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Do Extreme Low-Frequency Electromagnetic Fields Affect Soil Arthropods? Ongoing Studies at the Wisconsin Test Facility[1]

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ABSTRACT

A continuing study of possible impact of extreme low-frequency electromagnetic fields (Sanguine effect) on soil arthropods was enlarged in summer 1972 to include 11 test plots and six control plots. This report analyzes mite and collembolan populations in plots that have been under investigation for at least two years. New plots, initially sampled in 1972, will be sampled again in summer 1973 to provide a time dimension, and they will be reported on subsequently. These annual censuses provide data on within-year and between-year population changes of soil microarthropods in various habitats. As in 1971, no significant differences occurred between each of four groups of arthropods in the Main test and control subplots. In 1972, statistically significant differences were observed among the microfauna in some of the other plots that were absent in 1971. In some cases the density of a group was greater in the control plot; in other cases, the density was greater in the test plot. A general feature of the population curves of all groups in test and control plots is the midsummer peak with return to spring levels by mid-September. Within-plot peak amplitude varies from one year to the next, and both chronicity and amplitude appear to be independent of a Sanguine effect and are attributable to random, natural causes. Consequently, variations in absolute numbers are less reliable than intergroup ratios and annual population curves as evidence for significant population shifts. Four-year ratios of Cryptostigmata: Collembola in Hazleton plots disclose that populations of these two most numerous groups of decomposers are remarkably parallel in test and control plots. Numerous other examples are given of between-year populational changes which, because they occur in test and control plots alike, rule out a Sanguine effect.

A test facility for the Navy's Sanguine system has been operating in northwestern Wisconsin since July 1969. The system, as conceived, would enable land-based extreme low-frequency communication with American submarines while they are submerged in the ocean at operating depths and speeds, and with other strategic forces. To test possible biological impact from the electromagnetic fields and radiations of such a system, a population census of key soil arthropods living under the Sanguine antenna and in control plots 7–12 miles away, was made during summer 1971, at the Navy's Wisconsin Test Facility (Greenberg 1972).[2] Three groups of mites —Cryptostigmata, Mesostigmata, and Prostigmata and collembolans were used as indicators, because they are the numerically preponderant soil arthropods. Monthly data were obtained from soil samples collected June—September from test habitats, including the Hazleton test site at the S antenna ground terminal. This site had been sampled twice before, once in July 1969, before antenna turn-on, and again in July 1970, after about one year of operation. Although absolute figures could not be directly compared with our 1971 data because of differences in collecting procedures, the data could be used to compare ratios of the major groups from 1969 through 1971. Thus, the ratio of Cryptostigmata to Collembola, the 2 major groups, was roughly 2:1 and had changed very little following 2 years of exposure to Sanguine electromagnetic fields. Ratios of Cryptostigmata:Mesostigmata were likewise overlapping for the pretreatment and treatment years. Furthermore, during summer 1971, highly significant midsummer peaks occurred among both test and control populations of all groups of mites in woodland habitats. Finally, 16 statistical comparisons between test and control populations of mites and collembolans revealed no significant differences in 14 cases and 2 marginal or doubtful differences, additional evidence that Sanguine ELF fields had no demonstrable effect on numbers of these soil arthropods.

A census was made also at a power substation, in operation for over 20 years, where electric fields were many times greater than those at the Sanguine test plots. Here, too, analysis did not disclose significant alteration in arthropod abundance.

During summer 1972, the field study was enlarged to include, in addition, 6 new test plots and 4 new control plots. It is expected that the increase in the number of study sites and the time perspective provided by additional years of observation will enhance sensitivity of the program in monitoring for subtle, chronic effects. The new plots will be sampled again in summer 1973, and results will be reported subsequently. This report deals with plots under investigation for at least 2 years.

Methods

Sampling Sites

Each plot in the 1971 study was sampled again

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[1] Received for publication 28 Feb. 1973.

[2] See also Sanguine System Final Environmental Impact Statement for Validation and Full-Scale Development, Annex D, p. D-77 through D-105, April 1972, Department of the Navy.

in summer 1972 (Greenberg 1972). These plots are: Main test with its 3 subplots (Ala, Alb, Alc) and Main control with its 3 subplots (Bla, Blb, Blc); Clover test (A2) and control (B2); West (A3) and East (A4) Hazleton test plots,[3] and control (B3); and the 60-Hertz test (A5) and its control (B1). I (Greenberg 1972) gave detailed floristic descriptions of the foregoing plots and their situations relative to the Sanguine antenna. The Sanguine test facility is situated in the Chequamegon National Forest in northwestern Wisconsin. The antenna consists of N/S and E/W components, each 14 miles long. The Main test plots are situated near the W leg of the E/W antenna where the antenna crosses Forest Road 176. The area is an open meadow formed by logging about 9 years ago; control plots are about 7 miles from either antenna in a clearing made by a skid-trail 10–15 years ago. The Clover test plot is adjacent to the Main test plot on the antenna right-of-way and its control is about 12 miles from the nearest antenna; both plots were planted in red and white clover 2½–3 years before. The Hazleton test plots are situated in a northern hardwood forest, the West plot (A3) is 10 yds from the downlead of the antenna and the East plot (A4) is 500 ft N, and 5 ft from the antenna right-of-way; the control plot is ca. 8 miles from the nearest Sanguine antenna in a northern hardwood forest. The 60-Hertz test plot is situated at a ground terminal of Price Electric Cooperative substation, 2 miles E-SE of Butternut. A soil analysis of each plot was made by borings immediately adjacent to the plot, and Table 1 summarizes the soil classifications.[4]

Sampling Schedule

Each test and control plot was sampled 4 times at ca. monthly intervals, from mid-June to mid-September, 1972.

Sampling Design

All plots were 4×4ft (except the West Hazleton test (A3) and control (B3) plots whose original dimension of 10×10 ft was retained). Plots were roped off and left undisturbed, except for sampling. At each sampling period 8 randomized core samples were taken from each test plot and control plot, with the exception of the Main test and control where 4 cores were taken from each of the 3 test subplots and a like number from each of the 3 control subplots. Coring, transportation, and extraction of samples were performed as described previously (Greenberg 1972).

Sanguine Test Facility Operations

I (Greenberg 1972) described and graphed the history of Sanguine antenna operation from inception in July 1969 to summer 1971. From summer 1971 through summer 1972 the Test Facility continued to be operated with 300 amp of current in either the N-S or E-W antenna, or in both antennas simultaneously. Operation was roughly on a 5-days-a-week 6-hours-a-day schedule at a frequency of either 45 or 75 Hz.

Electromagnetic Field Measurements

Magnetic field was measured with an ELF ferrite loop sensor, and the electric field was measured with a one-meter probe wire both parallel and perpendicular to the E/W antenna. During control plot measurements, the 2 one-meter probe wires were positioned in a N/S and an E/W direction. The measurements were performed with the Test Facility operated in modes 1J (300 amp in E/W antenna) and 2J (300 amp in N/S antenna) at both 45 and 75 Hz. Measurements were also made at 60 Hz with the antenna inoperative (ambient).

Statistical Treatment

Analysis of variance was performed on all data. All tests except 60-Hertz vs. Main control and Main test vs. Main control were standard 2-way analyses of variance with replication after the method of Sokal and Rohlf (1969). The analysis of the 60-Hertz vs. Main control was treated as a 2-way analysis of variance with unequal, but proportional, subclass members (Sokal and Rohlf 1969, p. 333–7). The analysis of the Main test vs. Main control was performed using the crossed-nested 2-way analysis of variance described by Brownlee (1965). Two different transforms were used to normalize the data (log × + 1 transform and square-root transform) before the analysis of variance was done, to take into account a nonnormal distribution. Both the logarithmic and square root transformations make the variance independent of the mean (Sokal and Rohlf 1969, p. 384). Both transforms had little effect on the analysis results. The CL about the mean were calculated with a formula which assumes normality but at the same time broadens the confidence interval when small sample sizes are involved (Simpson et al. 1960, p. 165).

Results

A numerical census of mites and collembolans at the Wisconsin Test Facility during summer 1972 is presented for the Main, Clover, Hazleton, and 60-Hertz plots. These results are compared with data for 1971 and for 1969 and 1970 in the case of the Hazleton plots. Data on new sites that were sampled for the first time during summer 1972 will be compared with 1973 data and subsequently reported. This will provide additional perspective of the important aspect of natural population variation within and between years.

Table 1 summarizes results of a soil analysis of the plots. All pairs are essentially comparable, despite minor differences in classification. Related but differently classified soils are considered equivalent when the upper 2–3 ft have the same physical fea-

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[3] As described in the previous report the original or West Hazleton test plot differed from the control in several ways, including drainage, exposure, and plant cover. A new test plot, A4, was selected for study in 1971, while retaining the original for continuity.

[4] We thank Edward Neumann and James Wardensky, soil specialists with the Forestry Service of the USDA, for performing the soil classifications (see also R.S.A. Radtke, Chequamegon Soils, USDA, 115 p. 1972.

Table 1. – Soil type in test and control plots.

Test location	Soil series[a]	Slope	Drainage	Control	Soil series	Slope	Drainage
Main (A1)	PADUS, sandy substratum variant (1st 30″ same as PADUS)	B	Well	Main (B1)	IRON RIVER fine sandy loam	B	Well to moderately well
60-Hertz (A5)	IRON RIVER fine sandy loam	B	Well to moderately well				
Clover (A2)	PADUS, sandy substratum variant	B	Moderately well to well	Clover (B2)	IRON RIVER going to FREON	B	Moderately well to well
West Hazleton (A3)	PADUS over sand with a lacustrine layer at 24–35″ (in transition zone going to CABLE)	B	Poorly	Hazleton (B3)	BEVENT	A	Moderately well to well
East Hazleton (A4)	PADUS over sand	B	Moderately well				

[a] The soil series in test and control plots are identical, else they have the same pH and upper strata features.

tures and *p*H, although they differ at greater depth. This treatment is reasonable, because the bulk of soil animals inhabit the uppor foot of soil, and plots were selected also for their similarity of plant cover.

Tables 2 and 3 provide measurements of electric and magnetic fields in test and control plots when either antenna is operating at 45 or 75 Hz, respectively. Electromagnetic fields in 1971 and 1972 were comparable; again, as in 1971, there were large differences between test and control plots (Table 4). Only the Main test subplots are close enough to both antennas to have significant fields when either antenna is functioning. At 75 Hz, electric fields in Main test subplots were 125–190× greater than those in the control subplots when the E/W antenna was on, and 15–40× greater when the N/S antenna was on. Other test plots generally have highly significant fields with one of the antennas. As observed previously, the 60-Hertz plot acts as a control with respect to Sanguine-generated fields while it generates its own electric fields which, in summer 1972 were ca. 18,000× greater than those of the control; in summer 1971 they were 10,000× greater. It is also important to note that the power substation has been operating on an essentially around-the-clock, 7-day-week basis for over 20 years.

Table 5 summarizes for summer 1972 mean monthly numbers of mites and collembolans per core sample for each plot. Table 6 gives the 95% CL of mean summer populations with an analysis of variance.

The observations that follow are based on comparison of data for 1972 with those for previous years.

Main

The population effects described here occurred in test and control subplots alike.

1. All 4 groups of arthropods tended toward

Table 2. – Comparison of electric and magnetic fields at test and control plots. Antenna current 300 amp; frequency 45 Hz.

	Electric fields (millivolts/meter)			Magnetic fields (gauss)		
Test location	E/W antenna	N/S antenna	60 Hz	E/W antenna	N/S antenna	60 Hz
Main test (A1a)	122	32	0.17	0.049	—[a]	—
Main test (A1b)	116	28	.18	.036	—	—
Main test (A1c)	147	31.1	.18	.045	—	—
Main control (B1a)	1.7	2.05	.042	—	—	—
Main control (B1b)	2.35	2.56	.07	—	—	—
Main control (B1c)	2.15	2.48	.064	—	—	—
Clover test (A2)	126.0	32.0	.18	.061	—	—
Clover control (B2)	25.9	31.8	10.2	—	—	—
West Hazelton test (A3)	2.55	2500.0	.27	—	0.016	—
East Hazleton test (A4)	1.8	890.0	.047	—	.016	—
Hazleton control (B3)	2.94	3.33	.47	—	—	—
60-Hertz test (A5)	1.14	1.3	910.0	—	—	0.0013

[a] Magnetic field density less than 0.001 gauss.

Table 3. — Comparison of electric and magnetic fields at test and control plots. Antenna current 300 amp; frequency 75 Hz.

Test location	Electric fields (millivolts/meter) E/W antenna	N/S antenna	60 Hz	Magnetic fields (gauss) E/W antenna	N/S antenna	60 Hz
Main test (A1a)	199	41.4	0.14	0.061	—[a]	—
Main test (A1b)	186	31.4	.15	.032	—	—
Main test (A1c)	227	43.4	.17	.041	—	—
Main control (B1a)	1.19	1.48	.072	—	—	—
Main control (B1b)	1.21	2.23	.064	—	—	—
Main control (B1c)	1.49	1.86	.083	—	—	—
Clover test (A2)	208.0	28.0	.1	.064	—	—
Clover control (B2)	14.4	14.2	15.9	—	—	—
West Hazleton test (A3)	3.52	2560.0	.25	—	0.015	—
East Hazleton test (A4)	1.51	985.0	.095	—	.015	—
Hazleton control (B3)	2.42	2.9	.58	—	—	—
60-Hertz test (A5)	1.51	1.12	556.0	—	—	0.0016

[a] Magnetic field density less than 0.001 gauss.

maxima in August or early September (Fig. 1).

2. Cryptostigmates were more numerous in 1972 than in 1971, yet in both summers the actual increase above June minima did not exceed 2–3×. Collembolans were remarkably constant during both summers.

3. Ratios of cryptostigmates to collembolans (Fig. 3A) and to mesostigmates (Fig. 3B) correspond closely in test and control plots in 1971 and 1972.

4. Populations of prostigmates and mesostigmates fluctuated more in 1971 than in 1972.

5. As in 1971, analysis of variance showed there were no significant differences between arthropods in test and control plots. There were also no significant differences among the 3 test subplots or the 3 control subplots, thus validating the replicate design.

Hazleton

1. Arthropods in test (A4) and control plots shared July-August population peaks.

2. In 1971, population curves of test and control collembolans oscillated out of phase with one another, but in 1972 the chronicity and amplitude of the 2 curves were remarkably similar; in neither year was there a statistically significant difference between test and control collembolans.

3. There were no significant differences between test and control cryptostigmates (in 1971, $p < 0.05$) or mesostigmates. The slight differential increase in test prostigmates this year is of doubtful significance ($p < 0.05$) (Fig. 2).

4. The 4-year curves of cryptostigmata:collembolans are the same, but with peak amplitudes one year apart (Fig. 3C).

Clover

1. Test populations of collembolans and cryptostigmates were more explosive in 1972 than in 1971.

2. In 1971, collembolans in the control plot were significantly more numerous than those in the test plot, while there were no differences in the other groups. In 1972, collembolans, prostigmates, and mesostigmates were more numerous in the control plot ($p < 0.025$), while cryptostigmates were significantly higher in the test plot ($P < 0.001$). Inapparent factors appear to favor dominance of collembolans in the Clover control and dominance of cryptostigmates in the Clover test. Since both groups are primary decomposers, feeding upon fungi and decaying organic matter, these numerical differences are of doubtful importance in the energetics of the soil ecosystem. They should not obscure basic parallels in the 2-year population curves, particularly among prostigmates and mesostigmates which are predators of the foregoing (Fig. 1).

60 Hertz

1. Cryptostigmates continued more numerous in the control plot in 1972 ($P < 0.001$), while mesostigmates were more numerous in the test plot this year ($P < 0.05$), reversing last year's frequencies (Fig. 2).

2. Collembolans and prostigmates continued without significant differences.

3. During both summers cryptostigmates in the control plot overgrew collembolans, and vice

Table 4.—Magnitude of the difference between electric fields of test and control plots at 45 and 75 Hz.[a]

Test series	45 Hz	75 Hz
Main (A1)[b]	50–87×	125–190×
West Hazleton (A3)[c]	758×	883×
East Hazleton (A4)[c]	270×	340×
Clover (A2)[b]	5×	14×

[a] In every case, the electric fields are larger in the test plots by the figure shown.

[b] E/W antenna operating.

[c] N/S antenna operating.

Table 5.—95 percent confidence limits of mean numbers of arthropods per core sample for each site and sampling period.

	Mesostigmata		Prostigmata		Cryptostigmata		Collembola	
	Control	Test	Control	Test	Control	Test	Control	Test
MAIN								
June	13.3 (7.5-19.0)	11.5 (4.3-18.7)	4.8 (2.6-7.1)	13.6 (6.5-20.7)	27.0 (12.6-41.5)	36.2 (14.5-57.8)	13.7 (9.2-18.2)	26.1 (15.4-36.8)
July	13.8 (4.8-22.8)	11.1 (4.6-17.5)	10.7 (1.9-19.5)	8.3 (3.7-12.8)	54.6 (8.3-100.9)	66.0 (31.2-100.8)	36.0 (15.3-56.7)	22.3 (12.4-32.3)
August	14.8 (8.0-21.5)	14.6 (8.0-21.1)	14.9 (6.3-23.5)	18.0 (7.8-28.2)	89.7 (42.1-137.2)	102.6 (20.4-184.8)	33.6 (14.6-52.6)	39.6 (25.8-53.4)
September	13.0 (4.0-22.0)	14.4 (5.6-23.2)	9.3 (2.4-16.3)	10.3 (7.8-12.9)	37.3 (16.4-58.1)	65.3 (24.8-105.7)	35.3 (16.9-53.6)	39.8 (17.5-62.0)
CLOVER								
June	3.5 (0.90-6.1)	3.0 (1.3-4.7)	1.8 (0.2-3.3)	3.7 (1.7-9.1)	11.6 (4.8-18.4)	17.7 (5.4-30.1)	47.6 (34.4-60.9)	6.6 (0.9-14.0)
July	5.1 (1.9-8.4)	7.3 (1.6-12.9)	5.8 (0.09-11.6)	4.3 (1.6-6.9)	8.6 (0.7-16.6)	22.1 (7.9-36.3)	50.6 (7.4-93.8)	27.0 (10.1-43.9)
August	4.8 (3.0-6.5)	9.4 (5.6-13.2)	2.3 (0.1-4.4)	5.0 (0.2-10.2)	13.0 (3.8-22.2)	68.3 (29.6-106.9)	50.6 (24.4-76.8)	29.0 (18.3-39.7)
September	2.9 (0.71-5.0)	7.0 (2.7-11.3)	0.50 (0.3-1.3)	1.3 (0.5-2.0)	15.3 (2.5-28.0)	66.3 (32.1-100.4)	45.6 (30.9-60.3)	73.3 (29.2-117.3)
60 HERTZ								
June	13.3 (7.5-19.0)	16.6 (1.2-32.1)	4.8 (2.6-7.1)	5.6 (3.2-8.0)	27.0 (12.6-41.5)	13.3 (3.3-23.2)	13.7 (9.2-18.2)	28.3 (6.7-49.8)
July	13.8 (4.8-22.8)	15.9 (5.5-26.3)	10.7 (1.9-19.5)	5.8 (3.6-7.9)	54.6 (8.3-100.9)	13.0 (1.8-24.2)	36.0 (15.3-56.7)	21.5 (6.7-36.3)
August	14.8 (8.0-21.5)	29.8 (18.0-41.5)	14.9 (6.3-23.5)	6.4 (2.7-10.1)	89.7 (42.1-137.2)	18.9 (3.1-34.7)	33.6 (14.6-52.6)	18.0 (12.0-24.0)
September	13.0 (4.0-22.0)	20.8 (7.7-33.9)	9.3 (2.4-16.3)	3.9 (2.1-5.6)	37.3 (16.4-58.1)	19.4 (8.3-30.4)	35.3 (16.9-53.6)	22.6 (13.9-31.4)
HAZLETON								
June	9.5 (5.0-14.0)	16.0 (1.3-30.7)	5.9 (0.6-11.2)	5.1 (1.0-9.3)	57.6 (7.7-107.5)	83.6 (8.7-158.5)	56.4 (15.6-97.2)	53.0 (25.8-80.2)
July	18.6 (7.5-29.7)	19.9 (12.6-27.2)	10.5 (4.2-16.8)	14.8 (8.8-20.7)	85.9 (29.5-142.3)	105.5 (46.9-164.1)	85.3 (41.9-128.6)	75.1 (55.4-94.8)
August	10.3 (3.6-16.9)	17.0 (9.9-24.1)	8.1 (4.1-12.2)	16.6 (9.0-24.2)	47.1 (14.8-79.5)	149.5 (43.4-255.6)	81.8 (47.5-116.0)	88.5 (45.6-131.4)
September	6.8 (1.6-11.9)	16.3 (1.1-31.5)	4.4 (0.7-9.5)	6.1 (3.1-9.1)	63.5 (0.9-126.0)	89.9 (17.5-162.3)	55.0 (0.1-110.1)	59.9 (27.4-92.4)

Table 6.—Test and control means with 95 percent confidence limits.

	Control	Test	Significance
Main			
Mesostigmata	13.71 (10.81–16.61)	12.90 (10.14–15.65)	n.s.
Prostigmata	9.94 (7.13–12.75)	12.54 (9.88–15.21)	n.s.
Cryptostigmata	52.13 (37.67–66.59)	67.50 (47.93–87.07)	n.s.
Collembola	29.63 (22.93–36.32)	31.94 (26.03–37.84)	n.s.
Clover			
Mesostigmata	4.06 (3.14–4.98)	6.77 (5.14–8.41)	$<.025$
Prostigmata	2.41 (1.15–3.66)	4.00 (2.57–5.43)	$<.025$
Cryptostigmata	11.81 (8.63–15.00)	44.42 (32.13–56.71)	$<.001$
Collembola	48.63 (39.13–58.12)	34.84 (23.27–46.40)	$<.01$
60 Hertz			
Mesostigmata	13.71 (10.81–16.61)	20.75 (15.98–25.52)	$<.05$
Prostigmata	9.94 (7.13–12.75)	5.41	n.s.
Cryptostigmata	52.13 (37.67–66.59)	16.13 (11.77–20.48)	$<.001$
Collembola	29.63 (22.93–36.32)	22.59 (17.54–27.65)	n.s.
Hazleton			
Mesostigmata	11.28 (8.39–14.17)	17.28 (13.16–21.41)	n.s.
Prostigmata	7.22 (5.26–9.18)	10.66 (8.17–13.14)	<0.05
Cryptostigmata	63.53 (45.03–82.03)	107.13 (78.15–136.10)	n.s.
Collembola	69.59 (53.64–85.55)	69.13 (57.29–80.96)	n.s.

versa in the test plot, but their ratios converged toward unity in the fall (Fig. 3).

Discussion

Because there are very few long-range studies of soil arthropods, and since this is the 1st study of the effect of extreme low-frequency antenna output on soil organisms, it is useful to examine the appropriateness of the soil arthropod model and more specifically its sensitivity to Sanguine fields and frequencies. Ideally, an indicator population should be: (1) sensitive to Sanguine fields and frequencies; (2) numerically stable from one sampling period to the next and unperturbed by soil surveys; (3) sedentary; (4) rapidly reproducing. No such known population has all these features; in fact, items 2 and 4 are ordinarily mutually exclusive. Soil arthropods have the following features: they are sedentary, probably unperturbed by sampling, and some of the constituent species reproduce rapidly.

The sensitivity of arthropods or other organisms to Sanguine factors has been little explored. What is known, thus far, indicates that there is no demonstrable effect on natural populations of soil arthropods after 2 years of exposure (Greenberg 1972). In a companion study to this one, we (Greenberg 1973). found that there were no significant differences in oxygen consumption and respiratory quotient between exposed and control animals ranging from slugs and earthworms to salamanders. Nelson (1972) showed that selective heating of stored-grain insects occurs with very high frequencies between 40 MHz and 2450 MHz where the wavelengths approach the dimensions of the insect body. But conceptual Sanguine frequencies are 30-Hz to 100-Hz where the wavelengths are measured in thousands of miles, and the required field strength for a thermal effect would be many orders of magnitude greater than that proposed for the Sanguine system. Hopefully, additional light on possible Sanguine effects will be shed at the biochemical, chromosomal, embryologic, neural, and behavioral levels from studies underway in numerous laboratories under the administration of the Office of Naval Research. Lacking a known threshold, or if a threshold much higher than the conceptual Sanguine threshold is found, the task of proving a non-effect will be difficult if not impossible.

An increasing number of environmental scientists are convinced that below threshold there may not be a harmful effect or any effect at all, rather than an effect we are missing simply because we cannot measure it. Dinman (1972) argues that stochastic determinants impose a lower limit on the dose-response relationship between cells and chemicals. Thus, at certain low concentrations molecules of carbon monoxide probably do not have a deleterious effect on normal cellular function. In the absence of data points below an observed dose-effect line it is not justified to extrapolate the regression line through origin. The problem of seeking low-level dose effects from ionizing radiation is discussed by Grahn (1972) and Weinberg (1971). The latter asks, "What is the effect on human health of very low levels of physical insult?" and proposes that such questions are trans-scientific, viz. although seemingly part of science they transcend science because "they are incapable of resolution by science." The following quotation illustrates this dilemma:

"The dose of X-rays, given all at once, that is necessary to double the spontaneous mutation rate in mice is often taken to be 30 rems. One may well ask, assuming the dose-response curve to be linear down to zero dose, how large an experiment would be required to *demonstrate* empirically that 170 millirems (which until recently was about the yearly

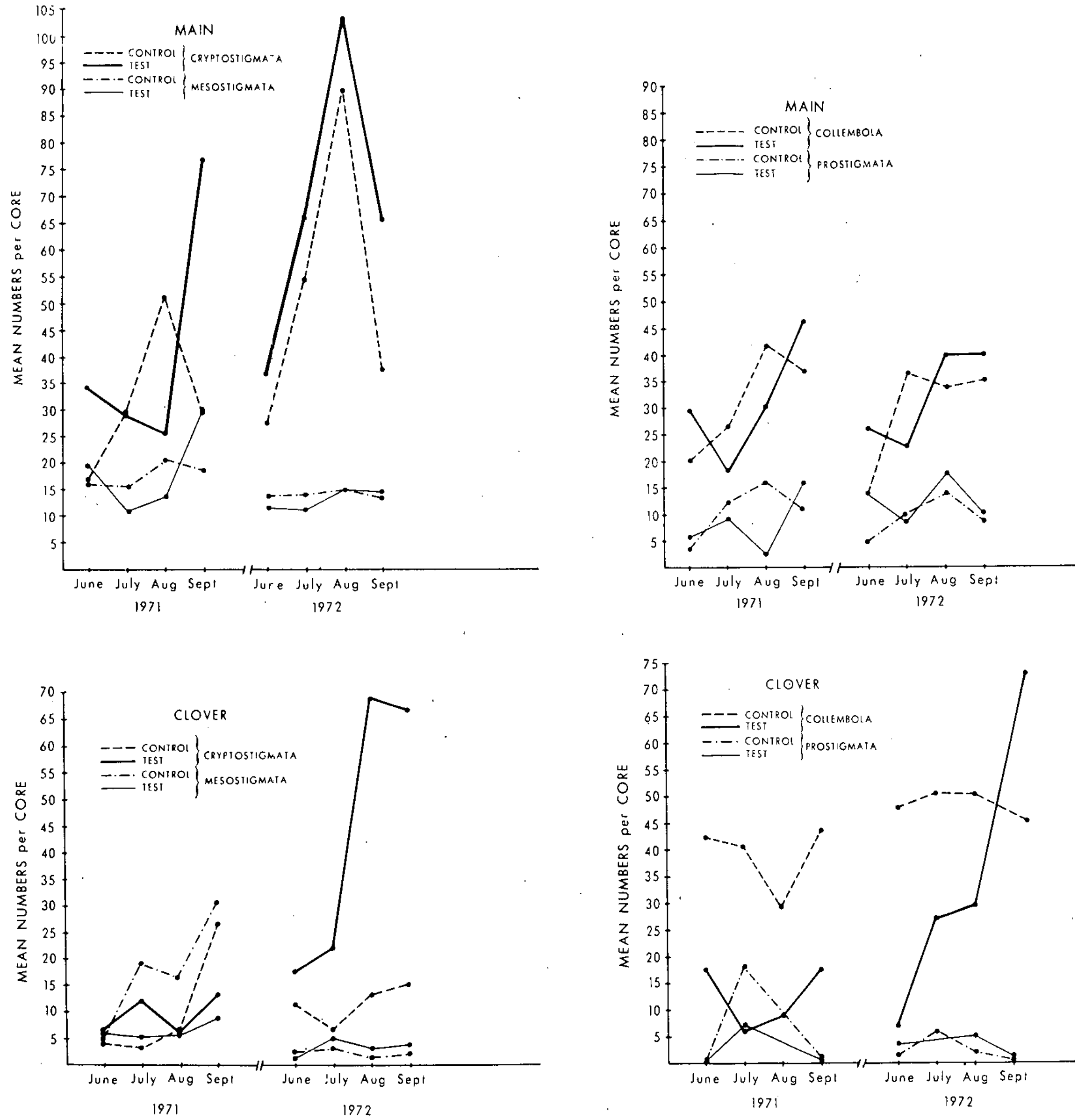

FIG. 1.—Two-year summer population curves of mites and collembolans in Main and Clover experimental plots, based on monthly means.

dose allowed to be imposed by nuclear industry) would increase the mutation rate by the 0.5 percent predicted by the linear dose-response theory? The answer is that around 8×10^9 mice would be required to demonstrate a 0.5% effect at the 95% confidence level. So large an experiment is beyond practical comprehension." The dilemma intensifies when the experimental dose approximates those levels normally present in the environment. This is particularly relevant, since electromagnetic fields produced by the Sanguine antenna are at the same or lower levels than electromagnetic fields normally encountered in and around the home.

Small, subtle Sanguine effects, if they exist, will be obscured by a multiple of environmental variables and obliterated by the elasticity of the populations under study. Obviously, the sensitivity of a monitor increases each year when cumulative effects are present, and it is further enhanced by the considerable biotic potential of soil arthropods. A long-term study enhances the reliability of an assessment of a Sanguine effect while it enables us to seek data on the following: are population pulses annually self-limited, or are they carried over to the next year? Conversely, what is the nature of population rebound from previous low levels? What are the upper and lower density limits of each group, and is there a demonstrable intergroup effect, e.g. are mesostigmate pulses synchronized with cryptostigmate or collembolan pulses? Are population swings correlated with exceptional meteorological factors, e.g. unusually wet or dry summers, cold spring, etc.? A time perspective is particularly necessary in comparing populations of microarthropods, because they normally fluctuate in time and tend to be discontinuous in space.

While it is obviously sound to select control and test plots with the same soils, one should appreciate that hard-and-fast soil classifications are limited in the microfauna. These limitations are due to variations in microhabitat within a single plot, and on a larger scale, to entire zones which may be evolving or in transition caused by logging operations, etc. For example, while young aspen are in process of reclaiming a logged area, and a greater amount of sunlight is reaching the forest floor, we can expect more severe soil temperature and moisture conditions to prevail than later when the cover is more mature. Even in stable soil situations, it is often difficult to relate chemical and physical differences to the composition of the fauna. Thus, Abrahamsen (1972) could not correlate numbers of enchytraeid earthworms in coniferous forest soils with amount of Ca, Mg, Mn, Na, and K. And Hale (1967) pointed out that many species of collembolans are equally common on acidic peats and base-rich soils. Most organisms are sufficiently adaptable to small variations in their environment; this is, in-

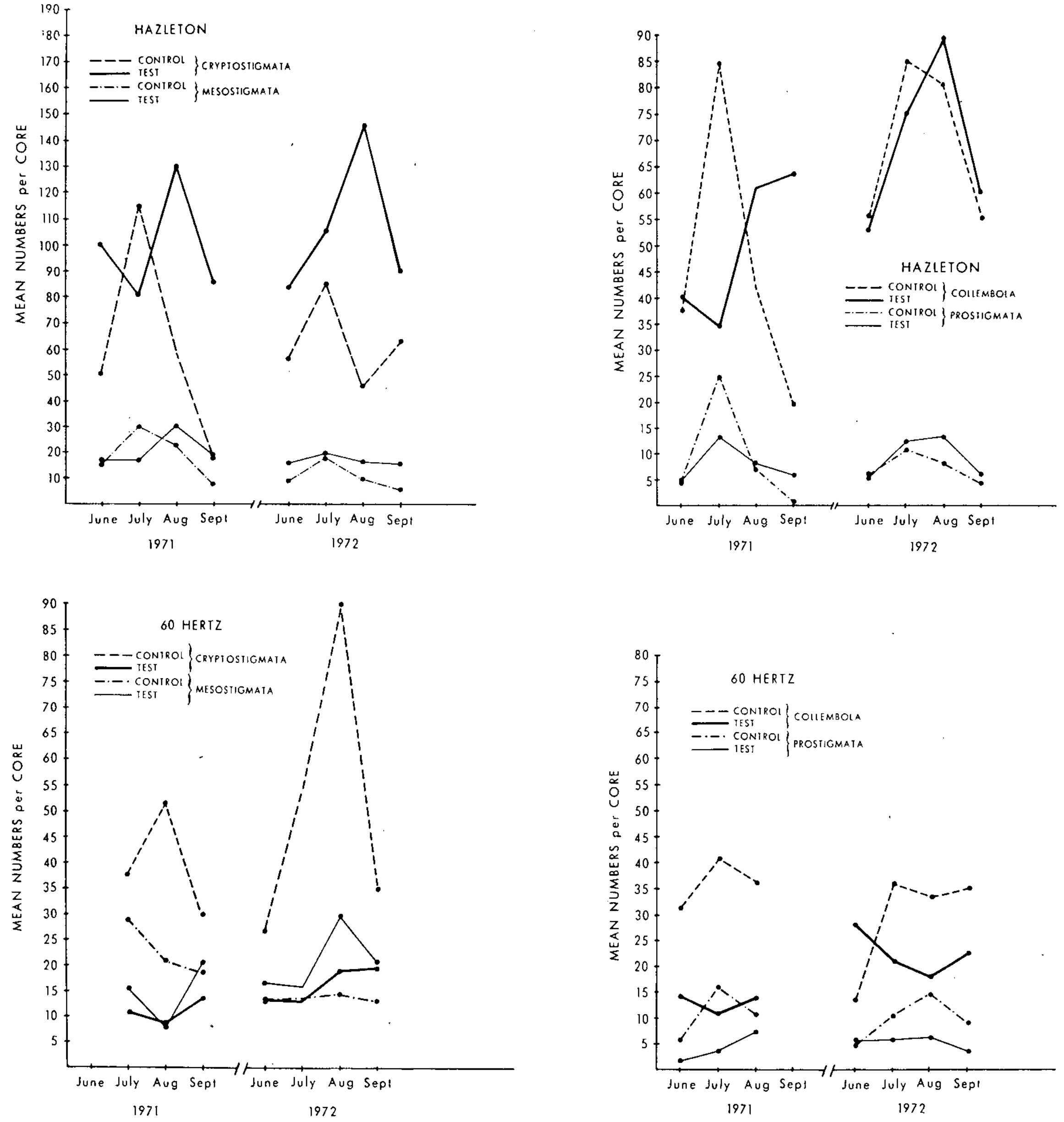

FIG. 2.—Two-year summer population curves of mites and collembolans in Hazleton and 60-Hertz experimental plots, based on monthly means.

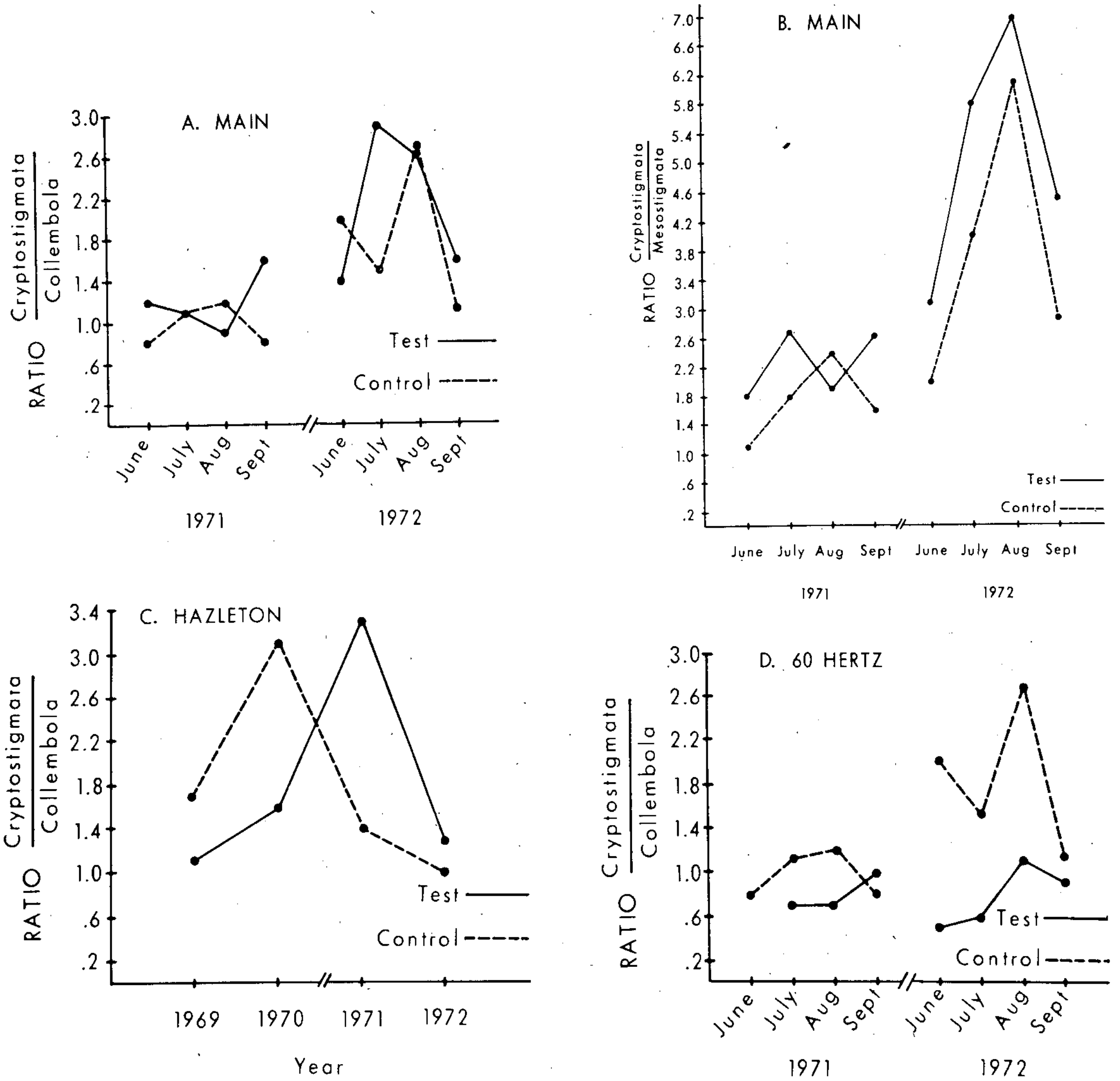

FIG. 3.—Ratio of Cryptostigmata to Collembola (A, C, and D) and to Mesostigmata (B) in test and control plots, based on monthly means. Four-year ratios in Hazleton plots based on July means.

deed, an essential attribute of living things. An analogous situation is the ability of man to adapt to lower oxygen tension at higher altitudes by producing more hemoglobin.

Important factors in the soil environment are moisture, organic matter, exposure, and soil interstices or "Lebensraum". Climate and meteorologic effects interact with these factors to influence population size. Drought accounts for summer minima among mite and collembolan populations in England (Ford 1938, Glasgow 1939, MacFadyen 1952), Denmark (Weis-Fogh 1948), and among cryptostigmates in North Germany (Strenzke 1951). Davis (1963) attributed marked differences in vertical distribution of mites and collembolans from one fall to the next to a very dry summer, and drought accounts for the minimal numbers of enchytraeid earthworms in Nordic soils in May and June (Nurminen 1967). Species of the cosmopolitan and predominant collembolan genus *Lepidocyrtus,* however, were most numerous in summer in uncultivated fields along the Ganges in India, migrating down in the soil to avoid the heat (Choudhuri and Roy 1971).

Ambient temperatures above 33°C are infrequent in our study area in northern Wisconsin, and the forested terrain is interlaced with organic swamps, bogs, and lakes that occupy about 33% of the area; therefore drought is not a general problem. In favorable reproductive temperatures (>12°C) spring often comes late to the North Woods, and fall is relatively early. Under these conditions test and control arthropods have their population peaks in July and August and counts generally fall to early June levels by mid-September. This fact agrees with observations made by investigators in Switzerland and Wales.

Species are not a reliable long-term indicator of a Sanguine effect, because species succession can occur at a surprisingly high rate in an undisturbed situation (Englemann 1961). The higher taxa have greater stability. Based on 4 summers of study of the Hazleton plots and 2 summers of the other plots, we report similar population fluctuations of these higher taxa in test and control plots. Careful comparison of these data reveals almost every combination of greater, fewer, or equal numbers of mites or collembolans without evidence of a correlation with Sanguine fields. Because absolute numbers within plots may vary considerably during and between years, greater reliance is placed on intergroup ratios and annual mean summer populations to provide evidence of significant population shifts. A few examples, drawn from the Hazleton plots, will make this point clear.

1. Although curves of test and control collembolans were 180° out of phase in 1971, they were remarkably similar in 1972 (Fig. 2).
2. Test prostigmates were more numerous ($P < 0.05$) than controls in 1972 but not in 1971. A glance at the curves for both years casts doubt that there is any more significance between tests and controls in 1972 than between controls in both years. In 1971, controls quintupled their spring population, while in 1972 they only doubled. The test group oscillated less in both years (Fig. 2).
3. Fig. 3 illustrates need for a long-range perspective, and it shows 4-year ratios of cryptostigmates: collembolans. If the plots had been studied only in 1970 and 1971 the similarity between test and control curves would have been missed.

The same kinds of examples can be selected from other plots, both test and control, and it is evident that caution must be exercised to avoid attributing a Sanguine effect to population fluctuations that are due to random, natural causes.

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I wish to thank Noreen Ash and Margaret Flowers for excellent technical assistance, and Henry Hegner of the field staff of IIT Research Institute for making electric and magnetic field measurements at all experimental plots. This work was performed for the U. S. Naval Electronic Systems Command under Contract N00039-72-C-0106 with IIT Research Institute.

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