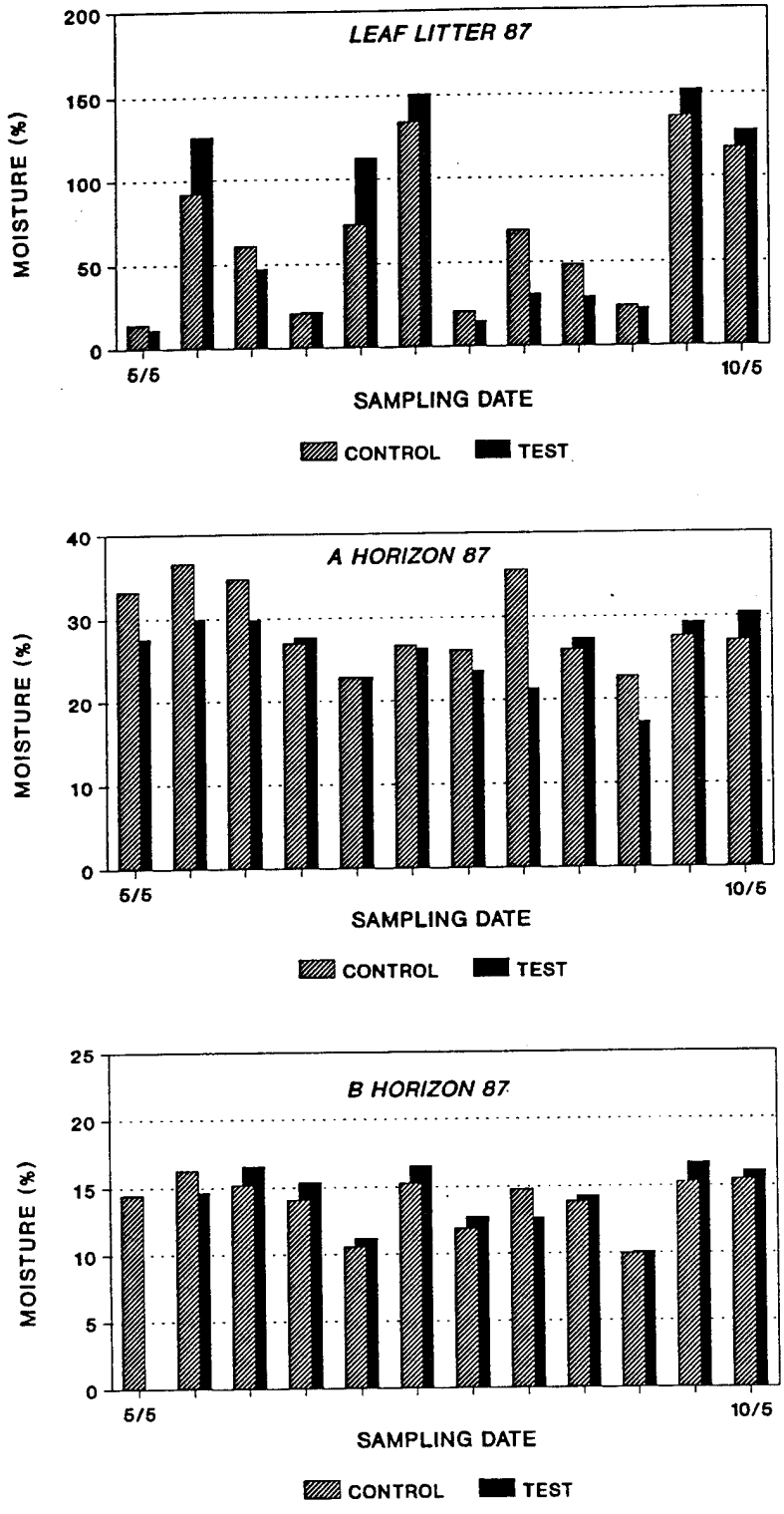


Fig. 3.4. Litter and soil moisture at biweekly intervals, 1987.

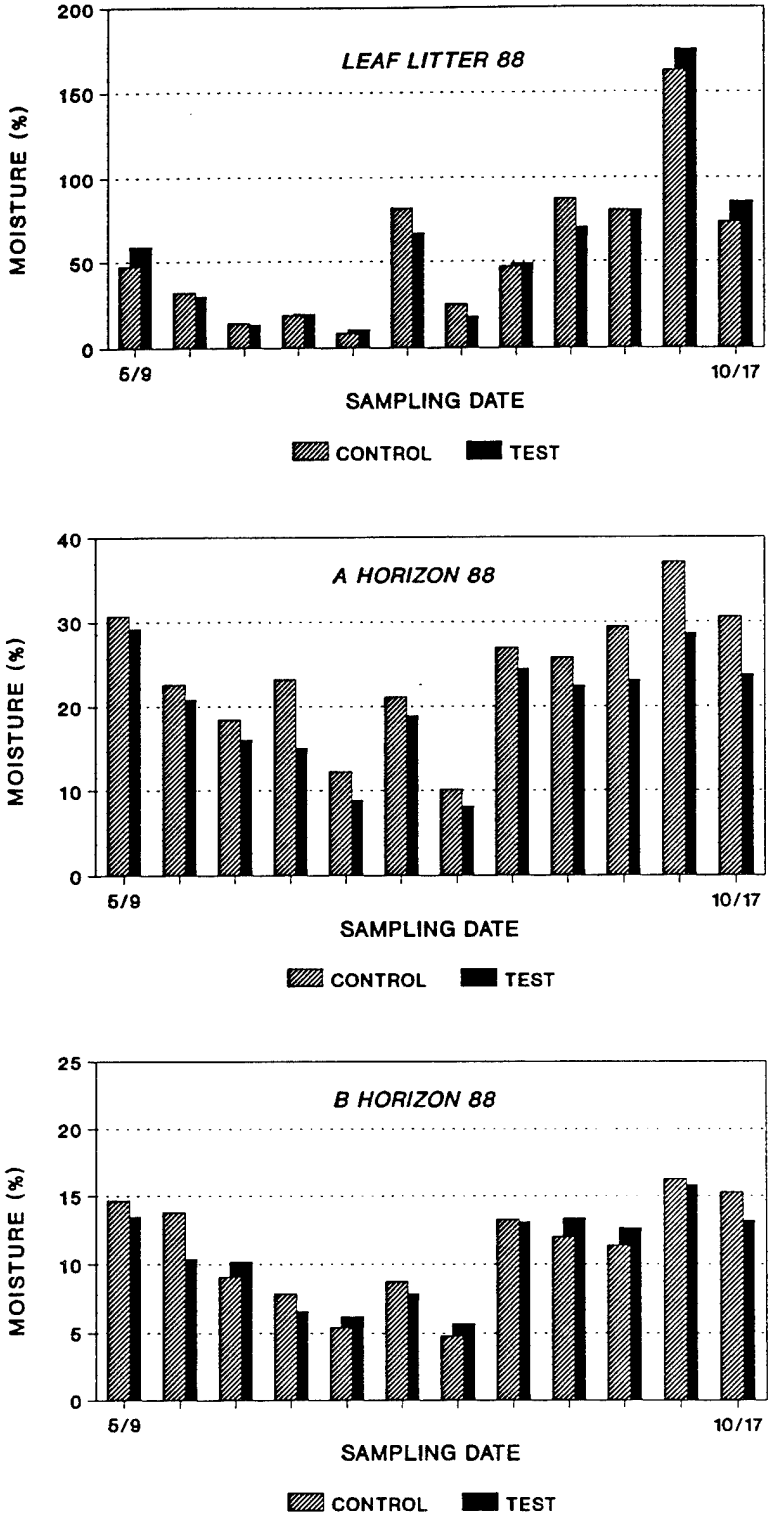


Fig. 3.5. Litter and soil moisture at biweekly intervals, 1988.

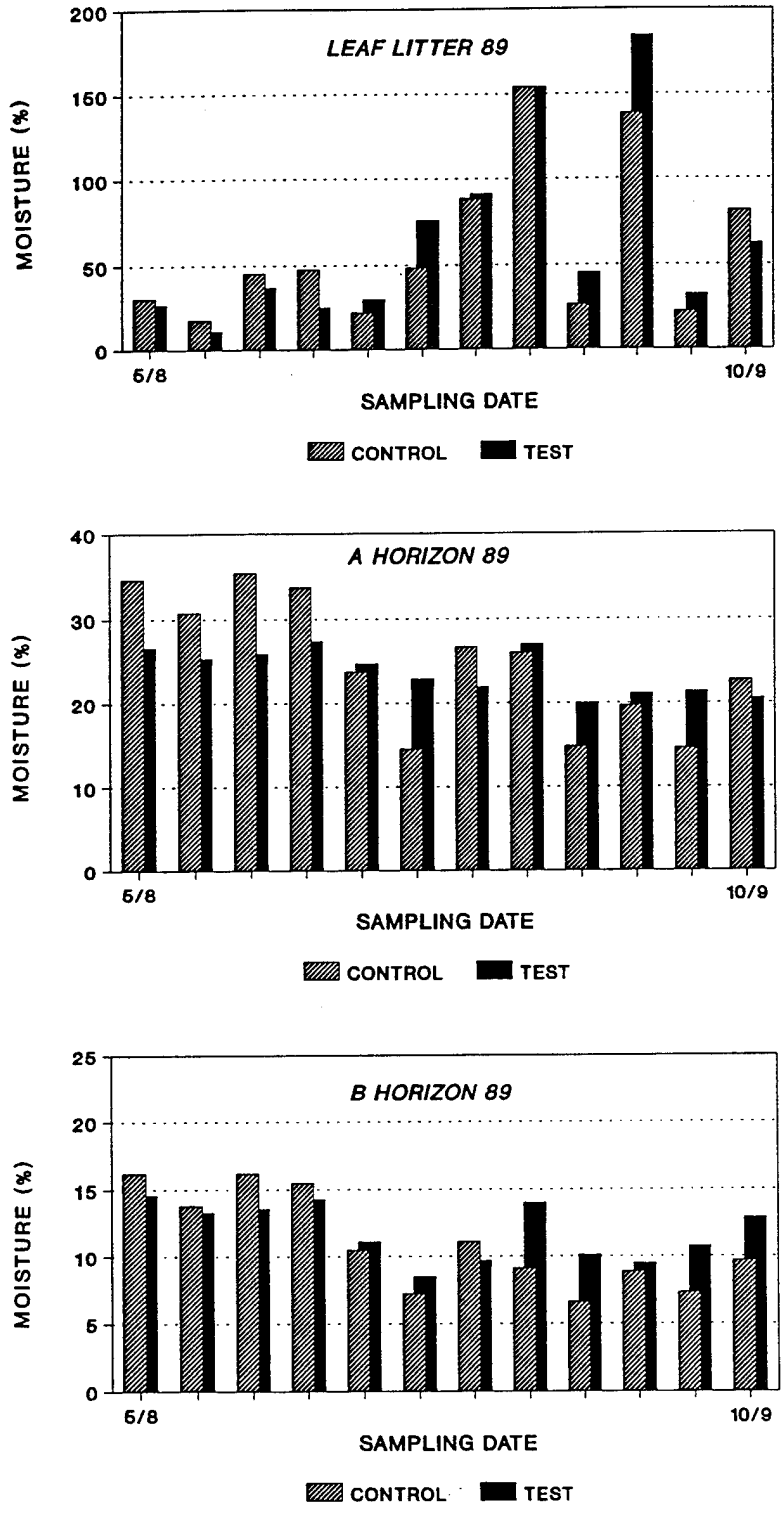


Fig. 3.6. Litter and soil moisture at biweekly intervals, 1989.

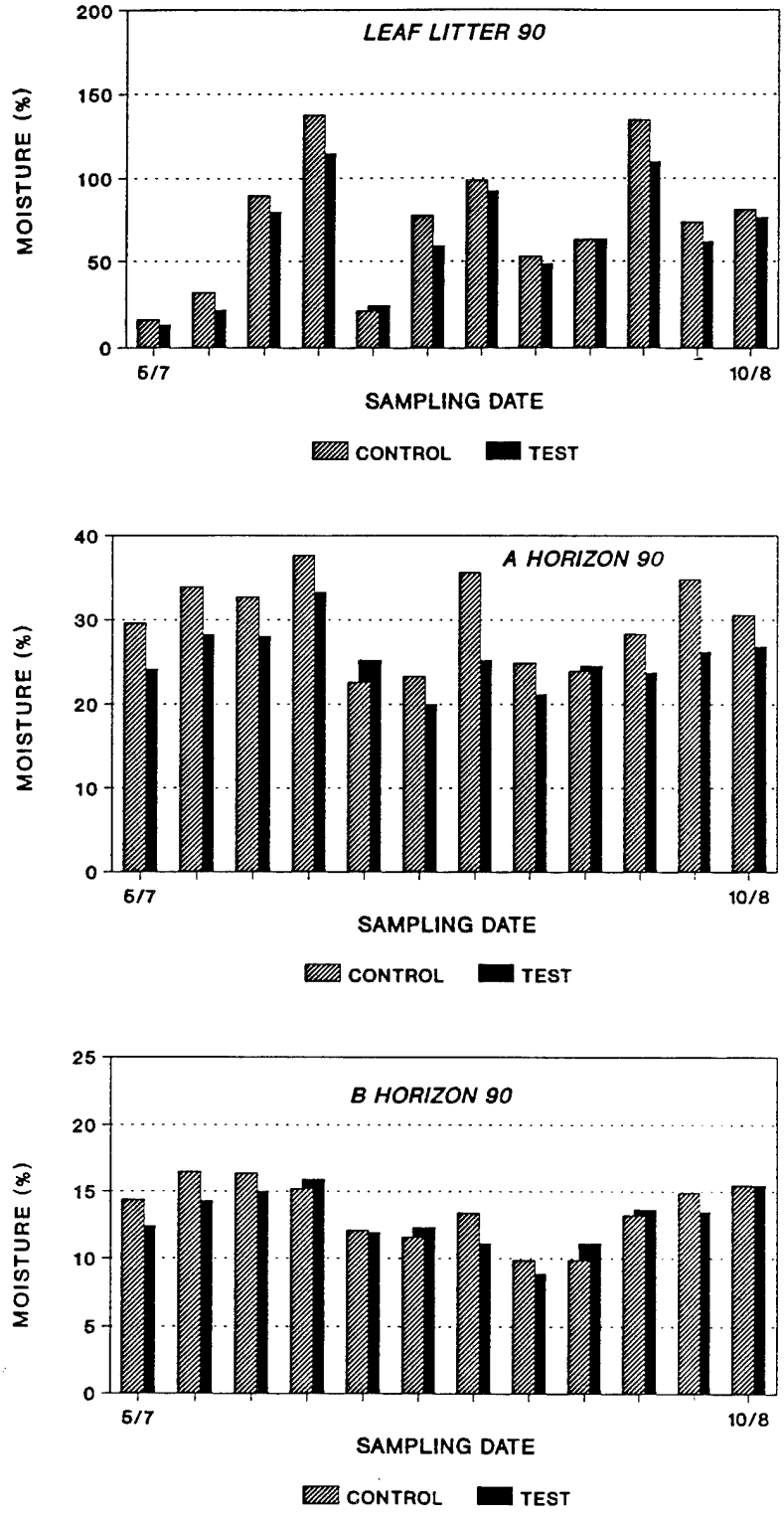


Fig. 3.7. Litter and soil moisture at biweekly intervals, 1990.

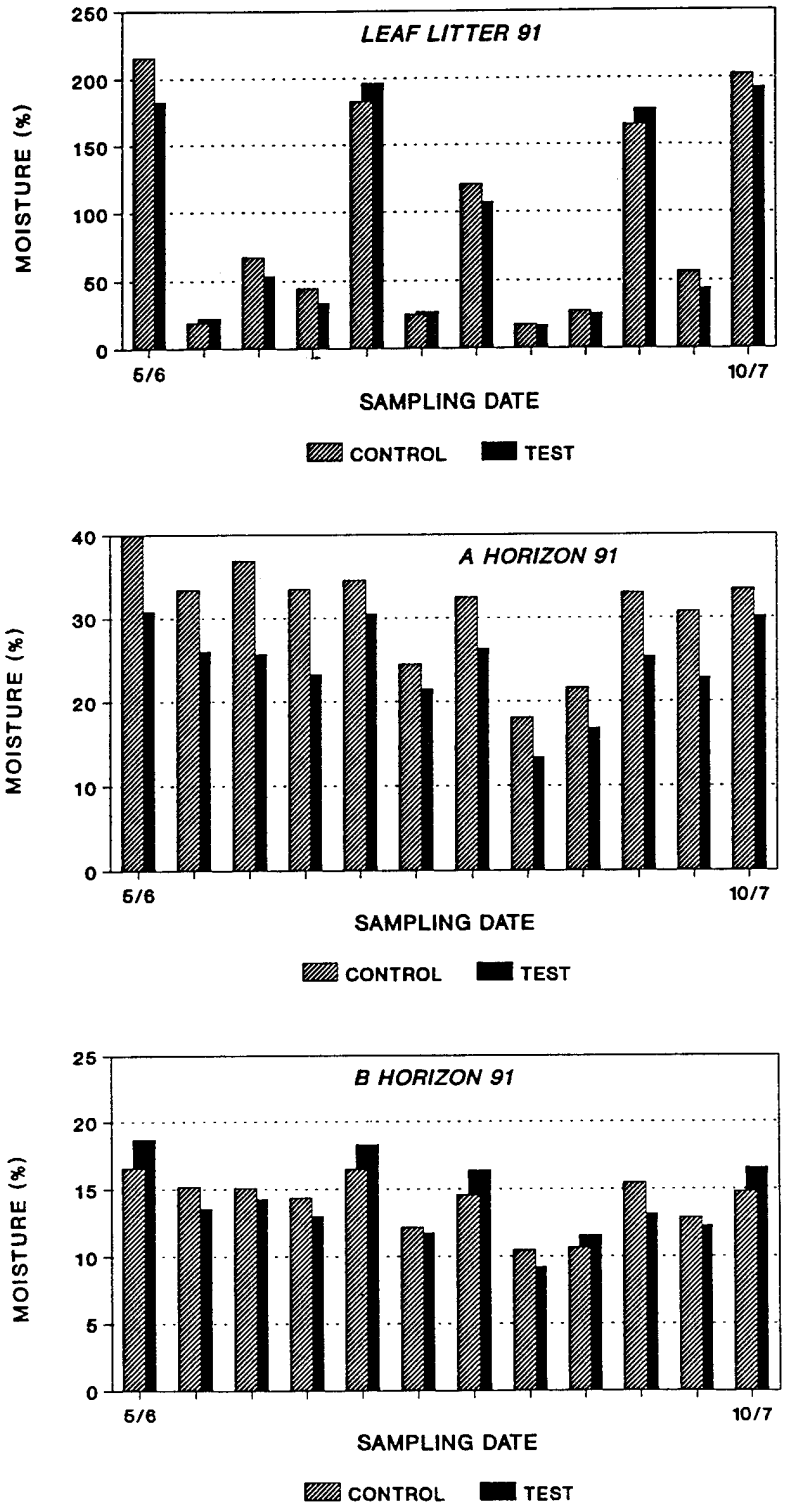


Fig. 3.8. Litter and soil moisture at biweekly intervals, 1991.

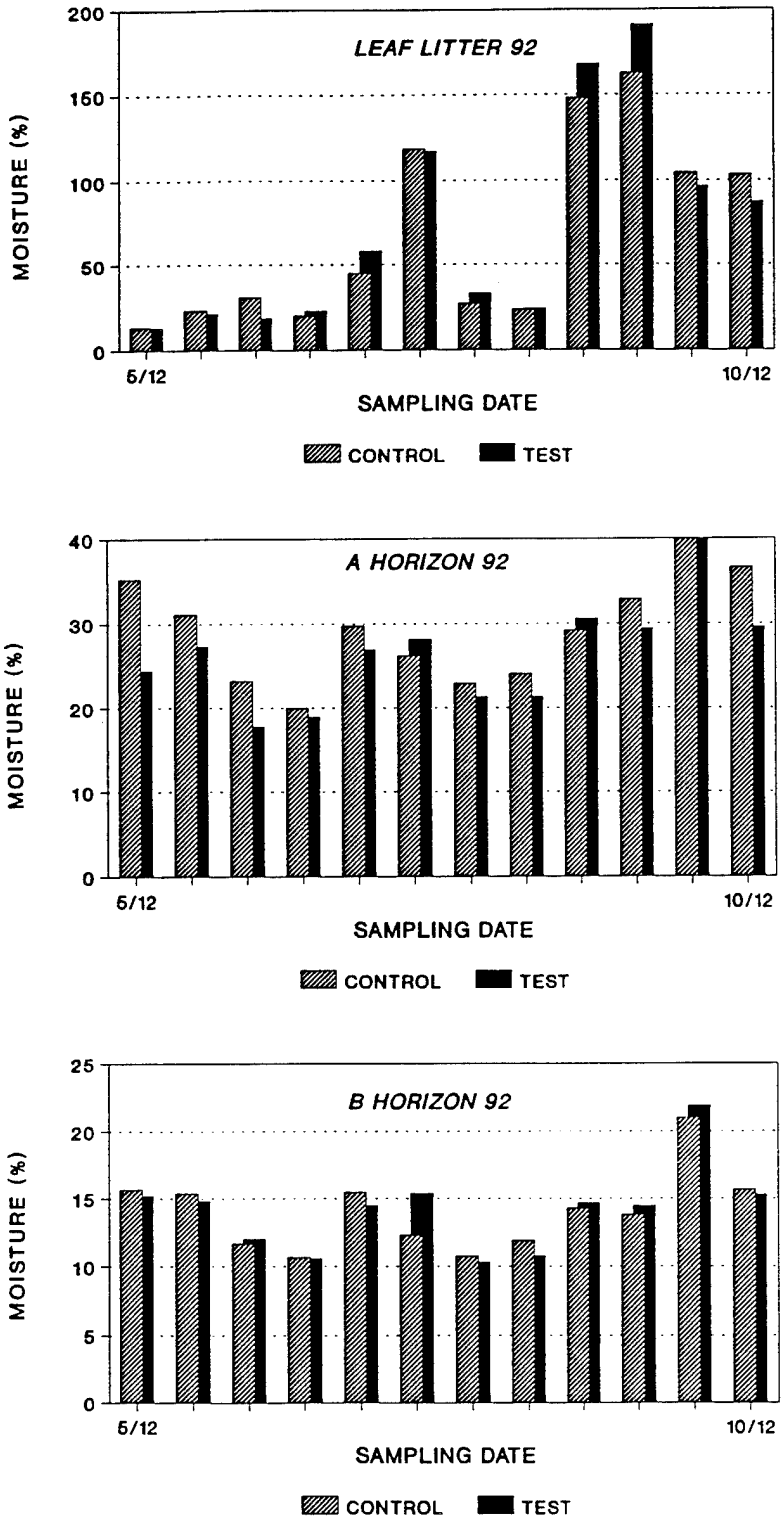


Fig. 3.9. Litter and soil moisture at biweekly intervals, 1992.

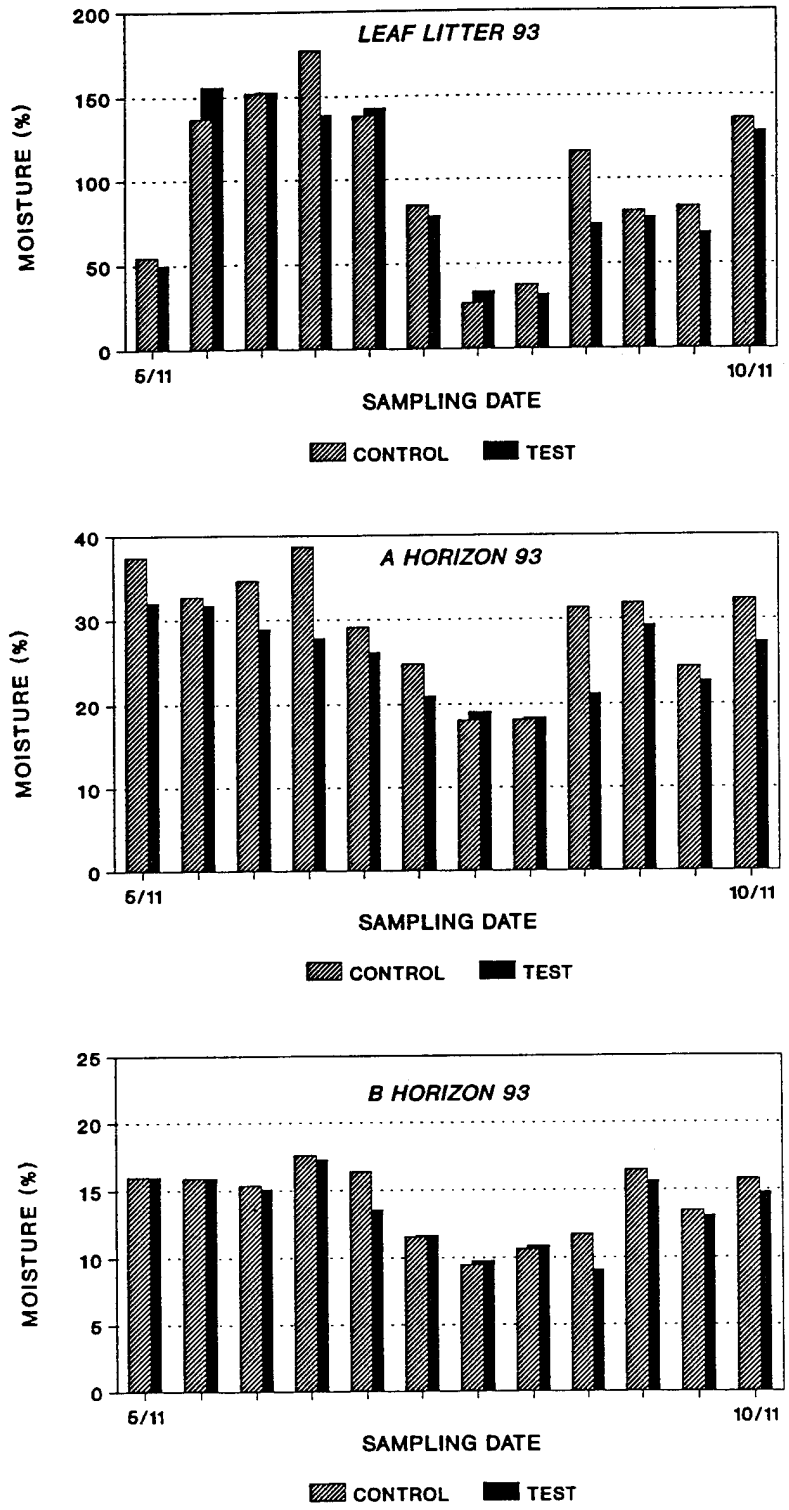


Fig. 3.10. Litter and soil moisture at biweekly intervals, 1993.

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**Appendix 4 .** Checklist of Collembola found in the Project ELF study area.

Order COLLEMBOLA
Suborder ARTHROPLEONA
Family HYPOGASTRURIDAE
Subfamily HYPOGASTRURINAE
*Hypogastrura (Hypogastrura) nivicola* (Fitch)
*Xenylla acauda* Gisin
*Xenylla christianseni* Gama
*Xenylla pallescens* (Scott)
*Willemia denisi* Mills
*Willemia intermedia* Mills
*Willemia similis* Mills

Subfamily NEANURINAE
*Odontella substriata* Wray
*Friesea sublimis* Macnamara
*Pseudachorutes aureofasciatus* (Harvey)
*Pseudachorutes caeca* Folsom
*Pseudachorutes indiana* Christiansen and Bellinger
*Pseudachorutes saxatilis* Macnamara
*Anurida (Anurida) granaria* (Nicolet)
*Anurida (Micranurida) furcifera* (Mills)
*Anurida (Micranurida) pygmaea* (Borner)
*Micranurida spirillifera* Hammer
*Neanura (Neanura) muscorum* (Templeton)
*Neanura (Neanura) barberi* (Handschin)

Family ONYCHIURIDAE
*Onychiurus (Archaphorura) affinis* Agren
*Onychiurus (Archaphorura) allanae* Christiansen and Bellinger
*Onychiurus (Protaphorura) encarpatus* Denis
*Onychiurus (Protaphorura) parvicornis* Mills
*Onychiurus (Protaphorura) similis* Folsom
*Onychiurus (Protaphorura) talus* Christiansen and Bellinger
*Onychiurus (Protaphorura) armatus* (Tullberg)
*Tullbergia clavata* Mills
*Tullbergia falca* Christiansen and Bellinger
*Tullbergia granulata* Mills
*Tullbergia hades* Christiansen and Bellinger
*Tullbergia iowensis* Mills
*Tullbergia mala* Christiansen and Bellinger
*Tullbergia yosiii* Rusek

Family ISOTOMIDAE
*Anurophorus (Anurophorus) altus* Christiansen and Bellinger
*Anurophorus (Anurophorus) septentrionalis* Palissa
*Anurophorus (Pseudanurophorus) binoculatus* (Kneseman)
*Proisotoma (Proisotoma) minima* (Absolon)
*Proisotoma minuta*
*Cryptopygus decemoculatus* (Folsom)
*Cryptopygus exilis* (Gisin)
*Folsomia bisetosa* Gisin
*Folsomia nivalis* (Packard)
*Folsomia prima* Mills
*Isotomiella minor* (Schaeffer)
*Isotoma (Desoria) creli* Fjellberg
*Isotoma (Desoria) nigrifrons* Folsom
*Isotoma (Desoria) notabilis* Schaeffer
*Isotoma (Desoria) nympha* Snider and Calandrino
*Isotoma pseudocinerea* (Fjellberg)
*Isotoma viridis* Bourlet
*Isotoma trispinata* MacGillivray

Family ENTOMOBRYIDAE
*Orchesella ainslei* Folsom
*Orchesella hexfasciata* Harvey
*Entomobrya (Entomobrya) assuta* Folsom
*Entomobrya (Entomobrya) clitellaria* Guthrie
*Entomobrya (Entomobrya) comparata* Folsom
*Entomobrya (Entomobrya) nivalis* (L.)
*Entomobrya (Entomobryoides) purpurascens* (Packard)
*Willowsia buski* (Lubbock)
*Lepidocyrtus helenae* Snider
*Lepidocyrtus hirtus* Christiansen and Bellinger
*Lepidocyrtus lignorum* (Fabricius)
*Lepidocyrtus paradoxus* Uzel
*Lepidocyrtus violaceous* (Fourcroy)
*Pseudosinella rolfsi* Mills
*Pseudosinella violenta* (Folsom)

Family TOMOCERIDAE
*Tomocerus (Pogonognathellus) flavescens* Tullberg
*Tomocerus (Tomocerina) lamelliferus* Mills

Suborder SYMPHYPLEONA

Family NEELIDAE

*Neelus (Megalothorax) minimus* (Willem)
*Neelus (Megalothorax) incertus* (Börner)
*Neelus tristani* (Denis)
*Neelus (Neelides) minutus* (Folsom)
*Neelus (Neelides) snideri* (Bernard)

Family SMINTHURIDAE

*Sminthurides (Sphaeridia) pumilis* Krausbauer
*Sminthurides (Sminthurides) lepus* Mills
*Sminthurides (Sminthurides) occultus* Mills
*Arrhopalites amarus* Christiansen
*Arrhopalites benitus* (Folsom)
*Arrhopalites caecus* (Tullberg)
*Sminthurinus (Katiannina) macgillivrayi* (Banks)
*Sminthurinus (Polykatianna) intermedius* Snider
*Sminthurinus (Sminthurinus) conchyliatus* Snider
*Sminthurinus (Sminthurinus) henshawi* (Folsom)
*Sminthurinus (Sminthurinus) quadrimaculatus* (Ryder)
*Sminthurus (Sminthurus) butcheri* Snider
*Sminthurus (Sminthurus) nigromaculatus* Tullberg
*Sminthurus (Allacma) purpurescens* (MacGillivray)

Family BOURLETIELLIDAE

*Bourletiella (Bourletiella) hortensis* (Fitch)
*Bourletiella (Deuterosminthurus) russata* Maynard
*Bourletiella (Heterosminthurus) koontzi* Snider and Calandrino

Family DICYRTOMIDAE

*Dicyrtoma (Dicyrtoma) aurata* (Mills)
*Dicyrtoma (Ptenothrix) atra* (L.)
*Dicyrtoma (Ptenothrix) marmorata* (Packard)

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**Appendix 5.** Mean annual density /$m^2$ for collembolan species in the Test site (Table 5.1.) and in the Control site (Table 5.2.).

**Table 5.1.** Mean annual density /$m^2$ (densities in soil and litter summed) for single species and family totals of Collembola **in the Test site.** ( + indicates densities of < 1; - indicates that none were obtained). A complete checklist of ELF Project species is given in Appendix 4. **Note**: data for 1984 and 1985 not corrected for efficiency of heat extraction.

| | YEAR | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 |
| TAXON | | | | | | | | | |
| *N. minimus* | - | 145 | 11 | 80 | 13 | 57 | 94 | 130 | 52 |
| *N. minutus* | + | 8 | - | 1 | - | - | - | + | - |
| *N. tristani* | 257 | 4 | 8 | - | - | - | - | 4 | - |
| *N. snideri* | - | + | - | - | - | - | - | - | - |
| NEELIDAE TOTAL | 257 | 157 | 19 | 81 | 13 | 57 | 94 | 134 | 52 |
| *S. henshawi* | 153 | 259 | 224 | 198 | 356 | 180 | 305 | 187 | 116 |
| *S. lepus* | 8 | 18 | 13 | 54 | 40 | 39 | 21 | 37 | 8 |
| *S. macgillivrayi* | 8 | 28 | 12 | 8 | 10 | 37 | 22 | 11 | 6 |
| *A. amarus* | 31 | 22 | 12 | 72 | 6 | 3 | 22 | 23 | 9 |
| *A. benitus* | 68 | 146 | 34 | 40 | 16 | 22 | 16 | 8 | + |
| *A. caecus* | - | - | + | 42 | 17 | 24 | 36 | 8 | 1 |
| *S. conchyliatus* | - | - | - | - | - | - | - | + | - |
| *S. pumilis* | - | - | - | - | - | - | - | + | - |
| *S. intermedius* | - | - | - | - | - | - | - | - | - |
| *S. quadrimaculatus* | - | - | - | - | - | - | - | - | - |
| SMINTHURIDAE TOTAL | 268 | 473 | 295 | 414 | 445 | 311 | 423 | 274 | 140 |
| *B. russata* | - | - | + | - | - | - | - | - | - |
| *B. atra* | - | - | - | - | - | - | - | - | - |
| *B. hortensis* | - | - | - | - | - | - | - | - | - |
| BOURLETIELLIDAE TOTAL | - | - | + | - | - | - | - | - | - |
| *D. aurata* | - | - | - | 4 | 4 | - | - | + | - |
| *D. marmorata* | - | - | - | - | 4 | + | + | - | - |
| DICYRTOMIDAE TOTAL | - | - | - | 4 | 8 | + | + | + | - |

**Table 5.1. continued:**

| | YEAR | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 |
| TAXON | | | | | | | | | |
| *W. intermedia* | - | 58 | 236 | 428 | 221 | 266 | 247 | 351 | 200 |
| *W. similis* | - | 77 | 162 | 281 | 183 | 308 | 327 | 300 | 354 |
| *A. furcifera* | - | 38 | 50 | 35 | 38 | 4 | 19 | 4 | - |
| *N. muscorum* | 14 | 31 | 48 | 71 | 69 | 21 | 50 | 22 | 6 |
| *A. pygmaea* | + | 4 | 12 | 58 | 25 | 54 | 31 | 50 | 50 |
| *X. acauda* | 4 | - | - | - | + | + | - | + | - |
| *X. pallescens* | - | 1 | + | + | 3 | 10 | 2 | + | 3 |
| *P. caeca* | - | - | 1 | - | - | - | 8 | - | - |
| *F. sublimis* | - | + | - | - | - | - | - | - | - |
| *W. denisi* | - | - | 8 | - | - | - | - | - | - |
| *M. spirillifera* | - | - | 8 | - | - | - | - | - | - |
| *A. granaria* | 4 | - | - | - | - | - | - | - | - |
| *O. substriata* | - | - | - | - | - | - | - | - | - |
| *N. barberi* | - | - | - | - | - | - | - | - | - |
| *X. christianseni* | - | - | - | - | - | - | - | - | - |
| *Pseudachorutes spp.* | 10 | 4 | 4 | + | - | 32 | 132 | 23 | 4 |
| HYPOGASTRURIDAE TOTAL | 32 | 213 | 529 | 874 | 539 | 695 | 816 | 754 | 617 |
| *T. mala* | 1080 | 1708 | 2343 | 4554 | 4055 | 5177 | 1896 | 3288 | 4458 |
| *T. granulata* | 1332 | 1286 | 3551 | 5563 | 4547 | 4476 | 3400 | 4027 | 2958 |
| *T. iowensis* | - | 359 | 1554 | 2449 | 2356 | 1879 | 2123 | 2506 | 2088 |
| *T. clavata* | 104 | 246 | 746 | 723 | 321 | 681 | 535 | 519 | 279 |
| *T. yosiii* | 288 | 100 | 25 | 78 | 18 | 39 | 58 | 39 | 52 |
| *T. falca* | - | 81 | 42 | 208 | 371 | 654 | 320 | 327 | 179 |
| *O. similis* | 50 | 35 | 269 | 165 | 183 | 85 | 158 | 73 | 54 |
| *O. encarpatus* | - | - | - | 8 | 38 | - | - | - | - |
| *O. affinis* | - | - | 8 | 4 | - | 4 | - | - | - |
| *O. armatus* | - | - | - | 4 | - | - | 11 | 27 | 17 |
| *O. talus* | - | - | - | - | - | - | 4 | - | - |
| *T. hades* | - | 4 | - | - | 4 | - | - | - | - |
| *O. parvicornis* | - | - | - | - | - | - | - | - | - |
| ONYCHIURIDAE TOTAL | 2854 | 3819 | 8538 | 13756 | 11893 | 12995 | 8505 | 10806 | 10085 |

**Table 5.1. continued:**

| | YEAR | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 |
| TAXON | | | | | | | | | |
| *I. notabilis* | 1141 | 1684 | 1782 | 2220 | 1076 | 1661 | 2383 | 1749 | 1401 |
| *I. minor* | 242 | 158 | 408 | 304 | 137 | 393 | 350 | 415 | 196 |
| *F. bisetosa* | - | 162 | 171 | 94 | 34 | 66 | 46 | 162 | 387 |
| *F. nivalis* | 9 | 90 | 97 | 232 | 80 | 12 | 146 | 51 | 17 |
| *A. binoculatus* | 30 | 41 | 23 | 31 | 18 | 16 | 21 | 100 | 8 |
| *I. nigrifrons* | 90 | 91 | 18 | 67 | 5 | 18 | 11 | 4 | 1 |
| *P. minima* | 15 | 11 | 12 | 43 | 14 | 17 | 6 | 35 | 13 |
| *I. viridis* | 5 | 19 | 75 | 66 | 30 | 20 | 32 | 21 | 15 |
| *A. septemtrionalis* | - | - | - | - | 6 | - | - | 4 | - |
| *C. exilis* | - | 4 | - | 42 | - | 12 | 19 | - | 4 |
| *C. decemoculatus* | 5 | - | - | - | - | 4 | 8 | - | - |
| *I. pseudocinerea* | - | 3 | - | - | - | - | - | - | - |
| *F. prima* | - | - | - | - | - | 1 | 9 | - | - |
| *I. nympha* | - | - | - | - | - | - | - | 1 | - |
| *A. altus* | - | - | - | - | - | - | - | - | - |
| ISOTOMIDAE TOTAL | 1537 | 2263 | 2586 | 3099 | 1400 | 2219 | 3031 | 2542 | 2042 |
| *O. hexfasciata* | 107 | 195 | 234 | 528 | 170 | 42 | 124 | 197 | 72 |
| *E. comparata* | 19 | 37 | 84 | 128 | 72 | 46 | 39 | 25 | 28 |
| *P. violenta* | 353 | 278 | 395 | 722 | 357 | 325 | 391 | 160 | 42 |
| *E. nivalis* | 23 | 40 | 69 | 19 | 40 | 45 | 47 | 41 | 17 |
| *L. helenae* | 3 | 5 | 4 | 8 | 10 | 2 | 6 | 6 | + |
| *L. violaceous* | 4 | 12 | 8 | 18 | 21 | 10 | 16 | 9 | 21 |
| *W. buski* | + | 12 | 46 | 74 | 30 | 52 | 31 | 38 | 18 |
| *E. purpurascens* | 4 | + | 4 | 4 | + | - | 1 | + | - |
| *L. lignorum* | + | + | 4 | 4 | 9 | + | 4 | + | 4 |
| *E. assuta* | - | - | - | - | - | - | - | - | - |
| *O. ainsliei* | - | - | - | - | - | - | - | - | - |
| ENTOMOBRYIDAE TOTAL | 514 | 580 | 848 | 1505 | 709 | 522 | 659 | 476 | 272 |
| *T. flavescens* | 219 | 440 | 495 | 876 | 277 | 175 | 246 | 206 | 69 |
| *T. lamelliferus* | 89 | 45 | 73 | 182 | 49 | 11 | 40 | 80 | 7 |
| TOMOCERIDAE TOTAL | 308 | 485 | 568 | 1058 | 326 | 186 | 286 | 286 | 76 |
| **COLLEMBOLA TOTAL** | 5770 | 7990 | 13387 | 20791 | 15333 | 16985 | 13814 | 15272 | 13211 |

**Table 5.2.** Mean annual density /$m^2$ (densities in soil and litter summed) for single species and family totals of Collembola **in the Control site.** ( + indicates densities of < 1; - indicates that none were obtained). A complete checklist of ELF Project species is given in Appendix 4. **Note**: data for 1984 and 1985 not corrected for efficiency of heat extraction.

| | YEAR | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 |
| TAXON | | | | | | | | | |
| *N. minimus* | - | 137 | 270 | 259 | 111 | 109 | 153 | 174 | 116 |
| *N. minutus* | 17 | 4 | 15 | 18 | 5 | - | - | 4 | 4 |
| *N. tristani* | 208 | + | 2 | + | - | 39 | - | 5 | - |
| *N. snideri* | - | 36 | 6 | 4 | - | - | 1 | 8 | - |
| NEELIDAE TOTAL | 225 | 177 | 293 | 281 | 116 | 148 | 154 | 191 | 120 |
| *S. henshawi* | 186 | 301 | 357 | 321 | 325 | 201 | 240 | 148 | 139 |
| *S. lepus* | 1 | 8 | 9 | 27 | 23 | 18 | 5 | 6 | 10 |
| *S. macgillivrayi* | 1 | 2 | 4 | 10 | 3 | 36 | 23 | 12 | 14 |
| *A. amarus* | 20 | 25 | 5 | 4 | 35 | 11 | 24 | 19 | 11 |
| *A. benitus* | 23 | 146 | 58 | + | 1 | 16 | 5 | 4 | + |
| *A. caecus* | - | - | 35 | 35 | 4 | 27 | 23 | 4 | + |
| *S. conchyliatus* | - | - | - | - | - | - | - | - | - |
| *S. pumilis* | - | - | - | - | - | - | - | - | - |
| *S. intermedius* | - | - | 12 | - | - | - | - | - | - |
| *S. quadrimaculatus* | + | - | - | - | - | - | - | - | - |
| SMINTHURIDAE TOTAL | 236 | 482 | 480 | 397 | 391 | 308 | 316 | 193 | 174 |
| *B. russata* | + | - | - | - | - | 4 | - | - | - |
| *B. atra* | - | - | + | - | - | - | - | - | - |
| *B. hortensis* | + | - | - | - | - | - | - | 4 | - |
| BOURLETIELLIDAE TOTAL | + | - | + | - | - | 4 | - | 4 | - |
| *D. aurata* | 16 | 13 | 9 | 19 | 8 | 6 | 8 | 6 | 5 |
| *D. marmorata* | - | + | 1 | 55 | 1 | 1 | + | + | 1 |
| DICYRTOMIDAE TOTAL | 16 | 13 | 10 | 74 | 9 | 7 | 8 | 6 | 6 |

**Table 5.2. continued:**

| | YEAR | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 |
| TAXON | | | | | | | | | |
| *W. intermedia* | - | 86 | 270 | 616 | 287 | 266 | 609 | 266 | 368 |
| *W. similis* | - | + | 69 | 227 | 237 | 246 | 693 | 142 | 596 |
| *A. furcifera* | - | 112 | 212 | 466 | 134 | 190 | 227 | 200 | 212 |
| *N. muscorum* | 24 | 107 | 26 | 165 | 16 | 27 | 94 | 56 | 10 |
| *A. pygmaea* | 8 | 8 | 100 | 155 | 42 | 82 | 127 | 19 | 42 |
| *X. acauda* | 86 | + | - | - | + | 8 | - | - | + |
| *X. pallescens* | - | 8 | 5 | - | 6 | 7 | 15 | 4 | 2 |
| *P. caeca* | - | 8 | - | 1 | 5 | - | 4 | + | - |
| *F. sublimis* | - | 25 | 24 | 8 | + | 8 | 4 | - | - |
| *W. denisi* | - | - | - | - | - | - | - | - | - |
| *M. spirillifera* | - | - | - | - | - | - | - | - | - |
| *A. granaria* | 85 | - | + | - | - | - | - | - | - |
| *O. substriata* | - | 23 | - | - | - | 8 | - | - | - |
| *N. barberi* | - | - | + | - | - | - | - | - | - |
| *X. christianseni* | - | - | + | - | - | - | - | - | - |
| *Pseudachorutes spp.* | 51 | 10 | 20 | 4 | - | 9 | 19 | 4 | - |
| HYPOGASTRURIDAE TOTAL | 254 | 387 | 726 | 1642 | 728 | 851 | 1792 | 695 | 1743 |
| *T. mala* | 5850 | 4382 | 17870 | 24347 | 17138 | 17935 | 13746 | 8215 | 10454 |
| *T. granulata* | 1421 | 1459 | 5658 | 11254 | 7721 | 6166 | 7027 | 4708 | 5638 |
| *T. iowensis* | - | 193 | 589 | 4188 | 2767 | 6693 | 7096 | 2467 | 4408 |
| *T. clavata* | 196 | 204 | 673 | 1989 | 742 | 535 | 519 | 219 | 321 |
| *T. yosiii* | 195 | 47 | 169 | 631 | 112 | 172 | 408 | 101 | 51 |
| *T. falca* | - | - | - | - | 13 | - | 15 | 8 | 1 |
| *O. similis* | 188 | 112 | 596 | 916 | 321 | 185 | 173 | 112 | 75 |
| *O. encarpatus* | 34 | - | 1 | - | - | - | - | - | - |
| *O. affinis* | - | 29 | 47 | 88 | 45 | 21 | 8 | 17 | 69 |
| *O. armatus* | - | - | - | - | - | 31 | + | + | - |
| *O. talus* | - | - | - | 12 | - | - | - | - | - |
| *T. hades* | - | - | - | - | - | - | - | - | - |
| *O. parvicornis* | - | 16 | - | - | - | - | - | - | - |
| ONYCHIURIDAE TOTAL | 7884 | 6442 | 25603 | 43425 | 28860 | 31739 | 28992 | 15847 | 21017 |

**Table 5.2. continued:**

| | YEAR | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 | 1992 |
| TAXON | | | | | | | | | |
| *I. notabilis* | 1628 | 2940 | 2690 | 3739 | 1542 | 2210 | 2138 | 1175 | 1362 |
| *I. minor* | 375 | 143 | 292 | 541 | 200 | 224 | 323 | 383 | 404 |
| *F. bisetosa* | 4 | 259 | 193 | 280 | 114 | 222 | 433 | 321 | 358 |
| *F. nivalis* | 223 | 194 | 178 | 179 | 127 | 427 | 429 | 269 | 249 |
| *A. binoculatus* | 77 | 88 | 101 | 152 | 41 | 48 | 62 | 37 | 62 |
| *I. nigrifrons* | 55 | 21 | 32 | + | 25 | - | + | + | + |
| *P. minima* | 49 | 90 | 5 | 44 | 90 | 22 | 65 | 185 | 9 |
| *I. viridis* | - | + | + | - | + | - | 7 | - | - |
| *A. septemtrionalis* | 315 | - | 66 | 46 | 24 | 69 | 3 | + | 1 |
| *C. exilis* | - | 15 | - | 15 | 12 | 42 | 4 | 8 | 54 |
| *C. decemoculatus* | - | - | - | - | - | 8 | 4 | - | + |
| *I. pseudocinerea* | - | - | - | - | - | - | - | - | - |
| *F. prima* | - | - | - | - | - | - | - | 4 | - |
| *I. nympha* | + | - | + | - | - | - | + | - | 1 |
| *A. altus* | - | 186 | 14 | - | - | - | 4 | 4 | - |
| ISOTOMIDAE TOTAL | 2727 | 3961 | 3595 | 5004 | 2175 | 3272 | 3472 | 2386 | 2502 |
| *O. hexfasciata* | 50 | 39 | 28 | 73 | 95 | 70 | 101 | 25 | 13 |
| *E. comparata* | 80 | 82 | 34 | 58 | 222 | 255 | 265 | 67 | 19 |
| *P. violenta* | - | - | 8 | + | - | + | 4 | - | - |
| *E. nivalis* | 5 | 4 | 8 | 4 | 8 | 20 | 12 | 10 | 2 |
| *L. helenae* | 11 | 7 | 8 | 1 | 8 | 16 | 7 | + | 1 |
| *L. violaceous* | 4 | - | + | 1 | - | + | 7 | + | 1 |
| *W. buski* | 17 | 4 | 12 | 29 | 39 | 51 | 58 | 39 | 47 |
| *E. purpurascens* | 1 | + | 12 | 23 | - | - | 12 | - | + |
| *L. lignorum* | - | - | - | - | - | - | - | + | - |
| *E. assuta* | - | - | - | - | - | - | + | - | - |
| *O. ainsliei* | - | - | - | - | - | - | - | 4 | - |
| ENTOMOBRYIDAE TOTAL | 168 | 137 | 110 | 189 | 372 | 412 | 466 | 145 | 83 |
| *T. flavescens* | 34 | 51 | 59 | 24 | 142 | 12 | 37 | 11 | 1 |
| *T. lamelliferus* | 16 | 1 | 4 | - | - | - | - | + | - |
| TOMOCERIDAE TOTAL | 50 | 52 | 63 | 24 | 142 | 12 | 37 | 11 | 1 |
| **COLLEMBOLA TOTAL** | 11555 | 11626 | 30856 | 51028 | 32793 | 36752 | 35238 | 19478 | 25648 |

**Appendix 6.** Population structure of *Isotoma notabilis*.

**Table 6.1.** Mean (±SD) annual densities of *Isotoma notabilis* in Test and Control sites, based on summed densities in litter + soil (N = N dates /year).
CNI, CNJuv, CNAdl, CNTotal, and TNI, TNJuv, TNAdl, TNTot = density /$m^2$ of instars I, larger juveniles, adults, and total population in Control and Test sites respectively.

| | | DENSITIES | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| YEAR | STATS | CNI | CNJuv | CNAdl | CNTot | TNI | TNJuv | TNAdl | TNTot |
| 1984 | N | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| | MEAN | 313.3 | 620.0 | 545.9 | 1479.2 | 207.8 | 438.0 | 330.3 | 976.1 |
| | SD | 258.2 | 397.9 | 428.7 | 717.2 | 141.8 | 374.8 | 260.4 | 612.2 |
| 1985 | N | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 |
| | MEAN | 478.3 | 868.1 | 1235.8 | 2582.3 | 342.0 | 670.5 | 673.8 | 1686.3 |
| | SD | 330.1 | 475.0 | 674.2 | 1188.2 | 298.7 | 431.8 | 545.8 | 915.6 |
| 1986 | N | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 |
| | MEAN | 629.1 | 1001.4 | 810.1 | 2440.6 | 326.5 | 687.6 | 464.0 | 1478.1 |
| | SD | 661.5 | 1014.9 | 542.2 | 2008.5 | 534.3 | 753.6 | 365.0 | 1343.8 |
| 1987 | N | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 |
| | MEAN | 799.9 | 1363.8 | 1049.0 | 3212.7 | 471.4 | 923.9 | 537.4 | 1932.7 |
| | SD | 887.9 | 1058.9 | 703.5 | 2066.7 | 444.9 | 619.7 | 397.0 | 1244.0 |
| 1988 | N | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| | MEAN | 302.8 | 613.8 | 514.9 | 1431.5 | 205.1 | 453.2 | 289.1 | 947.4 |
| | SD | 298.2 | 734.2 | 274.0 | 1087.7 | 230.8 | 295.1 | 137.7 | 545.3 |
| 1989 | N | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 |
| | MEAN | 723.7 | 650.0 | 604.2 | 1977.8 | 379.9 | 514.2 | 498.2 | 1392.2 |
| | SD | 600.9 | 325.6 | 358.1 | 926.4 | 400.1 | 300.8 | 385.5 | 894.6 |
| 1990 | N | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 |
| | MEAN | 500.5 | 793.0 | 639.4 | 1932.9 | 565.6 | 1017.3 | 687.7 | 2270.5 |
| | SD | 438.6 | 411.3 | 302.9 | 984.2 | 262.1 | 449.4 | 241.2 | 760.6 |
| 1991 | N | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 |
| | MEAN | 307.2 | 462.5 | 330.1 | 1099.8 | 390.2 | 672.4 | 393.4 | 1455.9 |
| | SD | 264.4 | 358.8 | 269.0 | 685.2 | 452.4 | 629.3 | 309.8 | 1241.8 |
| 1992 | N | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| | MEAN | 250.2 | 372.5 | 367.3 | 990.0 | 209.6 | 506.6 | 364.1 | 1080.3 |
| | SD | 271.3 | 205.4 | 242.0 | 589.5 | 186.6 | 281.8 | 228.9 | 549.8 |

**Table 6.1. continued.**

| YEAR | STATS | DENSITIES | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | CNI | CNJuv | CNAdl | CNTot | TNI | TNJuv | TNAdl | TNTot |
| 1984-88 | N | 63 | 63 | 63 | 63 | 63 | 63 | 63 | 63 |
| | MEAN | 510.9 | 902.2 | 840.7 | 2253.8 | 313.9 | 640.6 | 463.6 | 1418.2 |
| | SD | 568.0 | 813.8 | 604.9 | 1628.4 | 365.7 | 541.3 | 386.1 | 1040.5 |
| 1989-92 | N | 51 | 51 | 51 | 51 | 51 | 51 | 51 | 51 |
| | MEAN | 449.2 | 573.4 | 487.6 | 1510.2 | 389.8 | 680.9 | 488.2 | 1558.9 |
| | SD | 448.2 | 364.9 | 320.2 | 916.3 | 357.1 | 476.1 | 317.1 | 981.9 |

**Table 6.2.** Mean (± SD) annual proportions of total *Isotoma notabilis* populations in three developmental stages. N = N dates /year.
CPI, CPJuv, CPAdl, and TPI, TPJuv, TPAdl = proportion of total population in Instar I, larger juvenile, and adult classes in Control and Test respectively.

| YEAR | STATS | PROPORTIONS | | | | | |
|---|---|---|---|---|---|---|---|
| | | CPI | CPJuv | CPAdl | TPI | TPJuv | TPAdl |
| 1984 | N | 12 | 12 | 12 | 12 | 12 | 12 |
| | MEAN | 0.226 | 0.404 | 0.371 | 0.228 | 0.404 | 0.367 |
| | SD | 0.176 | 0.198 | 0.213 | 0.147 | 0.197 | 0.202 |
| 1985 | N | 13 | 13 | 13 | 13 | 13 | 13 |
| | MEAN | 0.187 | 0.334 | 0.479 | 0.202 | 0.410 | 0.388 |
| | SD | 0.106 | 0.086 | 0.178 | 0.111 | 0.134 | 0.165 |
| 1986 | N | 13 | 13 | 13 | 13 | 13 | 13 |
| | MEAN | 0.273 | 0.370 | 0.357 | 0.221 | 0.423 | 0.356 |
| | SD | 0.167 | 0.162 | 0.164 | 0.161 | 0.128 | 0.175 |
| 1987 | N | 13 | 13 | 13 | 13 | 13 | 13 |
| | MEAN | 0.233 | 0.429 | 0.338 | 0.216 | 0.468 | 0.316 |
| | SD | 0.148 | 0.114 | 0.148 | 0.122 | 0.155 | 0.174 |
| 1988 | N | 12 | 12 | 12 | 12 | 12 | 12 |
| | MEAN | 0.186 | 0.369 | 0.445 | 0.181 | 0.490 | 0.329 |
| | SD | 0.121 | 0.155 | 0.155 | 0.131 | 0.132 | 0.113 |
| 1989 | N | 13 | 13 | 13 | 13 | 13 | 13 |
| | MEAN | 0.345 | 0.340 | 0.315 | 0.251 | 0.405 | 0.343 |
| | SD | 0.169 | 0.118 | 0.136 | 0.150 | 0.119 | 0.138 |
| 1990 | N | 13 | 13 | 13 | 13 | 13 | 13 |
| | MEAN | 0.232 | 0.399 | 0.369 | 0.261 | 0.430 | 0.309 |
| | SD | 0.111 | 0.126 | 0.131 | 0.124 | 0.114 | 0.071 |
| 1991 | N | 13 | 13 | 13 | 13 | 13 | 13 |
| | MEAN | 0.277 | 0.441 | 0.282 | 0.228 | 0.464 | 0.307 |
| | SD | 0.226 | 0.242 | 0.178 | 0.126 | 0.136 | 0.149 |
| 1992 | N | 12 | 12 | 12 | 12 | 12 | 12 |
| | MEAN | 0.217 | 0.395 | 0.389 | 0.181 | 0.485 | 0.335 |
| | SD | 0.154 | 0.166 | 0.178 | 0.110 | 0.148 | 0.139 |

**Table 6.2. continued.**

| YEAR | STATS | PROPORTIONS | | | | | |
|---|---|---|---|---|---|---|---|
| | | CPI | CPJuv | CPAdl | TPI | TPJuv | TPAdl |
| 1984-88 | N | 63 | 63 | 63 | 63 | 63 | 63 |
| | MEAN | 0.221 | 0.381 | 0.398 | 0.210 | 0.439 | 0.351 |
| | SD | 0.145 | 0.146 | 0.164 | 0.132 | 0.150 | 0.165 |
| 1989-92 | N | 51 | 51 | 51 | 51 | 51 | 51 |
| | MEAN | 0.269 | 0.393 | 0.338 | 0.231 | 0.445 | 0.324 |
| | SD | 0.173 | 0.169 | 0.158 | 0.128 | 0.129 | 0.125 |

**Appendix 7 .** Checklist of carabid beetles collected during 1985-1991 in Test and Control sites; nomenclature following Lindroth (1969).

COLEOPTERA: FAMILY CARABIDAE

Tribe Cychrini
*Sphaeroderus lecontei* Dejean

Tribe Carabini
*Carabus granulatus* Linné
*Carabus sylvosus* Say
*Carabus serratus* Say
*Calosoma frigidum* Kirby

Tribe Notiophilini
*Notiophilus aeneus* Herbst

Tribe Scaritini
*Dischirius* sp.
*Clivina fossor* Linné

Tribe Bembidiini
*Bembidion quadrimaculatum* Linné
*Bembidion pseudocautum* Lindroth

Tribe Pterostichini
*Myas cyanescens* Dejean
*Pterostichus adstrictus* Eschscholtz
*Pterostichus pensylvanicus* Leconte
*Pterostichus mutus* Say
*Pterostichus melanarius* Illiger
*Pterostichus coracinus* Newman
*Pterostichus bryantoides* Ball
*Pterostichus adoxus* Say
*Pterostichus haematopus* Dejean
*Pterostichus honestus* Say
*Pterostichus corvus* Leconte
*Abacidus permundus* Say
*Calathus* spp.
*Synuchus impunctatus* Say
*Agonum retractum* Leconte
*Agonum decentis* Say
*Agonum placidum* Say

Tribe Amarini
*Amara* sp.

Tribe Harpalini
*Harpalus fuliginosus* Duftschmid
*Harpalus lewisi* Leconte
*Harpalus fulvilabris* Mannerheim

Tribe Licinini
*Diplocheila assimilis* Leconte

Tribe Lebiini
*Metabletus americanus* Dejean
*Cymindis cribricollis* Dejean

**Appendix 8.** Results of regression analyses of reproductive parameters of *Aporrectodea tuberculata* in the Test site.

**1. Dependent variable: CLITELLATE DENSITIES**

Independent variables: clitellate densities lagged (by one date); A moisture; A temperature; (A temperature)$^2$; (moisture x temperature).

| GROUP | SOURCE | SS | DF | MS | F | P | $R^2$ |
|---|---|---|---|---|---|---|---|
| 84-86 | Regression | 7920.4 | 5 | 1584.1 | 43.63 | 0.000 | 0.89 |
| | Residual | 980.2 | 27 | 36.3 | | | |
| 87-88 | Regression | 8506.4 | 5 | 1701.3 | 8.62 | 0.000 | 0.73 |
| | Residual | 3158.8 | 16 | 197.4 | | | |
| 84-88 | Regression | 17325.6 | 5 | 3465.1 | 36.62 | 0.000 | 0.79 |
| | Residual | 4636.3 | 49 | 94.6 | | | |
| 89-93 | Regression | 1677.9 | 5 | 335.6 | 4.13 | 0.003 | 0.30 |
| | Residual | 3976.7 | 49 | 81.2 | | | |

T-TESTS OF RESIDUALS:

| GROUP | N | MEAN | SD | P |
|---|---|---|---|---|
| 84-86 | 33 | -0.054 | 5.535 | |
| 87-88 | 22 | 1.707 | 14.232 | 0.585 |
| 84-88 | 55 | -0.094 | 9.266 | |
| 89-93 | 55 | -2.548 | 10.645 | 0.200 |

**2. Dependent variable: CLITELLATE PROPORTIONS** transformed: [ln (p/1-p)]
Independent variables: clitellate proportions lagged (by one date); A moisture.

| GROUP | SOURCE | SS | DF | MS | F | P | $R^2$ |
|---|---|---|---|---|---|---|---|
| 84-86 | Regression | 48.181 | 2 | 24.090 | 17.98 | 0.000 | 0.55 |
| | Residual | 40.195 | 30 | 1.340 | | | |
| 87-88 | Regression | 70.866 | 2 | 35.433 | 88.94 | 0.000 | 0.90 |
| | Residual | 7.570 | 19 | 0.398 | | | |
| 84-88 | Regression | 118.642 | 2 | 59.321 | 63.79 | 0.000 | 0.71 |
| | Residual | 48.359 | 52 | 0.930 | | | |
| 89-93 | Regression | 13.246 | 2 | 6.623 | 16.85 | 0.000 | 0.39 |
| | Residual | 20.435 | 52 | 0.393 | | | |

T-TESTS OF REGRESSION RESIDUALS:

| GROUP | N | MEAN | SD | P |
|---|---|---|---|---|
| 84-86 | 33 | -0.1361 | 1.1299 | |
| 87-88 | 22 | 0.0007 | 0.6004 | 0.562 |
| 84-88 | 55 | -0.0002 | 0.9463 | |
| 89-93 | 55 | -0.1127 | 0.6835 | 0.476 |

**3. Dependent variable: NEW COCOON DENSITIES**
Independent variables: clitellate densities; clitellate densities lagged (by one date).

| GROUP | SOURCE | SS | DF | MS | F | P | $R^2$ |
|---|---|---|---|---|---|---|---|
| 84-86 | Regression | 7487.6 | 2 | 3743.8 | 76.57 | 0.000 | 0.84 |
| | Residual | 1466.8 | 30 | 48.9 | | | |
| 87-88 | Regression | 8521.6 | 2 | 4260.8 | 56.56 | 0.000 | 0.86 |
| | Residual | 1431.3 | 19 | 75.3 | | | |
| 84-88 | Regression | 17612.9 | 2 | 8806.5 | 151.36 | 0.000 | 0.85 |
| | Residual | 3025.5 | 52 | 58.2 | | | |
| 89-93 | Regression | 4583.8 | 2 | 2291.9 | 27.97 | 0.000 | 0.52 |
| | Residual | 4260.9 | 52 | 81.9 | | | |

T-TESTS OF REGRESSION RESIDUALS:

| GROUP | N | MEAN | SD | P |
|---|---|---|---|---|
| 84-86 | 33 | -0.005 | 6.770 | |
| 87-88 | 22 | 1.161 | 9.047 | 0.609 |
| 84-88 | 55 | 0.001 | 7.488 | |
| 89-93 | 55 | 2.953 | 8.902 | 0.063 |

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**Appendix 9.** Basic density statistics for *Aporrectodea tuberculata* (Test site) by date, 1984-1993 (N samples = 10 or 12 /date);
NTOTAL, NIMM = mean /sample /date, total worms and immatures respectively;
DENSTOT, DENSIMM = density of total worms and immatures /$m^2$;
SD listed to the right of each mean or density column.

| YEAR | DATE | NTOTAL | SDTOTAL | NIMM | SDIMM | DENSTOT | SDTOT | DENSIMM | SDIMM |
|---|---|---|---|---|---|---|---|---|---|
| 84 | 1 | 17.9 | 9.279 | 13 | 6.58 | 286.4 | 148.464 | 208 | 105.28 |
| 84 | 2 | 18.1 | 8.787 | 13.6 | 6.91 | 289.6 | 140.592 | 217.6 | 110.56 |
| 84 | 3 | 13 | 5.944 | 9.8 | 5.43 | 208 | 95.104 | 156.8 | 86.88 |
| 84 | 4 | 18.5 | 3.342 | 12.7 | 4.27 | 296 | 53.472 | 203.2 | 68.32 |
| 84 | 5 | 14.6 | 5.25 | 9.4 | 3.66 | 233.6 | 84 | 150.4 | 58.56 |
| 84 | 6 | 14.8 | 8.08 | 10.3 | 7.07 | 236.8 | 129.28 | 164.8 | 113.12 |
| 84 | 7 | 15.1 | 8.62 | 11.3 | 7.33 | 241.6 | 137.92 | 180.8 | 117.28 |
| 84 | 8 | 15.8 | 6.14 | 11.3 | 5.29 | 252.8 | 98.24 | 180.8 | 84.64 |
| 84 | 9 | 17 | 6.56 | 12.5 | 5.27 | 272 | 104.96 | 200 | 84.32 |
| 84 | 10 | 12.8 | 3.94 | 8.8 | 3.52 | 204.8 | 63.04 | 140.8 | 56.32 |
| 84 | 11 | 16.3 | 10.45 | 11.7 | 7.66 | 260.8 | 167.2 | 187.2 | 122.56 |
| 84 | 12 | 14.9 | 6.33 | 9.7 | 4.27 | 238.4 | 101.28 | 155.2 | 68.32 |
| 85 | 1 | 17.75 | 7.41 | 13.42 | 7.29 | 284 | 118.56 | 214.72 | 116.64 |
| 85 | 2 | 18.6 | 12.48 | 14.17 | 10.17 | 297.6 | 199.68 | 226.72 | 162.72 |
| 85 | 3 | 21.25 | 9.79 | 15.92 | 8.53 | 340 | 156.64 | 254.72 | 136.48 |
| 85 | 4 | 20.25 | 9.39 | 15.17 | 8.03 | 324 | 150.24 | 242.72 | 128.48 |
| 85 | 5 | 19.17 | 10.29 | 14.75 | 7.52 | 306.72 | 164.64 | 236 | 120.32 |
| 85 | 6 | 17.5 | 7.49 | 13.67 | 7.02 | 280 | 119.84 | 218.72 | 112.32 |
| 85 | 7 | 13.75 | 6.18 | 11.42 | 5.43 | 220 | 98.88 | 182.72 | 86.88 |
| 85 | 8 | 14.08 | 4.12 | 10.08 | 3.37 | 225.28 | 65.92 | 161.28 | 53.92 |
| 85 | 9 | 17.75 | 9.61 | 13.5 | 7.67 | 284 | 153.76 | 216 | 122.72 |
| 85 | 10 | 19.5 | 11.77 | 15 | 11.15 | 312 | 188.32 | 240 | 178.4 |
| 85 | 11 | 27.75 | 7.63 | 21.75 | 6.38 | 444 | 122.08 | 348 | 102.08 |
| 85 | 12 | 21.33 | 12.47 | 16.67 | 9.32 | 341.28 | 199.52 | 266.72 | 149.12 |
| 86 | 1 | 18 | 4.16 | 14 | 4.16 | 288 | 66.56 | 224 | 66.56 |
| 86 | 2 | 19 | 7.8 | 14.08 | 7.57 | 304 | 124.8 | 225.28 | 121.12 |
| 86 | 3 | 21.92 | 6.2 | 17.33 | 4.27 | 350.72 | 99.2 | 277.28 | 68.32 |
| 86 | 4 | 18.67 | 4.1 | 15.17 | 3.59 | 298.72 | 65.6 | 242.72 | 57.44 |
| 86 | 5 | 15.75 | 7.7 | 12.33 | 8.72 | 252 | 123.2 | 197.28 | 139.52 |
| 86 | 6 | 16.75 | 7.14 | 13.25 | 5.99 | 268 | 114.24 | 212 | 95.84 |
| 86 | 7 | 15.17 | 7.58 | 12.75 | 7.6 | 242.72 | 121.28 | 204 | 121.6 |
| 86 | 8 | 18.42 | 7.84 | 14.08 | 5.81 | 294.72 | 125.44 | 225.28 | 92.96 |
| 86 | 9 | 17.17 | 5.73 | 12.08 | 4.98 | 274.72 | 91.68 | 193.28 | 79.68 |
| 86 | 10 | 19 | 8.01 | 14.25 | 7.47 | 304 | 128.16 | 228 | 119.52 |
| 86 | 11 | 17.33 | 8.21 | 13.58 | 6.67 | 277.28 | 131.36 | 217.28 | 106.72 |
| 86 | 12 | 14.75 | 5.21 | 10.42 | 4.42 | 236 | 83.36 | 166.72 | 70.72 |
| 87 | 1 | 14.83 | 5.64 | 10.75 | 4 | 237.28 | 90.24 | 172 | 64 |
| 87 | 2 | 17.7 | 6.57 | 11.6 | 6.11 | 283.2 | 105.12 | 185.6 | 97.76 |
| 87 | 3 | 19.8 | 9.04 | 14 | 7.97 | 316.8 | 144.64 | 224 | 127.52 |
| 87 | 4 | 13.5 | 6.36 | 8.9 | 5.8 | 216 | 101.76 | 142.4 | 92.8 |
| 87 | 5 | 14.6 | 5.54 | 10.6 | 5.72 | 233.6 | 88.64 | 169.6 | 91.52 |
| 87 | 6 | 20.1 | 7.78 | 13.4 | 4.97 | 321.6 | 124.48 | 214.4 | 79.52 |

**Appendix 9. continued**

| YEAR | DATE | NTOTAL | SDTOTAL | NIMM | SDIMM | DENSTOT | SDTOT | DENSIMM | SDIMM |
|---|---|---|---|---|---|---|---|---|---|
| 87 | 7 | 19.6 | 7.45 | 15 | 6.91 | 313.6 | 119.2 | 240 | 110.56 |
| 87 | 8 | 22.5 | | 16.8 | | 360 | 0 | 268.8 | 0 |
| 87 | 9 | 25.5 | 13.13 | 18.6 | 11.21 | 408 | 210.08 | 297.6 | 179.36 |
| 87 | 10 | 22.4 | | 15.2 | | 358.4 | 0 | 243.2 | 0 |
| 87 | 11 | 19.3 | 7.87 | 11.8 | 7.08 | 308.8 | 125.92 | 188.8 | 113.28 |
| 87 | 12 | 18.3 | | 12.5 | - | 292.8 | 0 | 200 | 0 |
| 88 | 1 | 21.6 | 8.26 | 14.9 | 5.93 | 345.6 | 132.16 | 238.4 | 94.88 |
| 88 | 2 | 25 | 9.02 | 17.5 | 6.75 | 400 | 144.32 | 280 | 108 |
| 88 | 3 | 19.4 | 8.55 | 14.1 | 6.17 | 310.4 | 136.8 | 225.6 | 98.72 |
| 88 | 4 | 24.1 | 9.19 | 16.8 | 6.58 | 385.6 | 147.04 | 268.8 | 105.28 |
| 88 | 5 | 17.2 | 7.8 | 13 | 7.77 | 275.2 | 124.8 | 208 | 124.32 |
| 88 | 6 | 25.4 | 13.7 | 19 | 13.3 | 406.4 | 219.2 | 304 | 212.8 |
| 88 | 7 | 22.3 | 9.44 | 16.9 | 6.42 | 356.8 | 151.04 | 270.4 | 102.72 |
| 88 | 8 | 21.8 | 9.81 | 15.4 | 7.59 | 348.8 | 156.96 | 246.4 | 121.44 |
| 88 | 9 | 20.6 | 7.54 | 14.6 | 4.97 | 329.6 | 120.64 | 233.6 | 79.52 |
| 88 | 10 | 14.8 | 5.07 | 10.8 | 5.29 | 236.8 | 81.12 | 172.8 | 84.64 |
| 88 | 11 | 17.2 | 7.27 | 12.9 | 5.24 | 275.2 | 116.32 | 206.4 | 83.84 |
| 88 | 12 | 15.4 | 4.4 | 11.3 | 3.83 | 246.4 | 70.4 | 180.8 | 61.28 |
| 89 | 1 | 17.1 | 5.93 | 11.2 | 3.91 | 273.6 | 94.88 | 179.2 | 62.56 |
| 89 | 2 | 13.8 | 4.71 | 9.3 | 5.01 | 220.8 | 75.36 | 148.8 | 80.16 |
| 89 | 3 | 17 | 5.46 | 12.8 | 5.67 | 272 | 87.36 | 204.8 | 90.72 |
| 89 | 4 | 12.7 | 4.92 | 9.7 | 3.59 | 203.2 | 78.72 | 155.2 | 57.44 |
| 89 | 5 | 21.4 | 6.8 | 16.3 | 6.36 | 342.4 | 108.8 | 260.8 | 101.76 |
| 89 | 6 | 13.7 | 6.53 | 10.3 | 5.79 | 219.2 | 104.48 | 164.8 | 92.64 |
| 89 | 7 | 14.9 | 5.17 | 11.8 | 3.99 | 238.4 | 82.72 | 188.8 | 63.84 |
| 89 | 8 | 18 | 5.46 | 12.7 | 6.22 | 288 | 87.36 | 203.2 | 99.52 |
| 89 | 9 | 21.4 | 7.96 | 16.7 | 7.41 | 342.4 | 127.36 | 267.2 | 118.56 |
| 89 | 10 | 22.4 | 15.39 | 17.2 | 14.61 | 358.4 | 246.24 | 275.2 | 233.76 |
| 89 | 11 | 25.4 | 9.03 | 19.9 | 6.71 | 406.4 | 144.48 | 318.4 | 107.36 |
| 89 | 12 | 20.9 | 7.23 | 16.4 | 6.9 | 334.4 | 115.68 | 262.4 | 110.4 |
| 90 | 1 | 28.8 | 17.43 | 21.4 | 15.36 | 460.8 | 278.88 | 342.4 | 245.76 |
| 90 | 2 | 25.9 | 9 | 19.6 | 7.93 | 414.4 | 144 | 313.6 | 126.88 |
| 90 | 3 | 23.8 | 14.02 | 19.1 | 11.73 | 380.8 | 224.32 | 305.6 | 187.68 |
| 90 | 4 | 23.9 | 6.74 | 17.1 | 5.59 | 382.4 | 107.84 | 273.6 | 89.44 |
| 90 | 5 | 26 | 13.78 | 19.2 | 11.79 | 416 | 220.48 | 307.2 | 188.64 |
| 90 | 6 | 20.1 | 5.45 | 15.4 | 4.17 | 321.6 | 87.2 | 246.4 | 66.72 |
| 90 | 7 | 21.1 | 6.79 | 17.2 | 6.05 | 337.6 | 108.64 | 275.2 | 96.8 |
| 90 | 8 | 16.6 | 4.01 | 13.5 | 4.38 | 265.6 | 64.16 | 216 | 70.08 |
| 90 | 9 | 19.4 | 10.47 | 15.9 | 9.24 | 310.4 | 167.52 | 254.4 | 147.84 |
| 90 | 10 | 14.4 | 5.29 | 9.3 | 3.2 | 230.4 | 84.64 | 148.8 | 51.2 |
| 90 | 11 | 13.8 | 9.7 | 11 | 9.25 | 220.8 | 155.2 | 176 | 148 |
| 90 | 12 | 16.4 | 5.85 | 13.2 | 5.43 | 262.4 | 93.6 | 211.2 | 86.88 |

## Appendix 9. continued

| YEAR | DATE | NTOTAL | SDTOTAL | NIMM | SDIMM | DENSTOT | SDTOT | DENSIMM | SDIMM |
|---|---|---|---|---|---|---|---|---|---|
| 91 | 1 | 17 | 6.73 | 12.4 | 7.62 | 272 | 107.68 | 198.4 | 121.92 |
| 91 | 2 | 17.5 | 4.9 | 13.1 | 5 | 280 | 78.4 | 209.6 | 80 |
| 91 | 3 | 16 | 4.88 | 10.9 | 2.96 | 256 | 78.08 | 174.4 | 47.36 |
| 91 | 4 | 15.9 | 5 | 11.1 | 5.04 | 254.4 | 80 | 177.6 | 80.64 |
| 91 | 5 | 23.5 | 8.62 | 17.3 | 8.92 | 376 | 137.92 | 276.8 | 142.72 |
| 91 | 6 | -12 | 5.33 | 8.7 | 4.37 | 192 | 85.28 | 139.2 | 69.92 |
| 91 | 7 | 18 | 7.23 | 13.5 | 5.34 | 288 | 115.68 | 216 | 85.44 |
| 91 | 8 | 19.5 | 7.82 | 15.2 | 7.37 | 312 | 125.12 | 243.2 | 117.92 |
| 91 | 9 | 15.1 | 7.85 | 11.4 | 7.78 | 241.6 | 125.6 | 182.4 | 124.48 |
| 91 | 10 | 13.2 | 5.88 | 8.3 | 4.32 | 211.2 | 94.08 | 132.8 | 69.12 |
| 91 | 11 | 19.8 | 7.66 | 13.7 | 5.66 | 316.8 | 122.56 | 219.2 | 90.56 |
| 91 | 12 | 19.4 | 6.89 | 14 | 4.99 | 310.4 | 110.24 | 224 | 79.84 |
| 92 | 1 | 19.7 | 7.89 | 13.7 | 7.94 | 315.2 | 126.24 | 219.2 | 127.04 |
| 92 | 2 | 17.1 | 5.82 | 12.8 | 4.73 | 273.6 | 93.12 | 204.8 | 75.68 |
| 92 | 3 | 17.1 | 5.62 | 13.6 | 5.48 | 273.6 | 89.92 | 217.6 | 87.68 |
| 92 | 4 | 18.3 | 9.37 | 14.3 | 7.64 | 292.8 | 149.92 | 228.8 | 122.24 |
| 92 | 5 | 15.1 | 10.86 | 11.1 | 8.57 | 241.6 | 173.76 | 177.6 | 137.12 |
| 92 | 6 | 13.6 | 5.97 | 9.6 | 4.37 | 217.6 | 95.52 | 153.6 | 69.92 |
| 92 | 7 | 14.6 | 6.99 | 10.2 | 7.34 | 233.6 | 111.84 | 163.2 | 117.44 |
| 92 | 8 | 14.6 | 7.52 | 10.9 | 6.28 | 233.6 | 120.32 | 174.4 | 100.48 |
| 92 | 9 | 16 | 9.27 | 9.9 | 6.31 | 256 | 148.32 | 158.4 | 100.96 |
| 92 | 10 | 15.9 | 7.28 | 11.3 | 6.73 | 254.4 | 116.48 | 180.8 | 107.68 |
| 92 | 11 | 16.7 | 5.06 | 11.9 | 3.93 | 267.2 | 80.96 | 190.4 | 62.88 |
| 92 | 12 | 16.6 | 11.06 | 12.2 | 8.19 | 265.6 | 176.96 | 195.2 | 131.04 |
| 93 | 1 | 15.9 | 4.84 | 11.3 | 3.8 | 254.4 | 77.44 | 180.8 | 60.8 |
| 93 | 2 | 18 | 6.16 | 11.4 | 5.81 | 288 | 98.56 | 182.4 | 92.96 |
| 93 | 3 | 16.4 | 8.04 | 10.8 | 5.83 | 262.4 | 128.64 | 172.8 | 93.28 |
| 93 | 4 | 17.8 | 8.65 | 14 | 7.76 | 284.8 | 138.4 | 224 | 124.16 |
| 93 | 5 | 18.3 | 8.03 | 14.3 | 8.34 | 292.8 | 128.48 | 228.8 | 133.44 |
| 93 | 6 | 13.4 | 7.17 | 11 | 6.63 | 214.4 | 114.72 | 176 | 106.08 |
| 93 | 7 | 14 | 6.39 | 10.8 | 6.14 | 224 | 102.24 | 172.8 | 98.24 |
| 93 | 8 | 12.6 | 4.55 | 9.3 | 3.95 | 201.6 | 72.8 | 148.8 | 63.2 |
| 93 | 9 | 20.2 | 7 | 15.4 | 5.72 | 323.2 | 112 | 246.4 | 91.52 |
| 93 | 10 | 22.2 | 9.46 | 17.2 | 5.94 | 355.2 | 151.36 | 275.2 | 95.04 |
| 93 | 11 | 24.1 | 9.25 | 19.5 | 8.8 | 385.6 | 148 | 312 | 140.8 |
| 93 | 12 | 19.7 | 8.3 | 14.5 | 7.01 | 315.2 | 132.8 | 232 | 112.16 |

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**Appendix 10 .** Litterbags: mean (and SD) mass remaining (AFDW) per date, in each series (identified by year of field placement and subsequent year of sampling; Date 1 through 6 or 7 = early May to November; N per date in parentheses after date 1 of each series. EXCH. = litter Exchange series (Control site litter in Test and vice versa).

| | | TEST | | CONTROL | |
|---|---|---|---|---|---|
| SERIES | DATE (N) | MEAN | SD | MEAN | SD |
| I (85-86) | 1 (10) | 67.60 | 5.47 | 66.00 | 7.72 |
| | 2 | 70.65 | 5.82 | 62.07 | 9.17 |
| | 3 | 62.7 | 6.49 | 60.14 | 9.45 |
| | 4 | 61.78 | 6.41 | 56.88 | 11.25 |
| | 5 | 53.23 | 6.72 | 54.78 | 9.10 |
| | 6 | 47.87 | 7.30 | 48.68 | 7.41 |
| | 7 | 40.16 | 5.44 | 38.68 | 7.89 |
| II (88-89) | 1 (10) | 73.77 | 4.07 | 70.54 | 2.92 |
| | 2 | 65.47 | 4.93 | 65.96 | 3.31 |
| | 3 | 61.23 | 6.08 | 65.27 | 5.23 |
| | 4 | 57.01 | 4.11 | 58.41 | 4.62 |
| | 5 | 53.46 | 6.24 | 53.51 | 6.54 |
| | 6 | 47.68 | 4.55 | 57.52 | 8.12 |
| | 7 | 44.96 | 4.14 | 57.12 | 5.05 |
| III (89-90) | 1 (12) | 76.96 | 2.42 | 76.99 | 1.87 |
| | 2 | 68.33 | 3.35 | 73.16 | 3.05 |
| | 3 | 62.65 | 4.16 | 66.47 | 6.25 |
| | 4 | 59.94 | 2.55 | 65.56 | 3.87 |
| | 5 | 50.49 | 3.84 | 56.86 | 5.19 |
| | 6 | 41.35 | 6.59 | 54.13 | 6.11 |
| | 7 | 40.14 | 4.30 | 51.19 | 3.74 |
| IV (90-91) | 1 (12) | 70.11 | 3.38 | 74.03 | 2.28 |
| | 2 | 65.37 | 3.63 | 69.669 | 3.33 |
| | 3 | 60.12 | 2.39 | 66.77 | 4.50 |

**Appendix 10** continued.

| SERIES | DATE (N) | TEST | | CONTROL | |
|---|---|---|---|---|---|
| | | MEAN | SD | MEAN | SD |
| | 4 | 54.72 | 5.48 | 62.95 | 4.03 |
| | 5 | 53.00 | 5.51 | 53.54 | 8.26 |
| | 6 | 41.93 | 2.52 | 50.88 | 5.88 |
| | 7 | 38.51 | 2.73 | 51.83 | 9.37 |
| EXCH. (90-91) | 1 (12) | 71.05 | 3.39 | 74.52 | 5.71 |
| | 2 | 63.76 | 2.66 | 70.34 | 3.82 |
| | 3 | 61.78 | 3.00 | 66.95 | 2.79 |
| | 4 | 56.06 | 5.49 | 64.44 | 4.84 |
| | 5 | 49.38 | 5.18 | 54.96 | 5.30 |
| | 6 | 40.08 | 5.00 | 51.6 | 6.19 |
| | 7 | 36.29 | 4.77 | 54.03 | 6.95 |
| V (91-92) | 1 (12) | 66.99 | 5.46 | 63.71 | 5.72 |
| | 2 | 57.41 | 3.76 | 62.42 | 3.84 |
| | 3 | 55.50 | 4.28 | 54.63 | 3.46 |
| | 4 | 47.82 | 4.80 | 46.21 | 4.31 |
| | 5 | 44.70 | 5.09 | 42.66 | 3.17 |
| | 6 | 39.17 | 9.57 | 42.62 | 8.53 |
| | 7 | 32.33 | 6.98 | 37.90 | 8.06 |
| VI (92-93) | 1 (12) | 70.46 | 7.24 | 73.13 | 3.62 |
| | 2 | 56.54 | 6.49 | 65.50 | 3.49 |
| | 3 | 54.34 | 4.78 | 59.07 | 5.74 |
| | 4 | 50.86 | 5.15 | 59.09 | 3.60 |
| | 5 | 46.50 | 7.28 | 45.30 | 5.98 |
| | 6 | 44.08 | 5.71 | 46.61 | 3.89 |