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ELF Communications System Ecological Monitoring Program: Small Vertebrate Studies – Final Report

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13. ABSTRACT *(Maximum 200 words)*

The U.S. Navy has completed a program monitoring 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 small mammals and nesting birds conducted near its transmitting antenna in Michigan.

From 1982 through 1993 researchers from the Michigan State University (MSU) monitored organismal and population aspects of vertebrates in areas near (treatment) and far (control) from the Michigan antenna. They examined the reproductive, developmental, behavioral, and physiological characteristics of representative vertebrate species. Studied species were the deer mouse, chipmunk, tree swallow, and black-capped chickadee. Investigators had also monitored ecological aspects of the mammalian community until 1988 when this study element was discontinued due to highly variable results. In a different project, ornithologists from the University of Minnesota-Duluth monitored the ecological characteristics of the bird community near the ELF System.

The MSU research team used several statistical tests to examine data; however, nested analysis of variance was the most often used test. Based on the results of their study, they conclude that the EM fields produced by the Naval Radio Transmitting Facility-Republic, Michigan did not affect small vertebrates.

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

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EXECUTIVE SUMMARY

The small mammal and nesting bird biological studies assessing the potential effects of the U.S. Navy's extremely low frequency (ELF) Communications System in the western Upper Peninsula of Michigan are summarized for all years of study (1985-1993).

Data on tree swallow fecundity, survival and growth were analyzed in relation to antenna operation period of the Communications System, plot (test or control) and years within operation periods. We focused on the interaction of operation period of the System and plot, since effects of the System would most likely be detected there. There were no convincing differences found due to antenna operation for any of the following variables: adult and immature annual survival probabilities, clutch size, distribution of clutch size, likelihood to hatch, hatch rate, likelihood to fledge, number fledging, growth rates (nonlinear growth constants) and maximum size and age at maximum size of nestlings for body mass, leg length (tarsus), forearm length (ulna), wing length including feathers as they develop, age at eye opening and feather eruption. These variables show significant year effects probably due to weather and also significant effects due to the nest in which they are reared.

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

An analysis of the growth of nestling tree swallows on the test plot in relation to electromagnetic field strengths at each nest box revealed no consistent patterns suggesting an effect

of the Communications System. The variables tested were the same as those used in the growth analysis.

Growth rates and age of incisor eruption of young deer mice were similar between test and control plots and antenna operation periods. However, age at opening of the eyes became significantly earlier on the test plot compared to the control plot when the Communications System entered full operation. This was clearly an effect attributed to full operation of the Communications System. We do not know the mechanism by which the Communications System caused earlier opening of the eyes of young deer mice on the test plot.

In the tree swallow homing study, we found greater numbers of displaced birds returned to test than control plots. The time required to return to the plot was less for test than control birds. We tested the possibility of the site of release as a cause and conclusively rejected it as the source of the differences. Significant differences between the performance of test and control birds were not due to operation of the Communications System because differences were observed every year, both prior to the antenna activation and during full antenna operation. An unexplained decrease in homing speed for test plot birds to the levels of control plot birds occurred over three years during full strength operation of the antenna.

Small mammal homing studies indicated no overall differences in frequency of return for chipmunks or deer mice that could be attributed to operation of the Communications System. In two years, we detected differences in return rates of displaced deermice. However, mice on test plots returned less often in one year and on the control plot in the other, leading us to conclude there was little evidence for an effect due to operation of the Communications System.

Developmental abnormalities in tree swallow embryos were not different in number on test and control plots overall. Means of weights and volumes of eggs from control plots were slightly higher than those from test plots, regardless of the operational status of the Communications System.

Both variables showed significant plot and year effects, but these could not be related to operation of the Communications System.

Maximum aerobic metabolism in winter exhibited no effect of antenna operation for deer mice, although values of metabolic rate for test plots were slightly lower than for control plots all years. Maximal metabolic rates for chickadees also showed no effect that could be attributed to operation of the Communications System.

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GLOSSARY OF ACRONYMS AND TERMS

A - ampere, a measure of electrical current

allometric - a mathematical relationship of the form $Y=aX^b$, where **a** and **b** are constants and Y and X are variables such as metabolic rate and body size

ANCOVA - analysis of covariance. A statistical test for differences between group means of a dependent variable after adjustment based on the relationship of the group means to an independent variable, called the covariate

annual survival probability - the likelihood of a bird being recaptured in following years

ANOVA - analysis of variance. A statistical test to compare means of study groups

blind study - an experiment where the observer does not know the origin of the sample

brood patch - a highly vascularized, unfeathered patch of skin on the female bird's abdomen which comes in contact with the eggs during incubation

catabolize - an animal's use of food for energy

CHT - Cleveland Homestead test plot. Designated by IITRI as 1T2

cloacal protuberance - a lengthened portion of the cloaca characteristic of male, but not female birds

clutch - number of eggs laid in a nest

confidence interval - the certainty (usually 95%) that the average of a variable will fall within the determined range if observed repeatedly

control plots - research areas far removed from the ELF antenna used for comparisons to test plots near the antenna

DF - degrees of freedom. A statistical term generally meaning the sample size minus 1

displaced - a bird or mammal removed from its home range and released at a distant point

diurnal - active during the daylight hours

embryogenesis - the formation and development of an embryo

GLOSSARY OF ACRONYMS AND TERMS (CONTINUED)

histological - microscopic examination of tissues

helox - helium-oxygen atmosphere mix of approximately 79% helium / 21% oxygen

emissivity - the fraction of temperature-dependent maximal possible radiation emitted by a surface at given wavelength

enclosures - large arenas made of acrylic sheeting used to contain deer mice for study

exponential model - a nonlinear mathematical model of the form $\mathbf{Y=ab^x}$ used in this study to describe tree swallow wing growth

F value - the result of the mean square÷error mean square in ANOVA tests

feather eruption - point in time at which primary feathers emerge from the feather sheath

fecundity - measures of reproductive output: clutch size, hatch rate, and fledge rate

fledge - when a nestling leaves the nest permanently

FNT - Ford North test plot. Designated by IITRI as 1T5

FST - Ford South test plot. Designated by IITRI as 1T6

full operation - period when the ELF antenna system was operating at 150 amperes

growth constant - the fitted parameter, K, in the exponential and logistic growth models

homing - the ability of animals to return to their nest box area or home range after displacement

homogeneity of variances - variances of samples in ANOVA tests which do not differ statistically

IITRI - Illinois Institute of Technology Research Institute, Chicago,Illinois

inflection point - for logistic growth curves, it is the age at which 50% of the asymptotic value is obtained

interaction - given two factors (**e.g.**, plot and operation), the effect of one factor (plot) is dependent on the level of another factor (**e.g.**, operation: pre, level one, or full)

intraclass correlation - degree of variability within a group relative to the population

kurtosis - the degree of flattening of the peak in a normal distribution

GLOSSARY OF ACRONYMS AND TERMS (CONTINUED)

landmark event - a specific, important, developmental occurrence common to the species

level one - period when the ELF antenna system was operating at 15 amperes

linear regression analysis - straight line relationship between dependent and explanatory variables

logistic model - a nonlinear mathematical model used to describe tree swallow growth

longitudinal electric field - an electric field in the earth that is the sum of fields induced by the magnetic field and the current flowing from the buried ground terminals of the ELF antenna

magic markers - large felt tip ink pens of various colors

magnetic fields - a field generated by the electrical current in the ELF antenna elements and ground terminals

maximum likelihood estimates - measure of the degree of agreement between the sample and expected frequencies

maximum aerobic metabolism - an animal's peak rate of metabolic heat production

MGE - Michigamme control plot. Designated by IITRI as 1C1 (north part) or 1C3 (south part)

minimum detectable difference - in this study, the smallest detectable difference given a specific sample size, a significance level of 0.05 and 70% power

mortality - a measure of the death rate

MS - mean square; variance associated with the group being tested in ANOVA tests

MSU-TVG - Michigan State University-Terrestrial Vertebrates Group

n - number of individuals in sample

NANOVA - nested analysis of variance. An elaboration of the ANOVA test

nested design - hierarchial (nested) experimental design

normality testing - to determine whether or not the sample was taken from a population with a normal (bell-shaped) distribution

NTT - North Turner test plot. Designated by IITRI as 1T4

GLOSSARY OF ACRONYMS AND TERMS (CONTINUED)

P - probability of obtaining an F value, or other statistic, of the magnitude calculated if in fact all subgroups in an analysis are alike

parsimonious - the simplest explanation

Pesola - brand name of spring scale used to measure weight or body mass

***post hoc* test** - comparison of group means following analysis of variance

power (statistical) - probability of correctly determining whether the ELF antenna had an effect on the variable in question

PPC - Panola Plains control plot. Designated by IITRI as 1C4

preoperation - period prior to the activation of the ELF antenna system

PRT - Pirlot Road test plot. Designated by IITRI as 1T1

R^2 - the fraction of the variability in the dependent variable that is explained by the factors used in an analysis of variance. Also termed the coefficient of multiple determination

robust - the ability of a statistical test to produce valid results irrespective of small irregularities in the data set

SD - standard deviation. Square root of the variance

SE - standard error. Standard deviation ÷ square root of *n*

sigmoidal - S-shaped. The form of most growth curves for tree swallows

skewness - symmetry (or lack of) of a normal data distribution

source (as in the ANOVA tables) - explanatory factor under consideration

SS - sum of squares in ANOVA tests

SYSTAT - statistical software package used for many of the analyses in this report

temporal - time or related to time of events

teratological - abnormal in growth or structure

test plots - research areas located beneath or adjacent to the ELF antenna system

GLOSSARY OF ACRONYMS AND TERMS (CONTINUED)

TMC - Tachycineta Meadows control plot. Designated by IITRI as 1C6

transformation - alteration procedure applied to a data set which eliminates non-normality and variance heterogeneity

transverse electric field - an electric field in the air that is produced as a result of the difference in potential between the antenna element and the earth or created as a by-product of the earth electrical field

variance - sum of the squared deviations from the mean ÷ *n*

X^2 - statistic used to assess differences between frequencies or counts

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PREFACE

This report begins with an extensive statement of the rationale for the studies conducted (see next section, titled "Rationale of Studies"). Next a section is provided outlining the overall research design and research facilities. Individual elements of the work are then described in detail in a series of subsequent sections. Each of the sections on individual work elements consists of four parts: (1) a brief restatement of the purpose (rationale) for the work, (2) a detailed description of research methods, (3) a presentation of results, and (4) conclusions reached concerning possible effects of the Communications System.

RATIONALE OF STUDIES

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

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

In our studies of attributes of individual birds and mammals, we have emphasized ecologically significant variables that are especially likely to be susceptible to perturbation. Reproduction and prenatal development, for example, have received particular attention because they are not only demographically important but are also more likely to be sensitive to adverse environmental changes than many other animal properties (*e.g.* Goodposture 1955, Koskimes 1950, Kluijver 1951, Krebs 1971, Lack 1954, 1966, Nice 1954, Perrins 1965, Perry and Rowlands 1973). Growth and maturation, as impacted by parental behavior, have been studied in depth because they are sometimes modified readily and such modifications can have major repercussions on the lives of individuals and populations (*e.g.* Cohen *et al.* 1980, Green 1979, Morse 1980, O'Connor 1978, Slobodkin 1968).

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

Behavioral Studies

In view of the established sensitivity of certain types of orientational behavior to alteration by ELF electromagnetic fields (*e.g.* Graue 1974, Keeton *et al.* 1974, Larkin and Sutherland 1977, Southern 1969, 1971, 1972a, 1972b, 1973, 1974, 1975, 1976), orientation and homing in the tree swallow, deer mouse, and chipmunk were tested to see if they are affected by the ELF Communications System. Specifically, the ability of animals to return to their home-range or territory after displacement was assessed. We know that animals are able to find food (Krebs 1971, Royama 1966) and escape predators (Metzgar 1967, Watson 1964) more effectively in their home-range or territory than in less familiar areas. Thus, any disturbance of their ability to return to their home-range or territory after wandering afar could decrease their probability of survival.

Reproduction, Growth, and Development

The frequency and types of prenatal developmental abnormalities were examined in tree swallows. Mammals were not studied in this respect because reproductive females would have had to be sacrificed to examine fetuses, and such deaths could have serious, adverse effects on population demographics. Prenatal developmental stages are especially likely to be susceptible to perturbation (Axelsson 1954). Developing avian embryos have two major periods of sensitivity (Hamilton 1952): the first four days following the onset of incubation and the period just prior to hatching. A majority of spontaneously occurring developmental abnormalities manifest themselves during these two periods (Hamilton 1952, Hutt and Crew 1929, Hutt and Greenwood 1929, Hutt and Pilkey 1930, Landauer 1943, Martin and Insko 1935, Riddle 1930). During these periods, the embryos are sensitive to changes in naturally occurring environmental agents such as temperature, humidity, and CO_2, and O_2 concentration (Alsop 1918, Babott 1937, Pembrey *et al.* 1894, Romanoff *et al.* 1938, Taylor *et al.* 1933). Additional teratological agents include vitamins and their antagonists (Cravens 1952), hormones (Zwilling 1956), alcohol and ether (Stockard 1914), metal ions (Ridgeway and Karnofsky 1952), narcotics (Reese 1912), various forms of radiation (Dixon 1952, Gilman and Baetjer 1904, Hinrichs 1927, and Windle 1893, 1895) and physical jarring (Stiles and Watterson 1937) and insecticides (Wyttenbach and Hwang 1984). There is no consensus that electric and magnetic fields of the magnitude generated by the ELF Communications System are capable of directly causing embryonic or fetal developmental defects. Since the onset of this investigation, effects of ELF electromagnetic radiation on the development of chickens in the laboratory studies have been reported (Delgado *et al.* 1982, Juutilainen and Sali 1986, Juutilainen *et al.* 1986, and Ubeda *et al.* 1983). Indirect effects are also possible, especially in field studies. For example, should the incubation behavior of parent birds be disturbed by the ELF Communications System, developing eggs might suffer developmental abnormalities by virtue of experiencing abnormal reductions or fluctuations in temperature (Hamilton 1965, Zwilling 1956). Additionally, should foraging behavior of parent birds be disturbed, the nutrient value of eggs could be affected either quantitatively or qualitatively, again resulting in abnormal development.

We also monitored aspects of fecundity in tree swallows. We counted the number of eggs produced per female and the number of viable eggs and young per clutch. Fecundity is an important variable to study not only because it is demographically significant but also because it reflects on a number of variables that could, in principle, be affected by the ELF Communications System. Alteration of male or female reproductive physiology could affect fecundity. Further, any serious disturbances of embryological development would likely be reflected in a decrease in fecundity inasmuch as abnormal embryos frequently fail to hatch or are discarded by the parents soon after birth.

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

Maximal Aerobic Metabolism

In the region of the ELF Communications System, low temperatures make winter potentially the most physiologically stressful time of year, at least for animals such as chickadees that live wholly or predominantly above the snow. We studied maximal aerobic metabolism, a physiological variable that affects the ability of birds and small mammals to cope with the severity of the winter climate. Deficits in the physiological ability to cope would be expected to decrease the probability of survival to the next reproductive season.

Birds and mammals keep warm in cold environments by producing heat metabolically to offset heat losses. The extent to which they can keep their body temperature above air temperature depends on how rapidly they can produce heat. In other words, the lowest air temperature at which they can maintain their usual body temperature is a function of their maximal rate of aerobic metabolism (= heat production) (Hart 1957). It is in view of these principles that we measured the maximal rate of aerobic metabolism of chickadees and deer mice during winter. This peak rate of heat production is informative not only because it determines the lowest air temperature at which thermoregulation is possible but also because it likely provides an index of metabolic endurance. The higher an animal's maximal rate of heat production is, the longer the animal will be able to maintain any particular submaximal rate of heat production (Astrand and Rodahl 1977, Wickler 1980). Endurance is important because low air temperatures demanding high heat production can persist for long periods of time.

Beyond its immediate significance for survival in a cold climate, the maximal rate of aerobic metabolism is an important measure because it provides an index of physiological health. In fact, peak aerobic metabolism is widely used as such an index in studies of humans. In their classic *Textbook of Work Physiology*, Astrand and Rodahl (1977) state that "the maximal oxygen uptake is probably the best laboratory measure of a person's physical fitness", if by physical fitness we mean the capacity of the individual for prolonged heavy work. Brooks and Fahey (1985), in the best of the recent texts on human exercise physiology, state that the maximal aerobic metabolism is "a good measure of fitness for life in contemporary society". Just as peak aerobic metabolism is used as an index of physical fitness for humans, it can also be so used in studies of animals. A deficit in the peak metabolism among individuals living near the ELF Communications System would indicate that some attribute of the all-important systems involved in oxygen supply and use has been adversely affected by the ELF electromagnetic fields. Additional tests would then be required to determine the particular attribute(s) affected. The ability of the respiratory system to provide oxygen, the ability of the circulatory system to transport oxygen and nutrients to metabolically active tissues, the ability of storage tissues (*e.g.*, adipose tissue) to mobilize stored nutrients, and the enzymatic competence of metabolically active tissues to catabolize nutrients are among the variables that influence an animal's peak rate of aerobic metabolism (Wang 1978). In human studies, peak aerobic metabolism is usually elicited by having individuals run on a treadmill. We elicited peaks by exposing animals to cold, in part because the method is technically simpler than treadmill running (given that deer mice require extensive training to use a treadmill successfully, and that chickadees can not use a treadmill at all) and in part because the cold-induced peak is of immediate relevance to understanding winter ecology.

OVERALL RESEARCH DESIGN AND SUPPORT FACILITIES

To detect possible effects of the ELF Communications System, we compared animal attributes on test plots (or test "sites") with those on paired, spatially separated control plots (or control "sites"). See Figure 1.

Test plots, as specified in the original IITRI Request for Proposals, were to be areas close enough to the Communications System that electric and magnetic fields attributable to the System, and measured near the earth's surface, would approximate 0.07 volt/meter and 0.03 Gauss, respectively. Furthermore, electric and magnetic fields attributable to ELF sources other than the System were to be at least an order of magnitude lower than those attributable to the System.

Control plots, according to the original Request for Proposals, were to be areas sufficiently distant from the Communications System that electric and magnetic fields attributable to the System, measured near the earth's surface, would be at least an order of magnitude, and preferably two orders of magnitude, below those at paired test plots. Furthermore, electric and magnetic fields in the air and earth attributable to ELF sources other than the System (especially 60-Hz sources) were not to differ by more than an order of magnitude between the control plots and their paired test plots.

For purposes of experimental design, the test plots used for any particular work element were paired with particular control plots (Table 1). The plots of a pair were matched as closely as

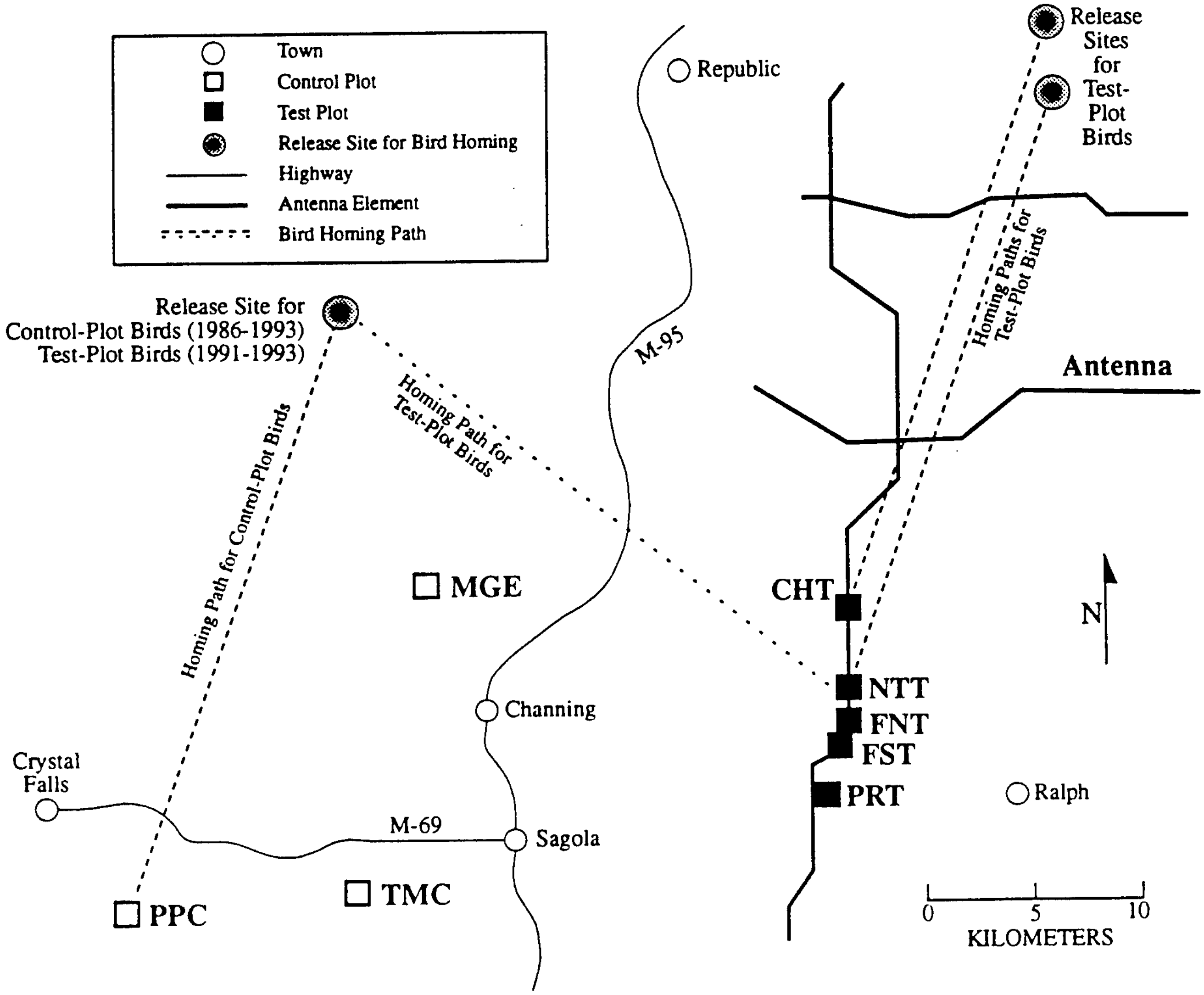

Figure 1. Location of test and control plots in relation to the antenna system. See Table 1 for plot codes

Table 1. Test-control plot pairings for the various work elements for small mammals and nesting birds. Plot code designations are those used by IITRI

STUDY ELEMENT	TEST PLOT	CONTROL PLOT
Deer mouse Growth & Maturation	PIRLOT ROAD (1T1)	MICHIGAMME NORTH & SOUTH (1C1, 1C3)
Small Mammal Homing	PIRLOT ROAD (1T1)	MICHIGAMME NORTH (1C1)
Deer mouse Winter Physiology	PIRLOT ROAD (1T1)	MICHIGAMME NORTH & SOUTH (1C1, 1C3)
Tree Swallow Growth & Maturation	PIRLOT ROAD (1T1)	TACHYCINETA MEADOW (1C6)
Tree Swallow Homing		
(Home Plots)	CLEVELAND HOMESTEAD (1T2)	PANOLA PLAINS (1C4)
	NORTH TURNER ROAD (1T4)	PANOLA PLAINS (1C4)
(Displacement Plots)	CLEVELAND HOMESTEAD DISPLACEMENT (1D1)	-
	NORTH TURNER DISPLACEMENT (1D2)	-
	-	PANOLA PLAINS DISPLACEMENT (1D3)
Tree Swallow Embryology	-	TACHYCINETA MEADOW (1C6)
	FORD RIVER NORTH (1T5)	PANOLA PLAINS (1C4)
	FORD RIVER SOUTH (1T6)	PANOLA PLAINS (1C4)
Black-capped Chickadee Winter Physiology	PIRLOT ROAD (1T1)	MICHIGAMME NORTH (1C1)

Note: Ford River North and Ford River South plots were small. Therefore they were used solely as tree swallow embryology study sites.

possible for vegetation, soil type, drainage, and other such features. By pairing plots in this way, we minimized the likelihood that non-Communications System differences between plots would introduce significant confounding effects into our results.

The paired plot design was a major strength of our research. Within a study year, we could compare possible ELF electromagnetic effects across plots. In addition, we could carry out comparisons for each plot between preoperational and operational years, thereby using each plot as its own control through time. We considered three temporal phases of Communications System operations: 1) pre-operation, 2) testing (or partial) operation[1], and 3) full antenna operation (see Table 10 below).

Different work elements were carried out on different pairs of plots for two major reasons. First, specific work elements could have interfered with other elements if both were carried out on the same populations of animals; areas where we artificially removed animals (*e.g.*, bird embryos), for example, could not be appropriately used for research focusing on attributes of natural populations. Second, the various species we studied do not all occur in similar habitat types; field habitats were required for the swallows, whereas forests were required for the deer mice.

To minimize potentially confounding differences between test and control plots, sham corridors were cut through the forests at the control plots. These corridors were clearings of the same width as the corridors cut for installation of the Communications System antenna near test plots. They were cut with similar equipment, and they were treated similarly after cutting. In brief, the sham corridors were as identical as possible to the antenna corridor except that antenna poles and wires were not installed in the shams. Areas for animal study on control plots and those for animal study on test plots were located about the same distance from the sham corridors and antenna corridor, respectively.

Modifications in Project Scope

The number of study elements was reduced in March, 1989, when budget cuts were made to meet increased wages of non-faculty employees on the project. The wage increases resulted from a labor settlement at Michigan State University. The following research elements were **dropped**: small mammal community studies, small mammal parental care, and tree swallow incubation. All remaining research elements were continued at full strength.

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[1] After the antenna was constructed, testing at increasing strengths and amounts of time occurred.

Support Facilities and Equipment

Our base of operations for the on-site field and laboratory studies has been a large house rented in Crystal Falls, MI (801 Crystal Ave.). The physiology laboratory was installed there. We had a shop for construction and maintenance of field equipment and a large shed for storage of traps, cages, construction materials, and seasonal field equipment. We also had a well established data management system housed there (see below), and living space was provided for employees. We leased and maintained trucks to provide transportation between our base of operations and field research sites in all weather conditions on a year-round basis. In addition, we rented a snowmobile to gain access to our more remote sites during winter and spring when traveling the entire distance by truck was impossible.

The holding facility for temporary housing of animals used in the physiology experiments was located approximately 3.5 miles south of Crystal Falls, MI, in an area with minimal electromagnetic interference.

For data management we employed various models of personal computers at the Michigan State University Museum in East Lansing and at the field laboratory in Crystal Falls. Field data were collected by NEC PC-8201A portable computers. We developed software to standardize and error-check field data as it was recorded, and the collected data were transferred directly to a personal computer at the field laboratory each day. Transferred data were immediately edited and stored on removable and fixed disks for later analysis. Certain data were analyzed as soon as they were collected. This data management design allowed us to collect and analyze large amounts of data very efficiently and accurately. In 1987, we added high-speed tape backup systems to aid in recovery of data should any computer system fail, and for archiving the then voluminous data sets for the various study elements.

Other major equipment is described in connection with individual work elements in the sections that follow.

Measurements of Electromagnetic Fields

Engineers from IITRI measured background 60-Hz electric and magnetic field intensities (produced by electric utility lines) every year starting in 1983 on our test and control plots. All the plot pairs we ultimately used adequately met the standards, described earlier in this report, for 60-Hz field intensities prior to the construction and testing of the antenna system (see below). Electric and magnetic fields produced by the antenna system (middle frequency: 76-Hz) were measured starting in 1986, when low amperage testing began. Measurements were continued each year thereafter.

Measures of antenna fields were made in September or October, except in 1993, when most measures were made in July with only a small number of follow-up measurements made in September. Details of the measurement procedures, measuring equipment, and results of the field-intensity measurements can be found in Enk and Gauger (1985), Brosh *et al.* (1985 and 1986), and Haradem *et al.* (1987, 1988, 1989, 1990, 1991, 1992, 1993 and 1994). For years when antenna operating amperage was constant all year, we have made the assumption that measures made in September and October are representative of field strengths produced by the antenna system during all other times of the year that the Communications System was operational (see page 22 for our approach to years wherein operating amperage changed). We also assumed that measures made at specific sites on a plot are representative of all locations within a plot the same distance from the antenna line.

A Note on Summary Data. On the following pages, we summarize data on electromagnetic fields at our test and control plots in six tables (Tables 2-4 and 7-9). Values for these summary tables were calculated by averaging all measures for a particular plot in each year. For example, measures were made at as many as 18 locations within plot 1T1 (Pirlot Road test plot). All measures made within a given year were averaged to obtain the value reported for a plot in the summary table. See the technical volumes mentioned in the preceding paragraph for greater

Table 2. Mean values for 60-Hz transverse electric fields (V/m) on control and test plots paired by research activity. The values in parentheses are the number of measurements

PLOT	1983-1985	1986	1987	1988	1989	1990	1991	1992	1993
Amps[a]	-	4 amp	15 amp	75 amp	150 amp	150 amp	150 amp	150 amp	150 amp
CONTROL[c]									
1C1	0.001 (4)	0.001 (2)	0.001 (2)	0.001 (2)	0.001 (2)	0.001 (2)	0.001 (2)	0.001 (2)	0.001 (2)
1C3	0.001 (5)	0.001 (2)	0.001 (2)	0.001 (2)	0.001 (2)	0.001 (2)	0.001 (2)	0.001 (2)	b
1C4	0.001 (7)	0.001 (3)	0.001 (3)	0.001 (3)	0.001 (3)	0.001 (3)	0.001 (3)	0.001 (3)	0.001 (3)
1C6	0.001 (4)	0.001 (3)	0.001 (3)	0.001 (3)	0.001 (3)	0.001 (3)	0.001 (3)	0.001 (3)	0.001 (3)
AVG	0.001 (20)	0.001 (10)	0.001 (10)	0.001 (10)	0.001 (10)	0.001 (10)	0.001 (10)	0.001 (10)	0.001 (8)
Tree Swallow release site for control plots									
1D3	d	0.001 (1)	0.001 (1)	0.001 (1)	0.001 (1)	0.001 (1)	0.001 (1)	0.001 (1)	0.001 (1)
TEST									
1T1	0.001 (11)	0.001 (14)	0.001 (14)	0.028 (18)	0.015 (8)	0.005 (18)	0.001 (11)	0.001 (10)	0.037 (10)
1T2	0.001 (3)	0.001 (4)	0.046 (5)	0.013 (5)	0.004 (5)	0.017 (5)	0.027 (5)	0.006 (5)	0.010 (5)
1T4	0.001 (4)	0.001 (5)	0.001 (10)	0.014 (10)	0.002 (10)	0.031 (10)	0.037 (10)	0.007 (10)	0.002 (10)
1T5	0.001 (5)	0.001 (6)	0.001 (9)	0.037 (9)	e	0.046 (9)	0.068 (7)	0.012 (9)	0.003 (8)
1T6	0.001 (4)	0.001 (1)	0.001 (7)	0.078 (7)	e	0.037 (7)	e	0.014 (7)	0.026 (7)
Avg	0.001 (27)	0.001 (30)	0.025 (45)	0.034 (49)	0.007 (23)	0.027 (49)	0.029 (34)	0.010 (41)	0.016 (40)
Tree Swallow release sites for test plots (averaged)									
1D1&2	d	1.251 (2)	0.001 (2)	4.601 (2)	0.372 (2)	0.678 (2)	1.254 (2)	4.407 (2)	10.003 (2)

[a] current flow in the antenna in amperes. [b] measures not taken. [c] measures reported by IITRI as < 0.001 were assigned the value 0.001. [d] plot not established in this year. [e] measurement precluded by antenna operation.

detail.

60-Hz Fields - Background measures. Measurement of background 60-Hz fields on control and test plots began in 1983. These fields are produced by existing power lines near the study plots. Plots were chosen to have minimal values for 60-Hz fields and to be matched as control and test plots so they would have values within one order of magnitude or less of each other. Transverse electric fields were initially at or near the lower limits of measurability on all plots (Table 2). After the antenna was constructed and low power testing was begun, starting in 1986 and continuing through 1988, values for transverse electric fields increased on all test plots but especially in 1987 on Cleveland Homestead test plot (1T2). Apparently the fields produced by power lines (inactive prior to 1986) near Cleveland Homestead test plot coupled to the antenna and re-radiated as 60-Hz fields (J. Gauger, IITRI, personal communication). Similar or greater increases occurred on Ford River North and South test plots (1T5, 1T6) in 1988 and later years, due to unknown factors. Control plots remained unaffected.

Among the control plots, Michigamme North and South (1C1, 1C3) tended to be higher than the others for 60-Hz longitudinal electric fields (Table 3). Test plots Ford River North and South (1T5, 1T6) were higher than other test sites in most years (perhaps due to a railroad track near these plots).

Table 3. Mean values for 60-Hz longitudinal electric fields (mV/m) on test and control plots for years 1983 to 1993. The values in parentheses are the number of measurements

PLOT	1983-1985	1986	1987	1988	1989	1990	1991	1992	1993
Amps[a]	-	4 amp	15 amp	75 amp	150 amp	150 amp	150 amp	150 amp	150 amp
CONTROL[c]									
1C1	0.093 (5)	0.100 (2)	0.114 (2)	0.338 (2)	0.137 (2)	0.056(2)	0.082 (2)	0.097 (2)	0.161 (2)
1C3	0.158 (5)	0.080 (2)	0.148 (2)	0.117 (2)	0.178 (2)	0.110 (2)	0.102 (2)	0.112 (2)	b
1C4	0.039 (7)	0.065 (3)	0.047 (3)	0.048 (3)	0.024 (3)	0.022 (3)	0.036 (2)	0.130 (3)	0.055 (3)
1C6	0.079 (4)	0.068 (3)	0.089 (3)	0.041 (3)	0.079 (3)	0.066 (3)	0.062 (3)	0.047 (3)	0.074 (3)
AVG	0.092 (20)	0.076 (10)	0.100 (10)	0.136 (10)	0.105 (10)	0.064 (10)	0.069 (9)	0.097 (10)	0.089 (8)
Tree Swallow release site for control plots									
1D3	[d]	0.052 (1)	0.156 (1)	0.053 (1)	0.290 (1)	0.260 (1)	0.103 (1)	0.039 (1)	0.008 (1)
TEST									
1T1	0.116 (11)	0.070 (14)	0.070 (14)	0.252 (18)	0.080 (8)	0.068 (18)	0.060 (18)	0.028 (10)	0.179 (10)
1T2	0.196 (3)	0.074 (4)	0.059 (5)	0.075 (5)	0.047 (5)	0.051 (5)	0.057 (5)	0.060 (5)	0.063 (5)
1T4	0.174 (4)	0.086 (5)	0.076 (10)	0.110 (10)	0.046 (10)	0.167 (10)	0.100 (10)	0.081 (10)	0.031 (10)
1T5	0.253 (5)	0.079 (6)	0.178 (9)	0.159 (9)	[e]	0.181 (9)	0.136 (9)	0.060 (9)	0.038 (9)
1T6	0.569 (3)	0.230 (1)	0.297 (7)	1.324 (7)	[e]	0.443 (12)	0.272 (11)	0.062 (7)	0.205 (7)
Avg	0.262 (26)	0.080 (30)	0.108 (45)	0.384 (49)	0.058 (23)	0.187 (54)	0.124 (53)	0.070 (41)	0.102 (41)
Tree Swallow release sites for test plots (averaged)									
1D1&2	[d]	5.035 (2)	1.280 (2)	0.715 (2)	1.695 (2)	1.275 (2)	1.540 (2)	2.275 (2)	1.170 (2)

[a] current flow in the antenna in amperes. [b] measures not taken. [c] measures reported by IITRI as < 0.001 were assigned the value 0.001. [d] plot not established in this year. [e] measurement precluded by antenna operation.

Magnetic 60-Hz fields were low on test and control plots in 1985 (Table 4) but increased on test plots from 1986 through 1991 and then declined in 1992. On test plots, average magnetic fields varied from a low of 0.001 mG (1T1 through 1T6, 1985) to a high of 0.094 mG (1T6, 1988) (Table 4). Magnetic fields show larger values for Tachycineta Meadows control plot (1C6) but no

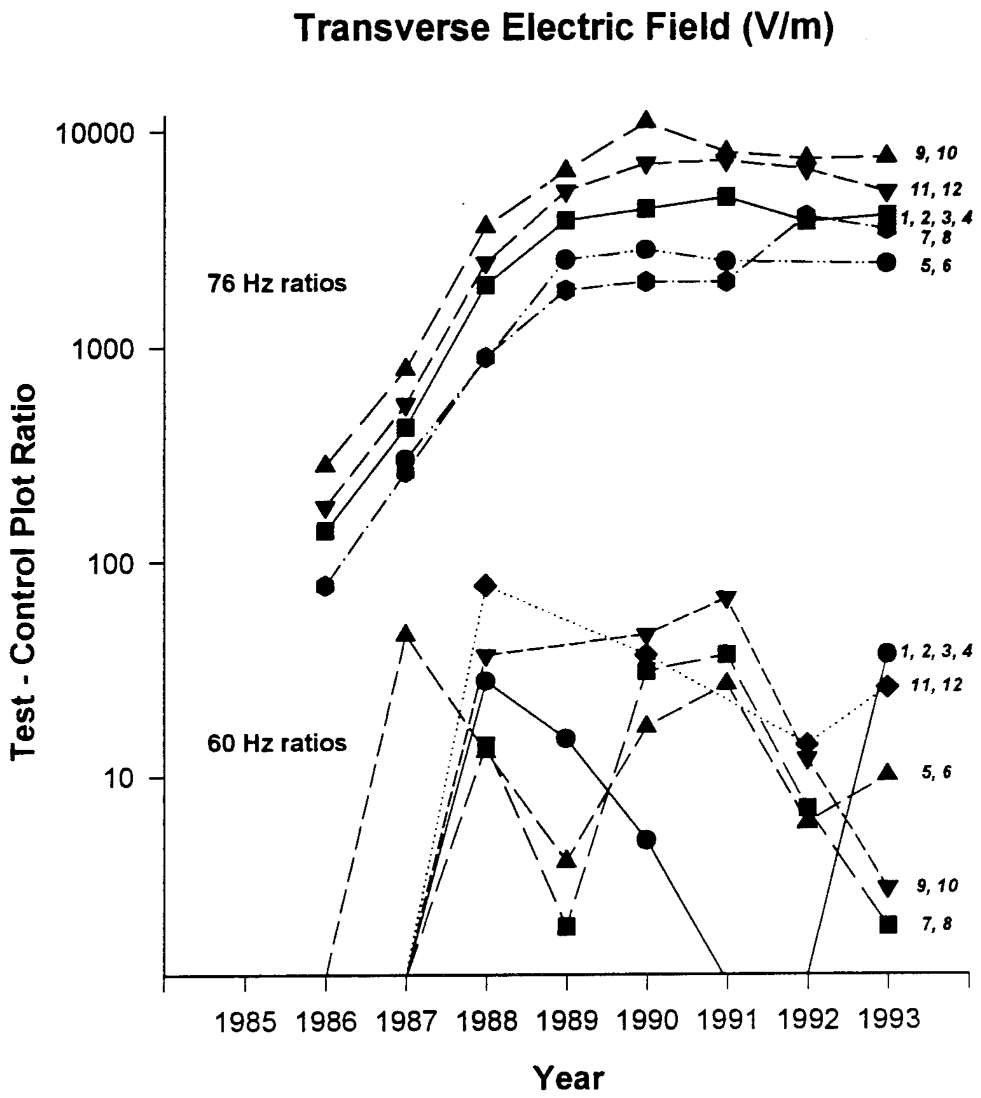

Transverse Electric Field (V/m)

Figure codes: 1= 1T1-1C1, 2= 1T1-1C3, 3= 1T1-1C4, 4= 1T1-1C6, 5= 1T2-1C6, 6= 1T2-1C4, 7= 1T4-1C4, 8= 1T4-1C6, 9= 1T5-1C4, 10= 1T5-1C6, 11= 1T6-1C4, 12=1T6-1C6.

Figure 2. Ratios of 60-Hz and 76-Hz transverse electric fields for test-control plots paired for various research tasks. See Table 1 for plot codes

patterns in other control plots.

The ratios of averaged 60-Hz transverse field values on combinations of test and control plots used for specific study tasks (see pairings in Table 1) indicate increasing levels of these fields on test plots (Figure 2).

Table 4. Mean values for 60-Hz magnetic fields (mG) on test and control plots for years 1983 to 1993. The values in parentheses are the number of measurements

PLOT	1983-1985	1986	1987	1988	1989	1990	1991	1992	1993
Amps[a]	-	4 amp	15 amp	75 amp	150 amp	150 amp	150 amp	150 amp	150 amp
CONTROL[c]									
1C1	0.001 (4)	0.001 (2)	0.001 (2)	0.001 (2)	0.001 (2)	0.001 (2)	0.001 (2)	0.001 (2)	0.001 (2)
1C3	0.002 (5)	0.001 (2)	0.001 (2)	0.001 (2)	0.001 (2)	0.001 (2)	0.001 (2)	0.001 (2)	b
1C4	0.002 (7)	0.001 (3)	0.002 (3)	0.001 (3)	0.001 (3)	0.002 (3)	0.001 (3)	0.003 (3)	0.003 (3)
1C6	0.003 (4)	0.003 (3)	0.003 (3)	0.002 (3)	0.003 (3)	0.003 (3)	0.002 (3)	0.003 (3)	0.003 (3)
AVG	0.002 (20)	0.002 (10)	0.002 (9)	0.001 (10)	0.002 (10)	0.002 (10)	0.001 (10)	0.002 (10)	0.002 (8)
Tree Swallow release site for control plots									
1D3	d	0.003 (1)	0.002 (1)	0.002 (1)	0.013 (1)	0.009 (1)	0.009 (1)	0.009 (1)	0.008 (1)
TEST									
1T1	0.003 (11)	0.009 (14)	0.010 (14)	0.052 (18)	0.018 (8)	0.008 (18)	0.012 (18)	0.006 (18)	0.040 (10)
1T2	0.001 (3)	0.025 (4)	0.018 (5)	0.010 (5)	0.006 (5)	0.018 (5)	0.019 (5)	0.011 (5)	0.013 (5)
1T4	0.001 (4)	0.012 (5)	0.021 (10)	0.018 (10)	0.007 (10)	0.033 (10)	0.031 (10)	0.013 (10)	0.002 (10)
1T5	0.001 (5)	0.018 (6)	0.026 (9)	0.047 (9)	e	0.038 (9)	0.048 (9)	0.017 (9)	0.002 (9)
1T6	0.001 (3)	0.020 (1)	0.033 (7)	0.094 (7)	e	0.040 (12)	0.024 (12)	0.017 (7)	0.020 (7)
Avg	0.001 (26)	0.014 (30)	0.020 (45)	0.044 (49)	0.010 (23)	0.026 (54)	0.025 (54)	0.022 (41)	0.016 (41)
Tree Swallow release sites for test plots (averaged)									
1D1&2	d	0.057 (2)	0.080 (2)	0.023 (2)	0.078 (2)	0.073 (2)	0.130 (2)	0.143 (2)	0.253 (2)

[a] current flow in the antenna in amperes. [b] measures not taken. [c] measures reported by IITRI as < 0.001 were assigned the value 0.001. [d] plot not established in this year. [e] measurement precluded by antenna operation.

Averaged values for longitudinal electric and magnetic 60-Hz fields (Table 3 and Table 4) were low and within an order of magnitude for test-control plot ratios prior to 1986 (Figure 3 and Figure 4), except for the plot pair Ford South test-Panola Plains control (1T6-1C4) for the longitudinal field. This pair had a ratio of 14.6 in 1985, which is slightly above the order of magnitude standard, but was considered acceptable. In 1986 and later years, some test plot values increased compared to control plots, producing test-control plot ratios from about 1 to over 32 fold.

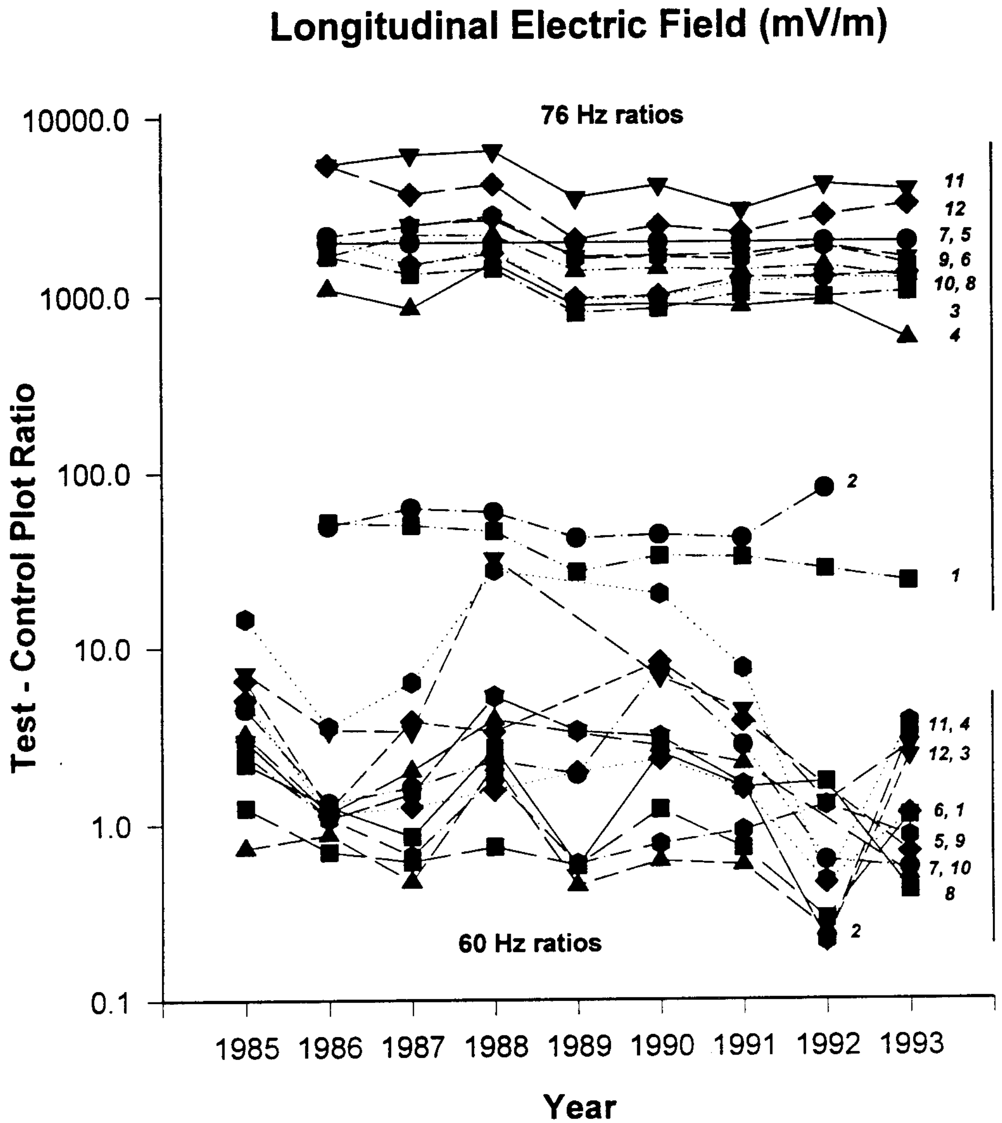


Figure codes: 1= 1T1-1C1, 2= 1T1-1C3, 3= 1T1-1C4, 4= 1T1-1C6, 5= 1T2-1C6, 6= 1T2-1C4, 7= 1T4-1C4, 8= 1T4-1C6, 9= 1T5-1C4, 10= 1T5-1C6, 11= 1T6-1C4, 12=1T6-1C6.

Figure 3. Ratios of 60-Hz and 76-Hz longitudinal electric fields for test-control plots paired for various research tasks. See Table 1 for plot codes

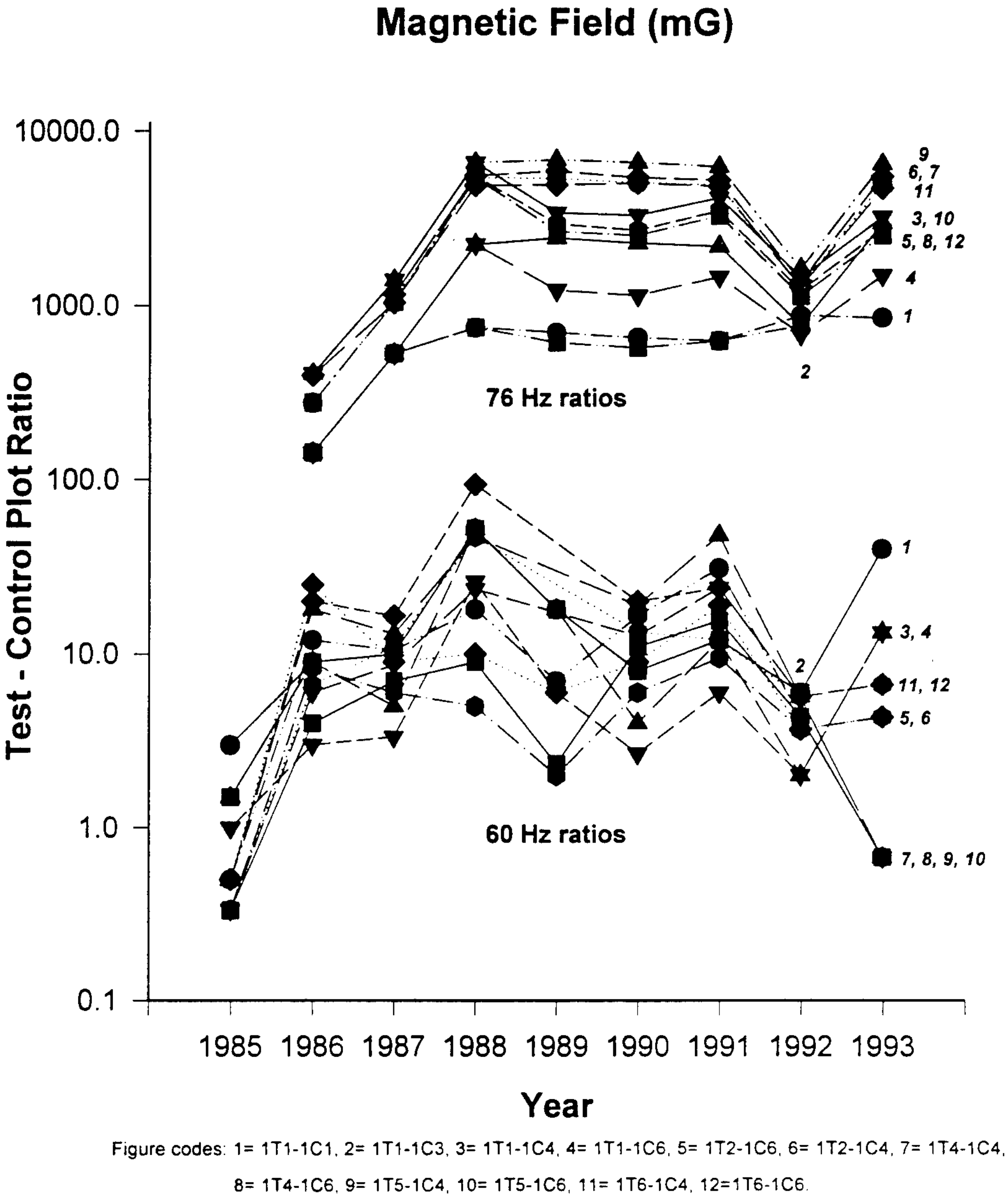


Figure 4. Ratios of 60-Hz and 76-Hz magnetic fields for test-control plots paired for various research tasks. See Table 1 for plot codes

with the highest value in 1988 for the plot pair Ford River South test-Tachycineta Meadows control (1T6-1C6) (Table 3). Test plots 1T2 through 1T6 all increased in 1986, 1987, and 1988 (Table 4) but then decreased in 1992.

The control release location (1D3) and Panola Plains control (1C4) nesting site for tree swallow homing showed small differences in field strength for electric and magnetic fields (Tables 2-4). However, much larger ratios appeared between test release locations (1D1 and 1D2) and their corresponding test nesting sites, Cleveland Homestead and North Turner (1T2, 1T4), for transverse, longitudinal and magnetic fields (Tables 2-4).

Table 5. 60-Hz air electric field intensities (V/m) measured at the laboratory where maximal aerobic metabolic was under study. From IITRI, Tech. Rept. D06205-1, Table A-9, pg A-66

					1990-Shielding	
Measure	1986	1987	1988	1989	Before	After
1L1-1	/	*	*	*	*	*
1L1-2	0.940	0.960	*	*	*	*
1L1-3	0.790	0.034	/	/	/	0.580
1L1-4	0.042	0.047	0.062	/	/	/
1L1-5	-	-	-	/	/	/
1L1-6	-	-	-	/	/	/
1L1-7	-	-	-	8.10	8.50	1.340
1L1-8	-	-	-	0.88	0.76	0.037
1L1-9	-	-	-	60.0	18.10	3.90[a]
1L1-10	-	-	-	-	/	0.010

- measurement point not established. * measurement point dropped. / data not taken. [a] with humidifier on, 4.0 V/m.

Assessments of 60-Hz fields were also conducted in the laboratory where the actual measurements of maximal metabolic rates were taken. Fields at locations near equipment and in the outdoor animal holding facilities were measured by IITRI personnel. Magnetic and electric field shielding was designed and provided by IITRI in 1990 for animal metabolic chambers which were placed in a water bath during metabolic runs. The water bath's compressor, electric motor and pump were also shielded. The shielding and grounding of lights, desks and large equipment significantly reduced the strength of electric and magnetic fields in the laboratory (Table 5 and Table 6).

76-Hz Fields. In 1986, and thereafter, measurements were made on 76-Hz fields produced by the antenna during testing and full operation. Variation of 76-Hz fields was examined among control plots to see if fields were homogeneous. Control plots were all uniform with respect to transverse electric (Table 7) and magnetic fields (Table 9). Longitudinal electric fields measured in control plots Michigamme North and Michigamme South (1C1, 1C3) were significantly greater than in Panola Plains and Tachycineta Meadows (1C4, 1C6) (Table 8).

Table 6. 60-Hz magnetic flux densities (mG) measured at the laboratory where maximal aerobic metabolism was under study. From IITRI , Tech. Rept. D06205-1, Table A-10, pg A-67, 1992

Measure	1986	1987	1988	1989	1990
1L1-1	9.13	*	*	*	*
1L1-2	0.179	0.156	*	*	*
1L1-3	0.080	0.143	/	/	0.071
1L1-4	0.114	0.118	0.080	0.075	/
1L1-5	-	-	-	14.1[a]	5.200[c]
				21.0[b]	0.620[d]
1L1-6	-	-	-	3.2[a]	2.400[c]
				44.0[b]	0.195[d]
					0.081[e]
1L1-7	-	-	-	0.65	1.69
1L1-8	-	-	-	1.46	0.88
1L1-9	-	-	-	48.0	0.86
1L1-10	-	-	-	-	0.75

[a] measurement made in vertical orientation only in an open, unshielded can, submerged to its rim. [b] measurement made above the bath surface. [c] measurement made in closed, unshielded, fully submerged can. [d] measurement made in closed, shielded, fully submerged can. [e] measurement made in closed, shielded, fully submerged can with motor and pump shielding. - measurement point not established. * measurement point dropped. / data not taken.

Among test plots, Ford River North (1T5) was greater than other sites for transverse electric fields, and Ford River South (1T6) was greater than other sites for longitudinal electric fields. No other patterns emerged.

The reasons for these differences are not known to us. The control plots Michigamme North and Michigamme South (1C1, 1C3) were closer to the antenna system than the other control plots by several km, perhaps explaining their higher values. Test site electric fields perhaps differed from each other because of variations in soil conductivity between and across sites.

76-Hz Test-control Plot Ratios. Since the values of the electric and magnetic fields varied over years and among plots, it is important to examine to what degree control and test plots differed. Transverse and longitudinal electric and magnetic 76-Hz fields were at least one to two orders of magnitude higher on test plots than on control plots during full operation of the antenna (Figures 2-4). This level of difference was present even during the part-time operation of low-amperage testing in 1986-1988. This produced a "treatment" condition on test plots during the time the antenna was functioning. However, the amount of time the antenna was functioning during these years varied greatly (see below).

The level of difference in test and control plot pairs used for specific research tasks was about the same for all test-control plot pairs, except for Pirlot Road-Michigamme North (1T1-1C1) and Pirlot Road-Michigamme South (1T1-1C3), which had consistently lower ratios for all years (Figures 2-4). Ratios a full order of magnitude lower occurred for longitudinal electric fields (Figure 3). These plot pairs were used for study of deer mouse growth and maturation and small mammal homing (Table 1). The reason for much lower test-control plot ratios was the much higher values of electric and magnetic fields on the control plots. As mentioned earlier, control plots Michigamme North and Michigamme South (1C1, 1C3) were closer to the antenna line (Figure 1) than other control plots, perhaps causing them to have higher levels of electric and magnetic fields.

The release sites for tree swallow homing studies compared to their respective nesting plots were uniformly low for control and somewhat higher for test sites (Tables 7-9). Using the values in Tables 7-9, one can see that test-control release site ratios generally increased from 1986 to 1991, although transverse fields showed a drop in 1988 and increased again in 1989 and 1991. However,

Table 7. Mean values for 76-Hz magnetic fields (mG) on test and control plots for years 1986 (4 amperes), 1987 (15 amperes), 1988 (75 amperes), 1989 - 1993 (150 amperes)

PLOT	1986	1987	1988	1989	1990	1991	1992	1993
Amps[a]	4 amp	15 amp	75 amp	150 amp	150 amp	150 amp	150 amp	150 amp
CONTROL[c]								
1C1	0.001 (1)	0.001 (2)	0.003 (2)	0.007 (2)	0.007 (2)	0.007 (2)	0.007 (2)	0.007 (2)
1C3	0.001 (1)	0.001 (2)	0.003 (2)	0.008 (2)	0.008 (2)	0.007 (2)	0.008 (2)	b
1C4	0.001 (1)	0.001 (3)	0.001 (3)	0.002 (3)	0.002 (3)	0.002 (3)	0.008 (3)	0.002 (3)
1C6	0.001 (1)	0.001 (3)	0.001 (3)	0.004 (3)	0.004 (3)	0.003 (3)	0.009 (3)	0.004 (3)
Tree Swallow release site for control plots								
1D3	0.001 (1)	0.001 (1)	0.002 (1)	0.008 (1)	0.008 (1)	0.004 (1)	0.011 (1)	0.009 (1)
TEST								
1T1	0.143 (14)	0.530 (14)	2.251 (18)	4.921 (18)	4.593 (18)	4.410 (18)	6.180 (10)	6.017 (10)
1T2	-[d]	1.164 (5)	5.538 (5)	11.800 (5)	10.860 (5)	10.520 (5)	11.060 (5)	11.060 (5)
1T4	0.278 (5)	1.050 (10)	5.410 10)	10.700 (10)	10.160 (10)	9.890 (10)	10.250 (10)	10.210 (10)
1T5	0.408 (5)	1.409 (9)	6.600 (9)	13.678 (9)	13.256 (9)	12.533 (9)	13.130 (9)	13.022 (9)
1T6	0.400 (1)	1.043 (7)	4.889 (7)	9.843 (7)	10.114 (7)	9.700 (7)	10.290 (7)	9.494 (7)
Tree Swallow release sites for test plots (averaged)								
1D1&2	0.001 (2)	0.002 (2)	0.007 (2)	0.090 (2)	0.105 (2)	0.121 (2)	0.090 (2)	0.104 (2)

[a] current flow in the antenna in amperes. The current flow listed is that prevailing during electromagnetic field measurements and in years before 1990 may not apply to all parts of the year (see text). [b] measures not taken. [c] measures reported by IITRI as < 0.001 were assigned the value 0.001. [d] plot not yet established

birds were only exposed to electric and magnetic fields at release sites for at most one hour. While this was a very short exposure time, we did test birds to see if release sites were having an impact in homing performance (see section on homing).

Operational Progression of the Communications System. Over the years of the study, the antenna system was gradually placed into full operation (Table 10). During the transition years between preoperation and full operation, the operation of the antenna varied markedly in time as well as in strength. Each study task was conducted at a time of year dictated by the biology of the animals under study. In categorizing years as preoperational, partially operational, or fully operational for particular study elements, we have been certain to use data on antenna operation relevant to the actual times when data on the particular study element were collected. In this regard, it should be noted, for example, that studies in 1988 were performed with the antenna current at 15

Table 8. Mean values for 76-Hz longitudinal electric fields (mV/m) on test and control plots for years 1986 (4 amperes), 1987 (15 amperes), 1988 (75 amperes), 1989 - 1993 (150 amperes)

PLOT	1986	1987	1988	1989	1990	1991	1992	1993
Amps[a]	4 amp	15 amp	75 amp	150 amp	150 amp	150 amp	150 amp	150 amp
CONTROL[c]								
1C1	0.021 (1)	0.085 (2)	0.430 (2)	1.505 (2)	1.185 (2)	1.251 (2)	1.350 (2)	1.360 (2)
1C3	0.022 (1)	0.068 (2)	0.335 (2)	0.960 (2)	0.895 (2)	0.945 (2)	0.470 (2)	b
1C4	0.001 (1)	0.003 (3)	0.013 (3)	0.046 (3)	0.044 (3)	0.046 (3)	0.040 (3)	0.047 (3)
1C6	0.001 (1)	0.005 (3)	0.020 (3)	0.079 (3)	0.074 (3)	0.062 (3)	0.060 (3)	0.057 (3)
Tree Swallow release site for control plots								
1D3	0.008 (1)	0.053 (1)	0.210 (1)	0.850 (1)	0.890 (1)	0.630 (1)	0.690 (1)	0.650 (1)
TEST								
1T1	1.089 (14)	4.244 (14)	19.900 (18)	40.606 (18)	39.433 (18)	39.778 (18)	37.730 (10)	32.300 (10)
1T2	-[d]	7.500 (5)	34.600 (5)	76.200 (5)	73.600 (5)	77.800 (5)	76.000 (5)	75.600 (5)
1T4	2.162 (5)	7.390 (10)	36.300 (10)	74.400 (10)	72.300 (10)	73.100 (10)	75.200 (10)	70.400 (10)
1T5	1.670 (5)	6.600 (9)	28.444 (9)	63.222 (9)	62.333 (9)	63.444 (9)	58.440 (9)	59.444 (9)
1T6	5.400 (1)	18.457 (7)	83.857 (7)	162.286 (7)	181.714 (7)	138.714 (7)	167.140 (7)	183.429 (9)
Tree Swallow release sites for test plots (averaged)								
1D1&2	0.068 (2)	0.320 (2)	1.365 (2)	8.650 (2)	8.150 (2)	7.950 (2)	8.800 (2)	11.300 (2)

[a] current flow in the antenna in amperes (see note to Table 7). [b] measures not taken. [c] measures reported by IITRI as < 0.001 were assigned the value 0.001. [d] plot not established in this year.

amperes, but the measurements made in the fall were done when the antenna current was 75 amperes. Thus, to estimate electromagnetic exposures during studies in 1988, it was appropriate to use electromagnetic field data gathered during a period of 15-ampere operation in 1987 rather than the data gathered in 1988 itself.

The values for electric and magnetic fields presented in Tables 2-4 and 7-9 are treated as averages for a plot during the time the antenna was actually in operation. As already noted, there were many days and months early in the testing of the antenna (1986-1988) when the antenna was not activated. Even in fully operational years, the antenna was still not active 100% of the time, but certainly most of the time. Because of the pattern of on and off times, some of our research tasks were less impacted than others. In the introduction to each research task (see below), we provide an estimate of the percentage of time the antenna was on during the research. It was assumed that the field strengths and the percentage of time on during a research task represented a good estimate of

Table 9. Means for 76-Hz transverse electric fields (V/m) on test and control plots for 1986 (4 amperes), 1987 (15 amperes), 1988 (75 amperes), 1989 - 1993 (150 amperes)

PLOT	1986	1987	1988	1989	1990	1991	1992	1993
Amps[a]	4 amp	15 amp	75 amp	150 amp	150 amp	150 amp	150 amp	150 amp
CONTROL[c]								
1C1	0.001 (2)	0.001 (2)	0.001 (2)	0.001 (2)	0.001 (2)	0.001 (2)	0.001 (2)	0.001 (2)
1C3	0.001 (2)	0.001 (2)	0.001 (2)	0.001 (2)	0.001 (2)	0.001 (2)	0.001 (2)	[b]
1C4	0.001 (3)	0.001 (3)	0.001 (3)	0.001 (3)	0.001 (3)	0.001 (3)	0.001 (3)	0.001 (3)
1C6	0.001 (3)	0.001 (3)	0.001 (3)	0.001 (3)	0.001 (3)	0.001 (3)	0.001 (3)	0.001 (3)
Tree Swallow release site for control plots								
1D3	0.001 (1)	0.001 (1)	0.001 (1)	0.001 (1)	0.001 (1)	0.001 (1)	0.001 (1)	0.001 (1)
TEST								
1T1	0.078 (14)	0.264 (14)	1.230 (13)	1.834 (18)	2.000 (18)	2.000 (18)	4.040 (10)	3.495 (9)
1T2	[b]	0.301 (5)	[b]	2.540 (5)	2.819 (5)	2.487 (5)	[b]	2.424 (5)
1T4	0.140 (5)	0.424 (10)	1.936 (10)	3.851 (10)	4.373 (10)	4.948 (10)	3.800 (10)	4.070 (10)
1T5	0.283 (5)	0.790 (9)	3.614 (9)	6.531 (9)	11.002 (9)	7.998 (9)	7.400 (9)	7.529 (9)
1T6	0.182 (1)	0.544 (7)	2.458 (7)	5.275 (7)	7.070 (7)	7.272 (7)	6.640 (7)	5.220 (7)
Tree Swallow release sites for test plots (averaged)								
1D1&2	0.001 (2)	0.001 (2)	0.001 (2)	0.009 (2)	0.012 (2)	0.014 (2)	[b]	0.026 (2)

[a] current flow in the antenna in amperes (see note to Table 7). [b] measures not taken. [c] measures reported by IITRI as < 0.001 were assigned the value 0.001. [d] measurement precluded by antenna operation.

the exposure our research animals experienced.

Summary. In summary, the background 60-Hz electric and magnetic fields on test and control plots were at or below levels required by the original Request for Proposals. As the antenna was gradually brought into operation over the years, the 60-Hz field strengths increased dramatically on test plots but also on control plots, although to a much smaller degree. This unexpected result (to us) may have been due to interaction of existing 60- Hz power lines and the antenna system (J. Gauger, IITRI, personal communication). As the antenna system was brought into operation, 76-Hz fields increased as much as three to four orders of magnitude on test plots, as expected. Much smaller increases occurred on control plots; these increases were mostly less than 1 order of magnitude but sometimes as high as nearly 1.5 orders of magnitude over pre-operation levels. Thus the electric and magnetic field environments in which we conducted our studies were not ones where large field strengths were present on test plots and none were present on controls. Rather, a large difference in field strengths existed, but the fields were present on both test and control plots.

Table 10. Levels of antenna operational strength matched to the time of research activities for major study elements

	Antenna Operational Status (Years)			
Study Element	Pre-operation	Level 1 15 amp	Level 2 75 amp	Full 150 amp
Tree Swallow Embryology	85-87	88	-	89-93
Tree Swallow Fecundity	85, 86	87, 88	-	89-93
Tree Swallow Mortality	85, 86	87, 88	-	89-93
Tree Swallow Growth	85, 86	87, 88	-	89-91
Tree Swallow Homing	86	87, 88	-	89-91, 93
Deer mouse Growth	86	87, 88	-	89-91
Small Mammal Homing	86[a]	87	88	89-93
Physiology	86, 87	88	89	90-92

[a] Antenna operation during small mammal homing in 1986 was intermittent, 3% of the time at 4 amperes and 1% of the time at 6 amperes.

Comments on Ambient Monitoring

We elected to use weather station data from several nearby sites to monitor the effects of climatic conditions impinging on our study plots. All plots were close enough to each other to experience the same major weather patterns. Differences probably existed due to variations in storm tracks, local topography and vegetative features. These differences could have produced some degree of variability in response in our study animals, but in most cases we expect this to have been small and random in direction. We judged that the greatest value of weather data would be for examination of year-to-year effects, rather than effects within a year among plots.

FECUNDITY, MORTALITY, GROWTH AND MATURATION STUDIES - TREE SWALLOWS

I. Purpose

The purpose of these studies was to characterize several aspects of the reproductive process in tree swallows at test and control sites and assess possible effects of the ELF Communications System on these variables. Specifically, the following aspects of reproduction were compared between test and control sites, and for each site from year to year: numbers of eggs per clutch, hatching success within clutches, fledging success, rates of growth and development of hatchlings, and probability of mortality for eggs, young and nests. These work elements are described together in this one section because they were all conducted on the same populations of birds.

ELF Exposure During Fecundity and Mortality Studies. Figure 5, Figure 6 and Table 10 depict temporal and field strength data for antenna operation during the times of the year these studies were being conducted. The "Time on" status of the antenna was measured as the percentage of the hours in a full year that the antenna was operational. Furthermore, since all of our study elements were located along the north-south leg, these hours are representative of only operation in this leg. Field strengths produced by the antenna were assumed to be the same throughout the year when operated at a particular amperage. The operational parameters for the fecundity and mortality studies were similar, with only minor differences.

II. Methods

These studies were conducted in natural or artificial clearings where we erected arrays of nest boxes. The boxes were made of cedar lumber and mounted on posts, 1.5 m above the ground. Sheets of high-density polyethylene wrapped around the posts helped prevent access by terrestrial predators. Tree swallows readily nested in the boxes, and adults at the nest were very tolerant of disturbance by investigators. The boxes could be opened to permit inspection and measuring of young.

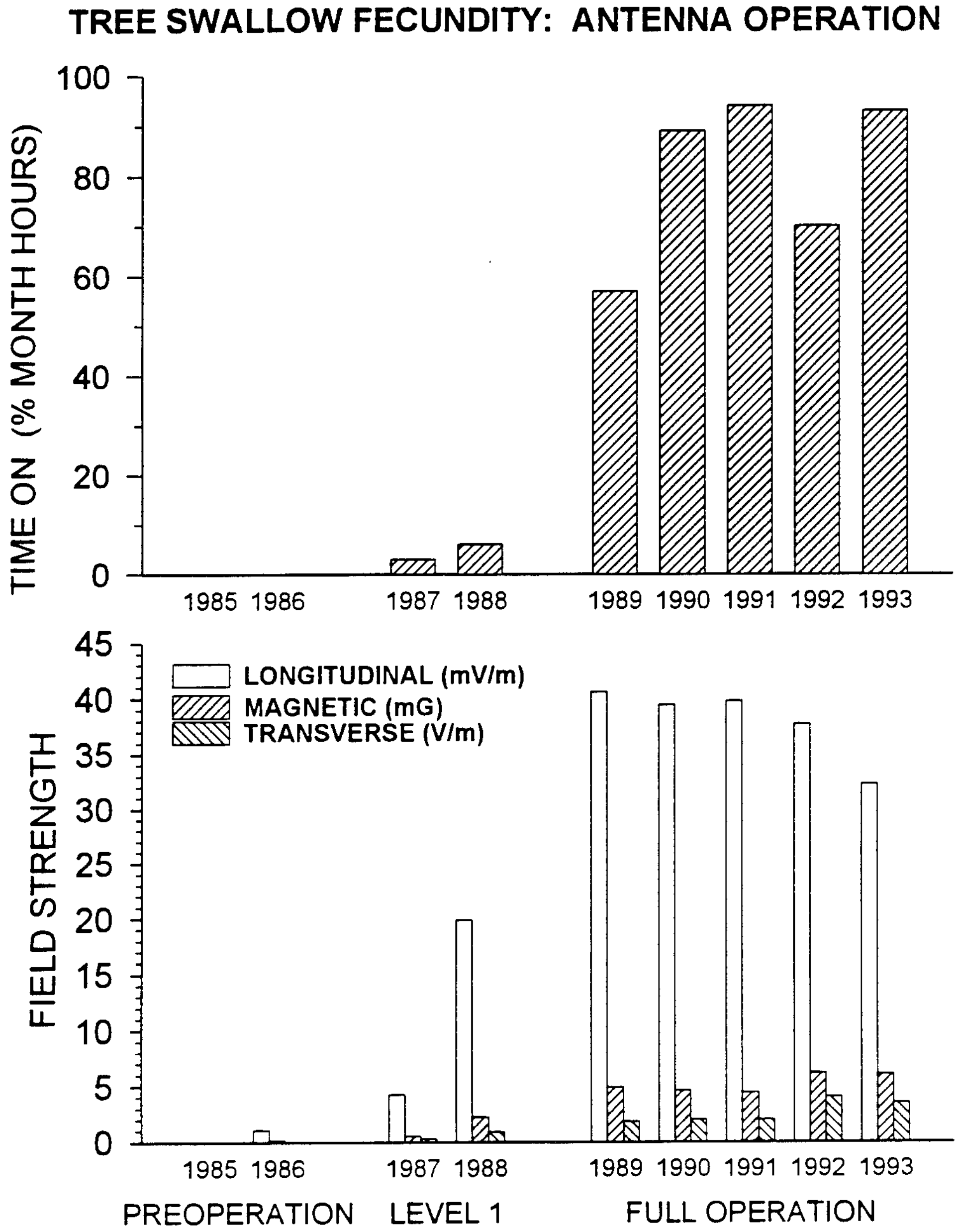


Figure 5. Times of operation, in % hours per month. and average field strengths during studies of tree swallow fecundity. "Level 1" signifies the antenna current was 15 amperes

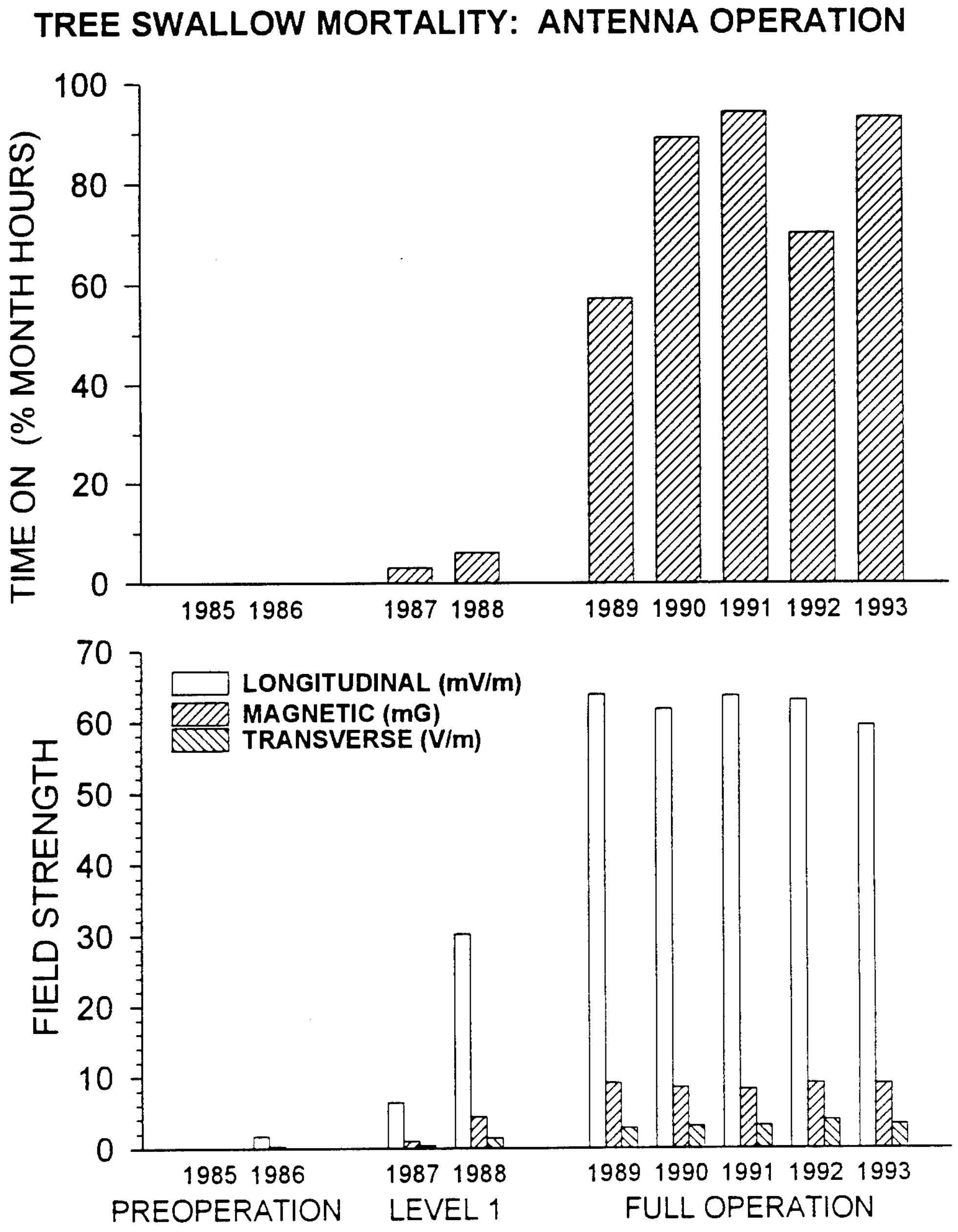


Figure 6. Times of operation, in % hours per month, and average field strengths during studies of tree swallow mortality. "Level 1" signifies the antenna current was 15 amperes

When possible, adults were captured on the nest when feeding young and were banded with U. S. Fish and Wildlife Service bands for permanent identification. In addition, as many young as possible were banded before fledging. Banding of adults and young allowed estimation of yearly survival rates and population sizes on study plots.

Active nests were generally checked daily or every other day to determine laying dates of eggs, clutch size, hatching dates of young, and overall hatching and fledging success. During hatching, nests used in the growth studies were checked twice daily to refine ages assigned to young (useful for curve fitting to growth data), as well as to determine the spread of hatching for the entire clutch over time. Monitoring of the nests for nestling growth and mortality then continued until all young reached 15-16 days of age. Checking of nests was then decreased to every other day, or if checked daily, this was done quickly and the young were not handled, since young in the nest tend to fledge unusually early if disturbed beyond day 16 of age.

For studies of growth and development, nestlings were weighed every other day with a Pesola spring scale accurate to 0.1 g. The lengths of the tarsus, ulna, and wing (all from the right side of the body) were measured with dial calipers accurate to 0.1 mm. Since it was impossible for one observer to measure all nestlings, we had at least two observers collecting growth data at any one time. We have noticed that even following intensive training, observers differ slightly in their techniques for measuring weights and body parts. Therefore we had observers rotate among the nests within and between plots so that every nestling was measured approximately equally by all observers. Each nestling was typically measured a total of seven or eight times. Regularly rotating the observers in this way had the effect of submerging the variance in measurement due to observers into the error in each nestling's growth curve. This measurement protocol unfortunately prevented us from being able to block observer effects in the statistical design. However, as we show below, when we use data from each individual bird's growth curve, even the significant effects of differences in observer technique do not prevent us from being able to detect small differences in patterns of growth.

For analysis of growth data, we used the procedure for fitting data to models of growth proposed by Ricklefs (1967, 1983) and used previously for tree swallows by Zach and Mayoh (1982). Briefly, the data for each nestling were subjected to curve fitting using an exponential or logistic model in a non-linear curve fitting routine in SYSTAT (Wilkinson 1988, 1990). The model of best fit each year, as judged by having the highest value of R^2 for all the nestlings taken collectively, was used in subsequent analyses to obtain the rate of growth, the intercept, and the inflection point. The model of best fit every year was the logistic for all parameters except wing length. For wing length, the model of best fit was the exponential. We also tested nestlings for values of maximum size attained for weight, tarsus and ulna (wing is still growing at fledging). These measures have been shown by Zach (1988) to be less variable than fitted values, as our data also show.

Nestling Transfer Experiment. In 1990 and 1991, we conducted a nestling transfer experiment to test for effects of short-term exposure to the ELF electromagnetic fields of the Communications System. The rationale for the experiment was that one of the most powerful tests of potential ELF electromagnetic effects would be to select a subset of individuals from the same brood and have them grow to independence in a nest on a corresponding test or control plot. Thus, individuals hatched on the test plot and transferred to the control plot would experience high ELF electromagnetic exposure only as eggs, and nestlings transferred to the test plot from the control would experience high ELF electromagnetic exposure only as nestlings. Controls were established for the effect of being raised by different parents and for transferring the young out of the nest. We selected nests at the same stage of development (young had to hatch on the same day) and assigned them randomly to a control group, within-plot exchange group, or across-plot exchange group. Next, nestlings were toe-marked with ink to indicate nestling 1 through 5 (all nests were standardized to five nestlings). Then a random set of three nestlings was chosen to be transferred; the other two nestlings remained in their parental nest. In the control situation, the set of three selected nestlings was taken from the nest, but then immediately replaced, simulating the procedure of moving nestlings among nests. In the within-plot exchanges, the set of three nestlings was exchanged with another nest on the same plot. In this case, nestlings were either unexposed (control plot) but exchanged, or exposed (test plot) but exchanged for their entire nestling life. In the across-plot exchanges, the set of three nestlings was exchanged with a set from the opposite plot. In this case, a set hatched on the control plot was transferred to the test plot and the set hatched on the test plot was transferred to the control plot. These individuals were not exposed as eggs but were as nestlings (control to test plot) or were exposed as eggs but not as nestlings (test to control plot). In both years, the setup of the experiment and coding of young was done by supervisory project personnel. Observers measuring growth of the experimental young had no knowledge of which young had been exchanged and therefore were "blind" to the experimental designations. Growth statistics were later matched to young by use of codes set up in the original design. The effect of being reared by different parents in exchanged young was included in the error term.

To summarize, the treatment levels in the design were:

1) no exposure with sham exchange; young on control plots were taken out of the nest and immediately placed back in the same nest (termed **control**)
2) no exposure with exchange; control plot young placed into another nest on the control plot (termed **control-swap**)
3) exposure as eggs but nestlings raised without exposure; test plot young removed after hatching to the control plot (termed **egg exposed**)
4) not exposed as eggs but raised as nestlings with exposure; control plot young removed after hatching to the test plot (termed (**young exposed**)

5) full exposure with no exchange; test plot young taken out of the nest and immediately returned to the same nest (termed **test**)

6) fully exposed with exchange with other exposed nests; a within-test-plot exchange following hatching (termed **test-swap**).

Analysis of Variance Tests and Intraclass Correlation. In previous reports, we have used the nest as the experimental unit, assuming that nestlings within a nest would be more strongly correlated with each other in their growth characteristics than with nestlings in other nests. In this report, we have tested for this correlation using intraclass correlation techniques (Zar 1984). For every variable measured, we have found the correlation of nestlings within a nest to be no greater than for the population as a whole. This finding allows us to use individual nestlings as the experimental unit. We have modified our analysis of variance tests to incorporate this change.

III. Results

Nest Occupancy Rates on Test and Control Plots. Higher occupancy rates of nest boxes were recorded on control plots in most years (Figure 7; based on five test plots, and two control plots). A nest box was considered occupied if at least one egg was laid there. Differences in occupancy may have resulted from the larger area of the two control plots, and perhaps also to the more recent creation of the test plots (or parts of them). Control plots were established in large, artificial openings 20 to 40 ha in size whereas test plots were established in much smaller artificial openings in the forests along the antenna route. While the box spacing was the same on all plots, the nearness of the adjacent forest was much greater on test plots. Tree swallows prefer open spaces for feeding and probably found the control plots more inviting.

Adult Return and Survival Rates. In 1993, 312 adults were captured on test and control plots combined; 199 (64%) were new individuals and 113 (36%) were returning birds which had been banded by our research group in previous years. The proportion of returning birds captured in 1993 was less than the proportion observed in recent years: 59% in 1992, 45.6% in 1991, 41.3% in

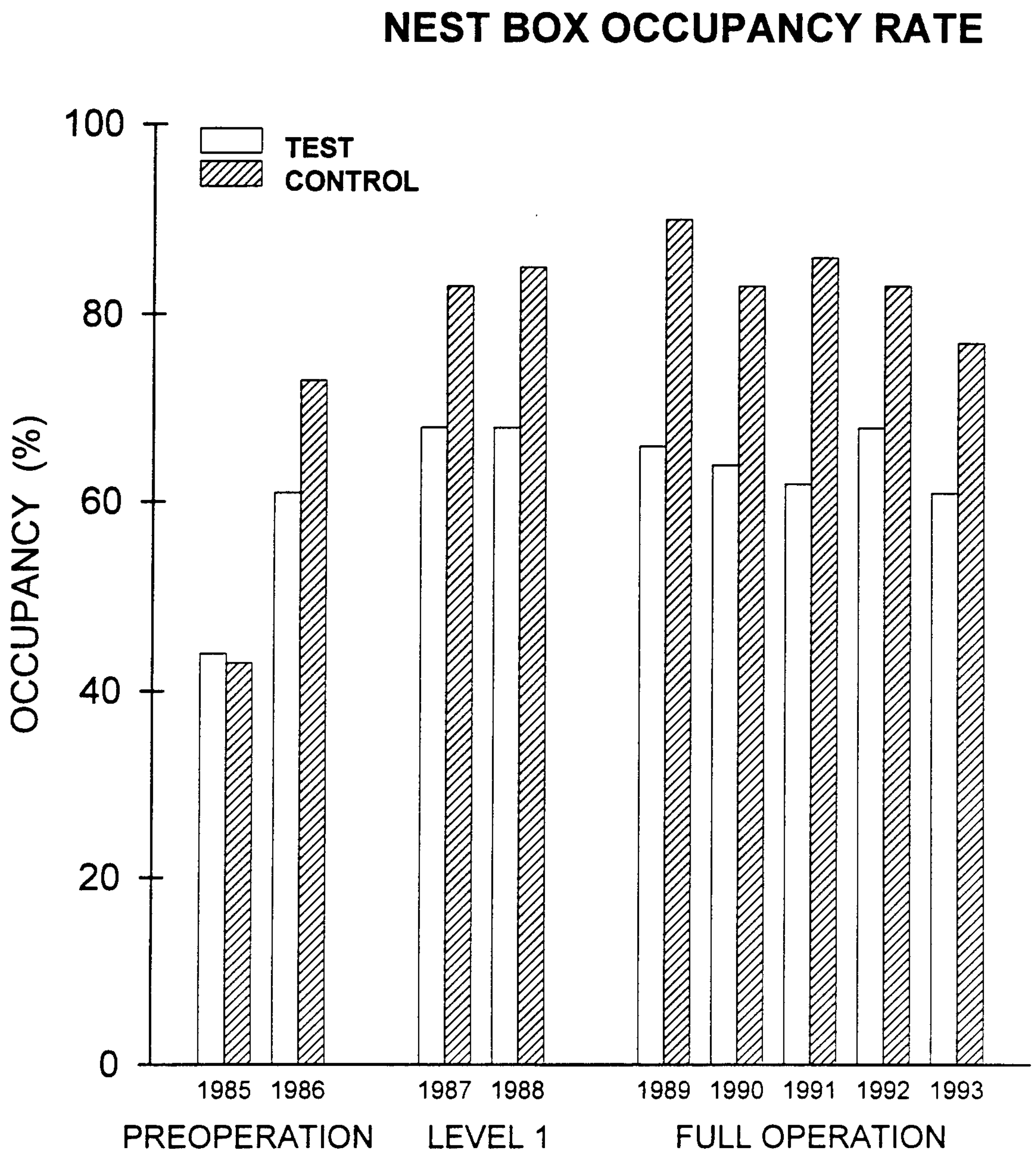


Figure 7. Nest occupancy rates of tree swallows as a percentage of nest boxes on test and control sites, 1985 through 1993. An active nest was one in which at least one egg was laid

1990 and 43.5% in 1989. These values represent higher rates of return by adults than two other long-term studies (Chapman 1955, and Houston and Houston 1987). During earlier years of the study (1985-1988), when we expended less effort on trapping and were using less effective nest box traps, the percentage of adults returning was below 34%. During 1993, 698 young were banded in the nest prior to fledging. Yearly return rates of young banded during the entire study have been very low, generally around 1%.

Annual probabilities of survival for adults and young were estimated from the capture and return data using the JOLLYAGE capture-recapture procedures detailed in Pollock *et al.* (1990). This procedure also allows tests of annual survival probabilities for adults and young. The assumption that capture probabilities are the same for adults and young can also be tested. We show data here through 1993, which estimate survival rates through 1992 for birds banded as adults or nestlings.

Adult tree swallows had probabilities of annual survival from 0.2 to 0.8 per year. These rates did not differ among test and control plots, nor can any pattern be discerned relative to the operation of the antenna system (Figure 8). The estimated variance in survival rate is large, which does not allow a sensitive measure of potential ELF electromagnetic effects. The values of adult survival we report here are similar to those for the tree swallow in other locations (Butler 1988). Butler reported on the survival and return rates of over 802,000 tree swallows banded in North America up to 1984 (data from the Bird-banding Laboratory). According to his analysis, on average about 79% of tree swallows die in their first year and about 60% die in each subsequent year. The average expected life was 2.7 years.

Young tree swallows, banded as nestlings, experienced much lower survival probabilities than adults (Figure 9), but again no difference between test and control plots nor for levels of antenna operation could be seen. Survival probabilities ranged from 0.02 to 0.09, a full order of magnitude below that estimated for adults. These probabilities are somewhat lower than the 0.11

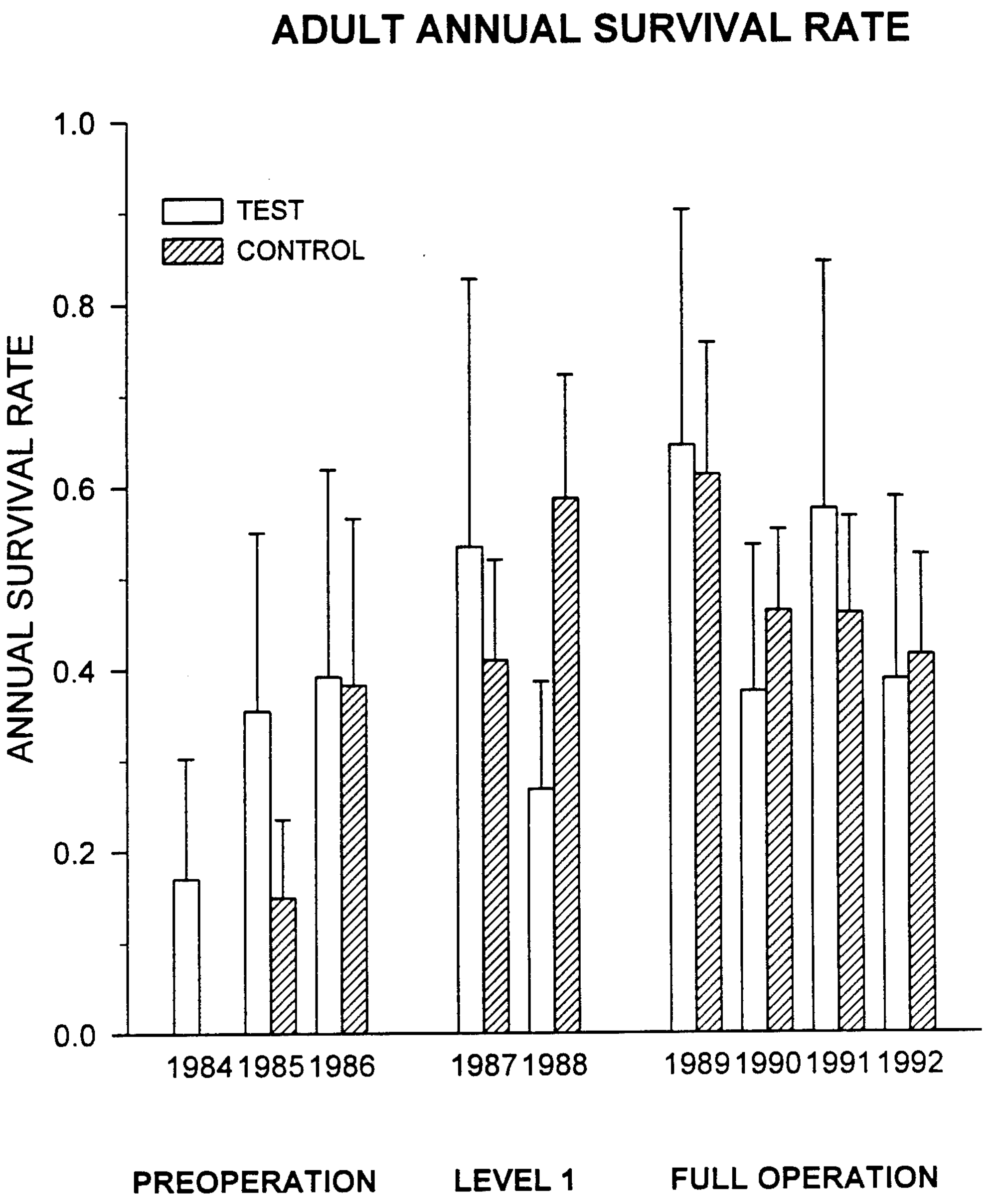


Figure 8. Probability of annual survival (±95% confidence interval) of adult tree swallows on test and control plots from 1984 through 1992

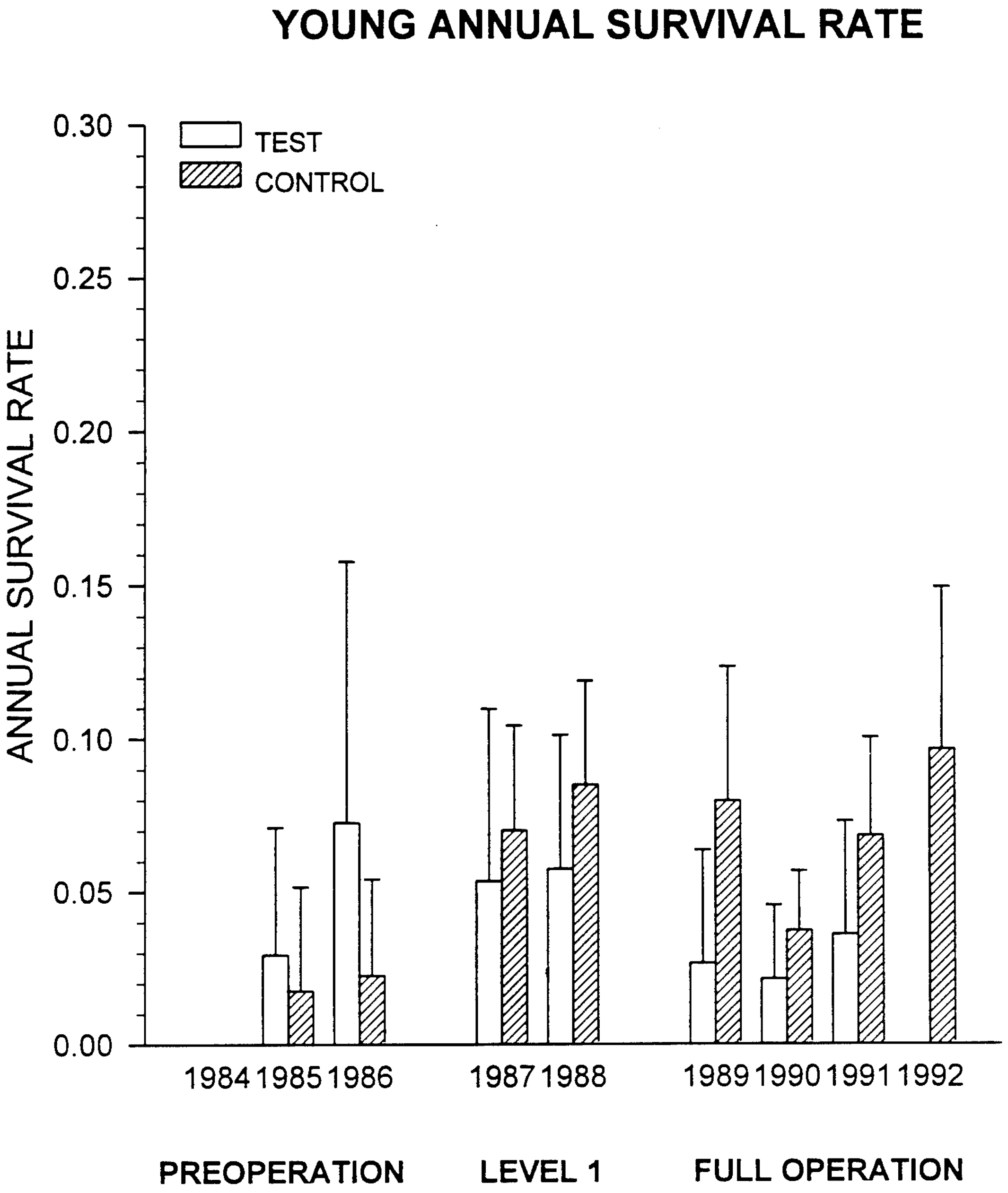


Figure 9. Probability of annual survival (±95% confidence interval) of young tree swallows from fledging to their second year on test and control plots for the years 1984 through 1992

average survival rate for first year tree swallows reported by Butler (1988) noted above. The lower survival of young birds is a general pattern exhibited by small temperate-region birds everywhere they have been studied (Lack 1966).

Fecundity. Summarized fecundity data for tree swallows in 1993 and previous years (1985-1992) are presented in Figure 10, Figure 12, and Figure 13. These data exclude any renesting attempts, and analyses of fledging success exclude any nests manipulated for the reciprocal transplant growth studies in 1990 and 1991 (see tree swallow growth section). Due to low nesting activity on the test plots normally used for embryology (Ford North and South), sample sizes for the embryology study in that year were augmented by collecting additional clutches from the Pirlot Road test plot. These collections precluded the use of the Pirlot Road test plot for any studies except clutch size determination and exposure data analysis (see Mortality section below), so no data on hatching and fledging are reported for this plot for the 1993 field season. Even without the 1993 field season data for these elements, we report nine years of data for clutch size and eight years of hatch and fledge data.

Table 11. Nested analysis of variance for clutch size in tree swallows. Data were transformed by squaring

SOURCE	DF	SS	MS	F	P
OPERATION	2	125.728	62.864	0.619	0.570
PLOT	1	182.584	182.584	2.711	0.100
YEAR(OPER)	6	609.532	101.589	1.508	0.173
OPER*PLOT	2	520.305	260.153	3.862	0.021
ERROR	712	47949.805	67.345		

Mean clutch sizes in 1993 were the same at Pirlot Road test (5.3 eggs/nest) and Tachycineta Meadows control (5.3 eggs/nest, t-test, t = -0.046, P = 0.964). These values are within the range reported elsewhere for tree swallows (Chapman 1955, DeSteven 1978, Hussell 1983b, Low 1933,

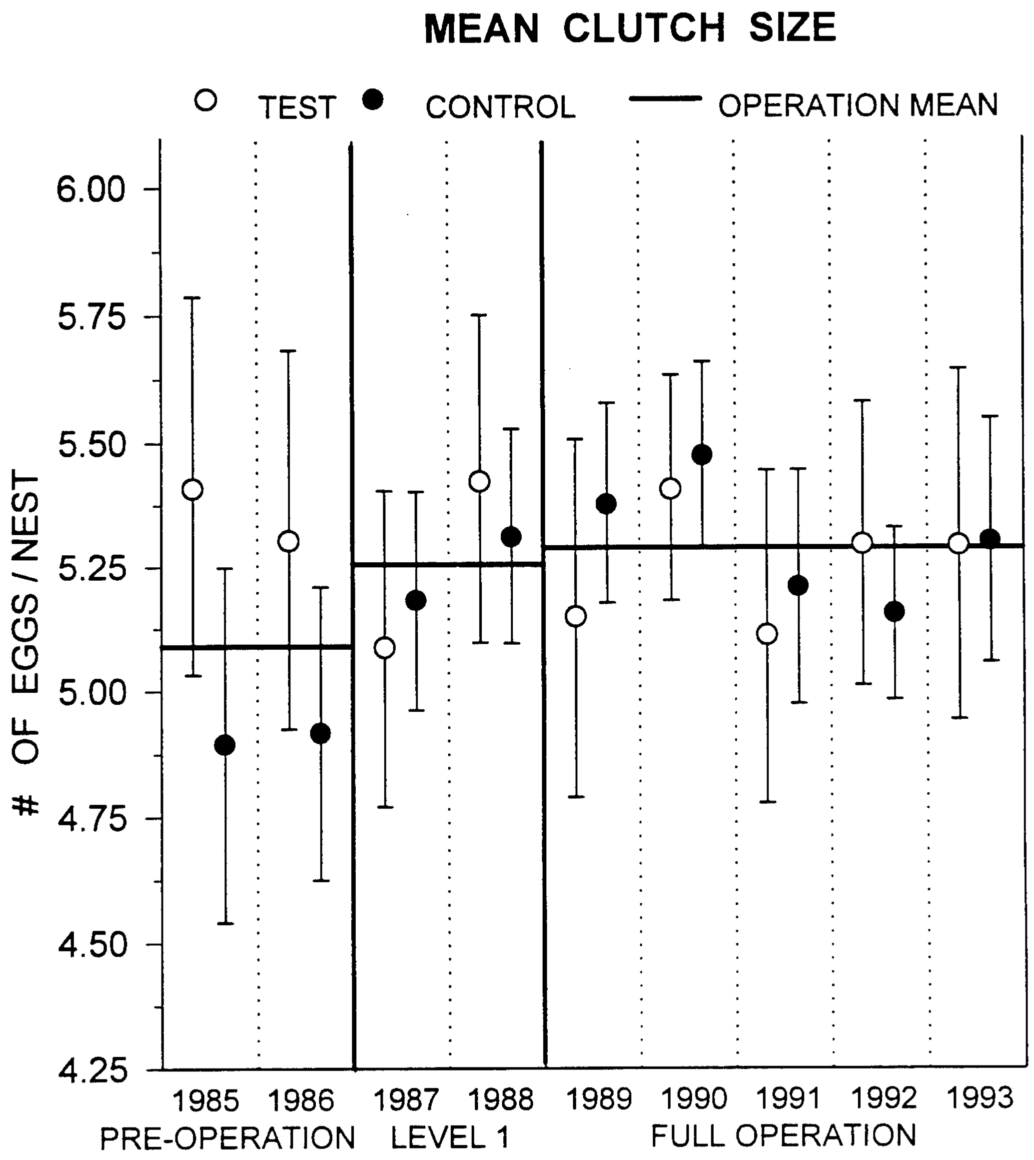


Figure 10. Clutch size (mean ±95% confidence interval) of nesting tree swallows on test and control plots for 1985 through 1993

Paynter 1954, Zach and Mayoh 1982,). In addition, there was no difference in the distribution of clutch sizes between test and control plots in 1993 ($\chi^2 = 0.493$, $P = 0.782$).

We analyzed data on clutch size from all years of the study (1985-1993) in a nested analysis of variance to assess the potential effects due to antenna OPERATION (preoperation: 1985 and 1986, level 1: 1987 and 1988, fully operational: 1989 through 1993), PLOT (test vs. control plot), YEAR (nested within operation), and OPERATION*PLOT interaction. Due to the nested design, the error term used to compute the OPERATION effect F value was the YEAR (nested within operation) mean square. Prior to running this analysis, the data were tested for normality using the methods of D'Agostino *et al.* (1990). A transformation by squaring resulted in normality and homogeneous variances at all levels of the analysis of variance model (Bartlett's test, Sokal and Rohlf 1981, all $P > 0.09$). Results of the analysis of variance on the transformed data (Table 11) showed no significant effects due to antenna operation, treatment plot, or year. A significant OPERATION*PLOT interaction was detected ($F = 3.862$, $P = 0.021$). This effect is attributable to test plot means being relatively constant over the entire nine years of study while the control means were lower than test means during the preoperational phase. Control plot means then increased to the level of test plot means during level 1 and full operation (Figure 11). Therefore, the significant interaction is due to an increase in the clutch size on control plots coincident with level 1 operation of the Communications System. It seems clear that this difference in clutch size is not attributable to the operation of the Communications System.

Next we consider data on hatching of eggs. As mentioned above, hatching data from 1993 were not included in the following analyses. Transformations (following use of the D'Agostino *et al.* 1990, procedures) resulted in elimination of problems with skewness but not kurtosis. However, we choose to apply the analysis of variance anyway since the test is robust with respect to departures from normality, particularly with large sample sizes (see Zar 1984; for this analysis total $n = 447$ nests). In addition, all levels in the analysis of variance model proved to have

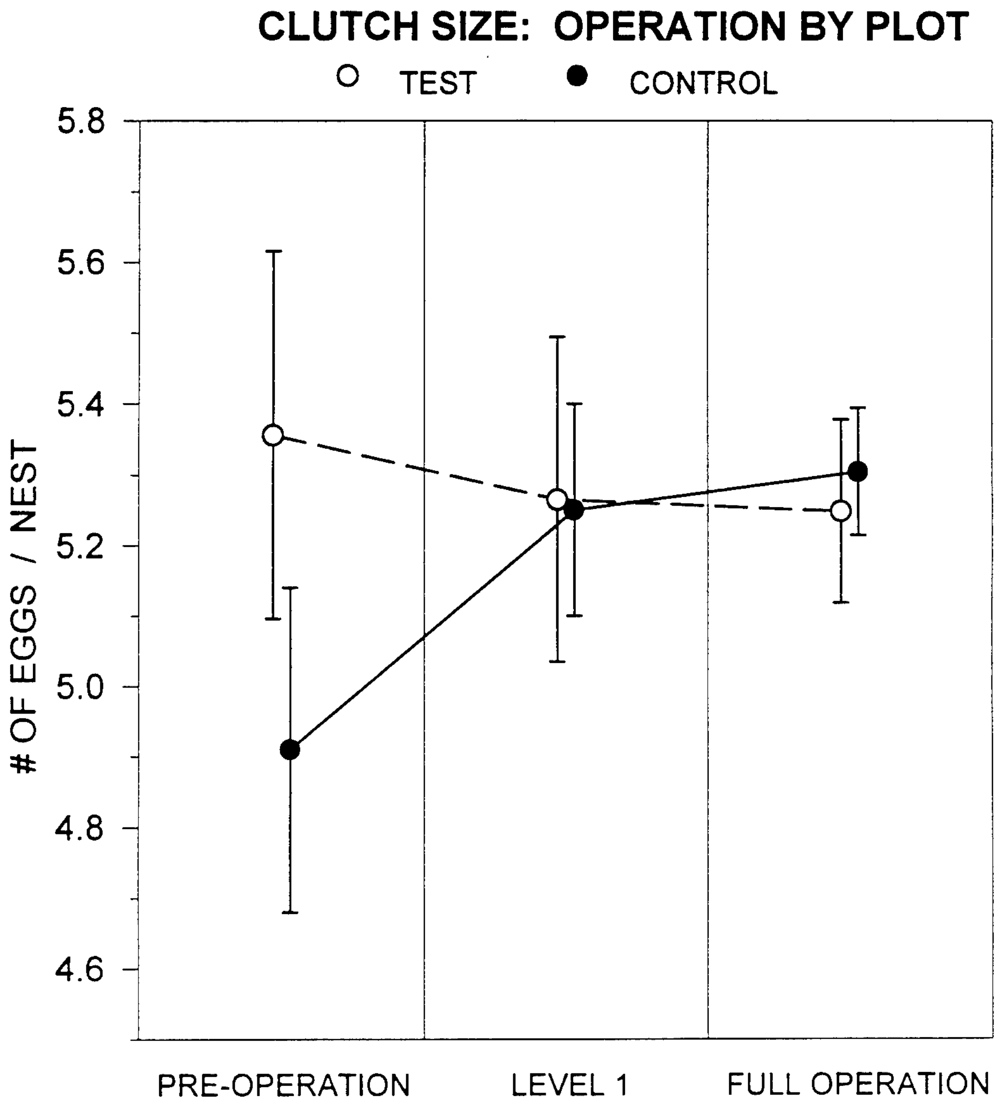


Figure 11. Mean clutch size (±95% confidence interval) within operation period showing the operation-by-plot interaction

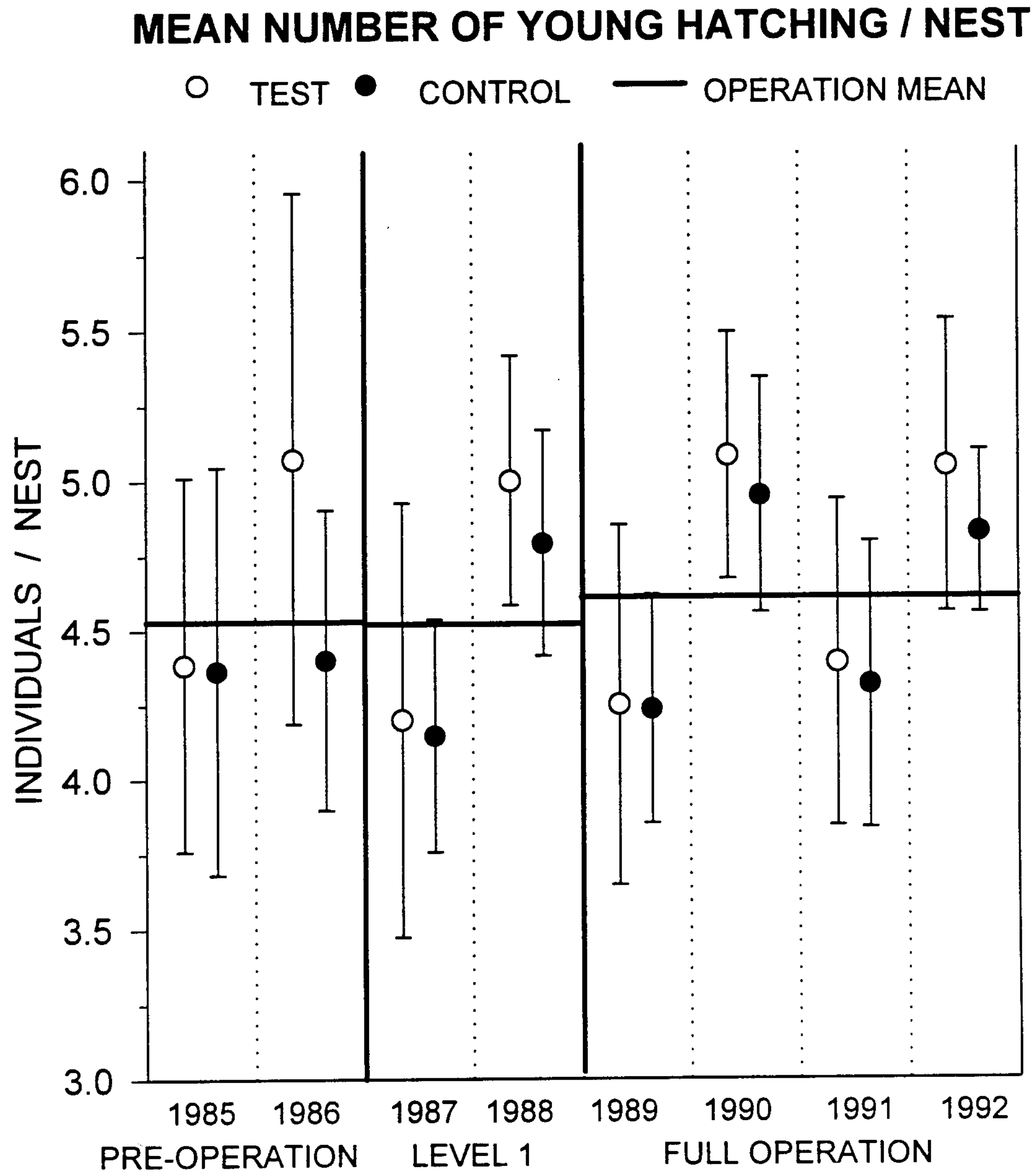


Figure 12. Mean hatch rate (± 95% confidence interval) within nests of tree swallows observed on test and control plots for 1985 through 1992

homogeneous variances using the F_{max} test (all $P > 0.05$). The F_{max} test was used in this case because Bartlett's test is overly sensitive to departures from normality (Sokal and Rohlf 1981). Results of the analysis of variance (Table 12) show no significant effects due to antenna operation or treatment plot, nor was any significant interaction detected. A significant effect of year was detected ($F = 5.874$, $P < 0.001$), which results from hatch rates being essentially equal between test and control plots during all years of the study, yet showing overall fluctuations from year to year (Figure 12). Mean hatch rates at both test and control plots were high in 1988, 1990 and 1992, and low in 1985, 1987, 1989 and 1991.

Table 12. Nested analysis of variance for hatch rate in Tree Swallows. Untransformed data

SOURCE	DF	SS	MS	F	P
OPERATION	2	1.090	0.545	0.061	0.941
PLOT	1	3.595	3.595	2.375	0.124
YEAR(OPER)	5	44.473	8.895	5.874	<0.001
OPER*PLOT	2	1.220	0.610	0.403	0.669
ERROR	436	660.179	1.514		

Another approach to the analysis of hatching data is to assess the likelihood of eggs to hatch, with the data treated as counts, using contingency table analysis. This is in contrast to using the number of eggs hatching per nest as if it were a continuous variable, as was done in the analysis of variance above.

Comparing likelihood to hatch between test and control plots, no significant differences were detected during any year of the study (Table 13). In other words, the proportion of eggs hatching was shown to be independent of treatment plot in every year. Further analysis showed that test-control comparisons were homogeneous across all years of the study (heterogeneity χ^2 testing, Zar 1984, pg. 67, $\chi^2 = 3.007$, df = 7, $P > 0.5$, see also Gill, 1978).

Table 13. Likelihood of eggs to hatch over all years of the study at Pirlot Road test plot and Tachycineta Meadows control. Test and control plots were compared using a χ^2 test

Year	Plot	Hatch	Not Hatch	% Hatch	χ^2	P
1992	Test	106	4	96.4	0.426	0.514
	Control	198	11	94.7		
1991	Test	101	16	86.3	0.346	0.556
	Control	177	34	83.9		
1990	Test	122	7	94.6	2.064	0.151
	Control	203	22	90.2		
1989	Test	85	17	83.3	0.000	0.988
	Control	216	43	83.4		
1988	Test	90	8	91.8	0.283	0.595
	Control	206	23	90.0		
1987	Test	63	11	85.1	0.013	0.909
	Control	170	31	84.6		
1986	Test	71	6	92.2	2.972	0.085
	Control	132	25	84.1		
1985	Test	57	8	87.7	0.246	0.620
	Control	48	5	90.6		

The method of heterogeneity χ^2 testing is accomplished by first summing χ^2 values and degrees of freedom for each of the yearly samples. This value is termed the total χ^2. The data over all years of the study are then pooled and a χ^2 value is calculated for the resulting 2 x 2 table. This value is termed the χ^2 of totals. To calculate the heterogeneity χ^2, the χ^2 of totals is subtracted from the total χ^2 and the respective degrees of freedom are also subtracted. The obtained values of heterogeneity χ^2 can be compared to tabulated critical values with the appropriate degrees of freedom. A rejection of the null hypothesis of homogeneity between the yearly samples would indicate that yearly samples were heterogeneous. This technique is useful in a study such as ours to help in determining, for example, whether dramatic changes occurred in the proportions of eggs which hatch over years of the study or whether the relationships remained relatively stable from year to year. In addition, heterogeneity χ^2 testing can be used to assess whether or not yearly samples can be pooled within antenna operational status. If yearly samples can be pooled, then a full multidimensional contingency table model can be used which employs antenna operation as one of the levels of analysis.

Even though likelihood to hatch was shown to be homogeneous across all years of the study, it is desirable to assess any potential effects of operational status by first pooling years within operational status and then making appropriate comparisons between antenna operational levels. Yearly data within all three levels of operation were found to be homogeneous (all $P > 0.1$) so were pooled within operational status (Table 14). With yearly data pooled within operational status, the hypothesis of mutual independence (Zar 1984, Everitt 1977) was rejected ($\chi^2 = 18.29$, df = 7, P = 0.011). We conclude that likelihood to hatch, treatment plot location and operational status of the antenna somehow interact.

Table 14. Likelihood of eggs to hatch with years pooled within operational status. Test and control plots were compared using a χ^2 test

Operation	Plot	Hatch	Not Hatch	% Hatch	χ^2	P
Full	Test	414	44	90.4	1.988	0.159
	Control	794	110	87.8		
Level 1	Test	153	19	89.0	0.263	0.608
	Control	376	54	87.4		
Pre	Test	128	14	90.1	1.518	0.218
	Control	180	30	85.7		

To examine this interaction, we tested three hypotheses of partial independence, which permitted evaluation of which of the three factors is independent of the other two. These three hypotheses were:

1) likelihood to hatch is independent of treatment plot and antenna operational status

2) treatment plot is independent of operational status and likelihood to hatch

3) operational status is independent of likelihood to hatch and treatment plot.

Hypotheses 2 and 3 were rejected (both $P < 0.02$), but hypothesis 1 was not rejected ($\chi^2 = 4.34$, df = 5, $P = 0.502$) which leads to the conclusion that likelihood to hatch is independent of treatment plot and antenna operational status. This conclusion is supported by earlier analyses as well. No significant differences in proportions of eggs hatching were detected between test and control during any year of the study (Table 13), and no significant differences in likelihood to hatch were detected between test and control within categories of antenna operational status with pooled yearly data (Table 14). The conclusion is also supported by the fact that all years were considered homogeneous by heterogeneity χ^2 testing.

The broad conclusions we can draw from information collected on hatching are that although there appears to be a significant year effect detected by the analysis of variance (Table 12 and Figure 12), there have been no changes observed either in the number of young hatched per nest or the likelihood of eggs to hatch, which could be attributable to antenna operation.

We now consider rates of fledging of young from the nest (Figure 13). As mentioned above, fledging data from 1993 were not included in the following analyses. We analyzed data on fledging rate from all years of the study (1985-1992) in a nested analysis of variance to assess the potential effects due to antenna OPERATION (preoperation: 1985 and 1986, level 1: 1987 and 1988, fully operational: 1989 through 1992), PLOT (test vs. control treatment plot), YEAR (nested within operation), and OPERATION*PLOT interaction. Due to the nested design, the error term used to compute the OPERATION effect F value was the YEAR (nested within operation) mean square. The fledging data contained many zero values (no young fledging from many nests during bad-weather years), which made them inherently non-normal. We could not transform them to produce normally distributed data. In addition, for the YEAR effect, variances proved to be

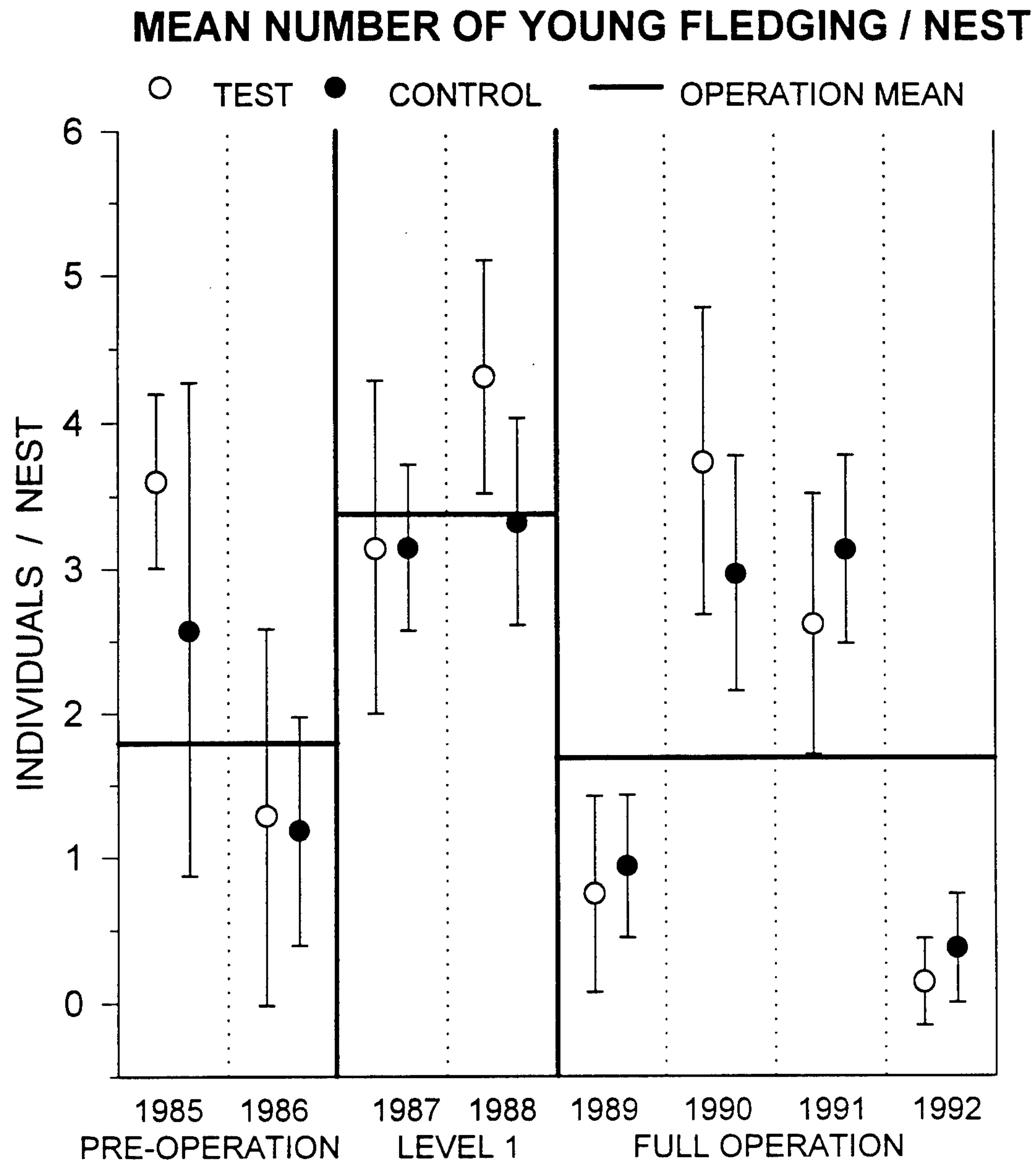


Figure 13. Mean fledge rate (±95% confidence interval) of nesting tree swallows observed on test and control sites for 1985 through 1992

heterogeneous (F_{max} test, $P < 0.01$). This variance heterogeneity is not an unexpected result given the highly variable nature of fledging due to episodes of inclement weather in 1986, 1989 and 1992 when the number of young fledged per nest was low. Variances were low due to uniform and widespread nest failure during those years, compared to relatively normal fledging rates with higher variability during other years. Analysis of variance was run on the untransformed data, realizing that all of the strict assumptions of the test were not met (see earlier discussion). Results of the analysis of variance (Table 15) show no significant effects due to antenna operation or treatment plot, nor was any significant interaction detected. A significant effect of year was detected ($F = 25.346$, $P < 0.001$), which results from mean fledge rates being approximately equal between test and control plots during all years of the study, yet showing overall fluctuations from year to year. These yearly fluctuations were clearly due to episodes of inclement weather during 1986, 1989 and 1992 which resulted in very low mean numbers of young fledging from each nest. Very few birds fledged at all in 1992. Even though the data are decidedly non-normal and all of the assumptions of the analysis of variance were not met, the year effect attributable to episodes of inclement weather is clearly shown graphically in Figure 13.

Table 15. Nested analysis of variance for fledging rate in Tree Swallows. Untransformed data

SOURCE	DF	SS	MS	F	P
OPERATION	2	171.014	85.507	1.051	0.416
PLOT	1	4.503	4.503	1.402	0.237
YEAR(OPER)	5	406.932	81.386	25.346	<0.001
OPER*PLOT	2	6.715	3.357	1.046	0.352
ERROR	389	1249.064	3.211		

We also examined the likelihood of fledging using contingency table analysis. The likelihood of young to fledge proved to be significantly different between test and control plots during four years (1985, 88, 90 and 91) of the eight-year study (Table 16). During three of these four years, likelihood to fledge on the test plot was greater than the control plot. Heterogeneity χ^2 testing also revealed a lack of homogeneity across all years of the study ($\chi^2 = 30.623$, df = 7, $P < 0.001$). Further heterogeneity χ^2 testing within antenna operational status showed that although years could be pooled during the preoperational phase ($\chi^2 = 0.930$, df = 1, $P > 0.1$), years could not be pooled within the level 1 testing phase ($\chi^2 = 6.604$ df = 1, $P < 0.025$) or the fully operational phase ($\chi^2 = 15.779$, df = 3, $P < 0.005$). Due to the lack of possible pooling during two of the three operational phases, it is not possible to build a full model for the multidimensional contingency test which would include the factors: antenna operational status, treatment plot and likelihood to fledge. Because of the high degree of variability between years which precludes pooling within operational status, there are few avenues of analysis available beyond those already shown. We are left with assessing trends from the yearly χ^2 comparisons as the most reasonable approach.

During the preoperational antenna phase (1985 and 1986) one of two years shows significant lack of independence, and in this case the proportion of young fledging is greater on the test plot than on the control. During level 1 antenna testing (1987 and 1988) the difference between the test and control is significant in one year; again the proportion of young fledging is greater on the test than on the control plot. During the four years of full antenna operation (1989-1992), two years show significant lack of independence, yet test and control differences for these two years are in opposite directions. Likelihood to fledge was significantly greater on the test plot in 1990, but in sharp contrast, was greater on the control in 1991.

For data on fledging collected throughout the study, we can conclude that there are important yearly differences in fledging rate, primarily due to episodes of inclement weather during 1986, 1989 and 1992 (Figure 13). Interestingly, the three years of poor weather seemed to have equal impact on test and control plots, as there were no significant differences in likelihood to fledge during these years (Table 16). In terms of antenna operational status, these data and those from the analysis of variance do not provide evidence for antenna operation as an influence on the

Table 16. Likelihood of young to fledge over all years of the study at Pirlot Road test plot and Tachycineta Meadows control. Test and control plots were compared using a χ^2 test

Year	Plot	Fledge	Not Fledge	% Fledge	χ^2	P
1992	Test	3	103	2.8	2.953	0.086
	Control	15	178	7.8		
1991	Test	55	36	60.4	6.012	0.014[a]
	Control	116	38	75.3		
1990	Test	56	17	76.7	6.236	0.013[a]
	Control	89	60	59.7		
1989	Test	15	70	17.6	0.784	0.376
	Control	47	164	22.3		
1988	Test	69	12	85.2	7.832	0.005[a]
	Control	123	56	68.7		
1987	Test	44	17	72.1	0.927	0.336
	Control	126	35	78.3		
1986	Test	18	53	25.4	0.071	0.790
	Control	32	86	27.1		
1985	Test	36	7	83.7	6.012	0.014[a]
	Control	18	13	58.1		

[a] Significant at 0.05 or greater

mean number of young fledged per nest, or the likelihood of young to fledge.

We have examined the power of our statistical tests and minimum detectable differences for the measures of clutch size, hatch rate and fledge rate discussed above (Figure 14). We are currently able to detect changes of 5% or less when comparing between test and control plots for all three variables but at very low power. When comparing levels of antenna operation we are able to detect changes of 3% for clutch size, 10% for hatch rate, but only 20% for fledge rate which is highly variable. Once again the power of the test is quite low.

If we set the power of test at 70% certainty, we are able to detect differences of 6% or less for clutch size and hatch rate when comparing between test and control treatment plots. However,

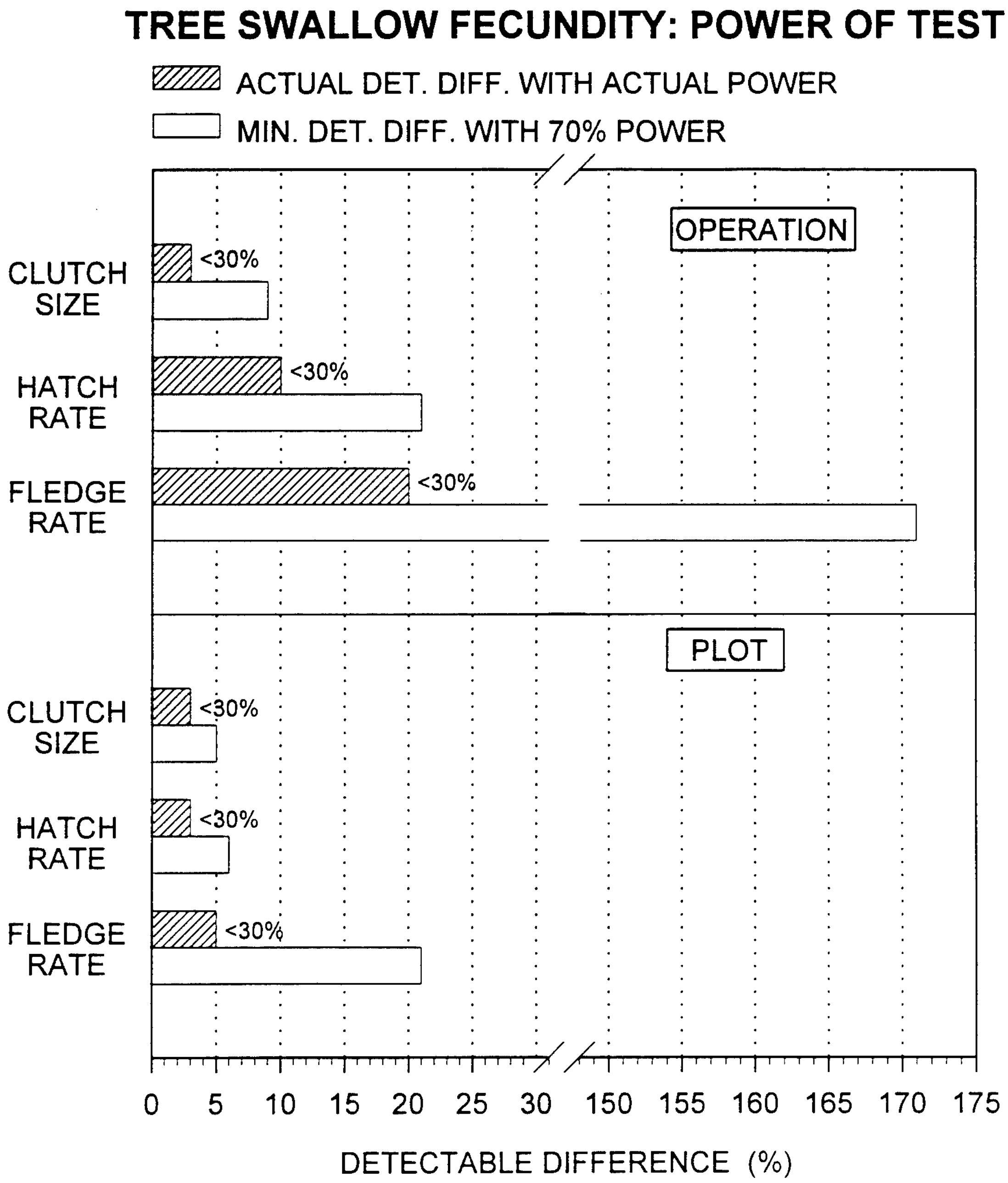


Figure 14. Detectable differences of Tree Swallow fecundity variables for operation and plot effects

at this 70% level we can detect only a 21% difference in fledge rate. When comparing between antenna operation status levels at the 70% level of certainty we can detect only a 9% difference for clutch size, a 21% difference for hatch rate, and a 171% difference in fledge rate. The poor showing for fledge rate is, again, due to the fact that this measure has proven to be highly variable from year to year on account of weather events which severely impact the survival of young in the nest.

Mortality. Whereas our detailed study of fecundity variables was carried out at just the Pirlot Road test plot and Tachycineta Meadows control plot, we monitored mortality in all active nests at two additional test plots (North Turner and Cleveland Homestead) and one additional control plot (Panola Plains). Thus, three test plots and two control plots could be pooled to provide the basis for an analysis of overall nesting success based on the Mayfield method (Mayfield 1961, 1975). This method takes into account the exposure of each nest to potential mortality factors over the number of days the nest is under observation. The unit of observation used for comparisons between groups is the nest-day. A nest that makes it through a full 24-hour period without total mortality (all young killed) is counted as a single nest-day. For example, one nest under observation for 10 days without mortality but with total mortality on the 11th day is counted as 10 nest-days without mortality and one nest-day with mortality. Similarly, the nest-days of five nests observed for 15 days with three nests surviving the full 15 days and two not would be the sum of mortality-free days for all nests and two nest-days with mortality. Therefore the total number of observations of a group of nests (say, at a test plot) would be the summation of mortality free nest-days for each nest in the group and a count of the number of nests that did suffer mortality and failed.

Other units of observation which provide a finer-tuned approach are the egg-day and the young-day. The egg-day is defined as the number of days each egg is present in the nest without mortality. Young-day is similarly defined for each nestling. For example, a nest with five eggs observed for eight days represents 40 egg-days of observation. Should one egg suffer mortality after day four, then only 36 egg-days would be counted and there would be one egg-day of mortality. Young-days are dealt with in the same manner. The difference between the nest-day statistic and the egg-day and young-day statistics is that nest-days are counted for nests so long as at least one egg or young bird is alive in the nest, whereas eggs and young birds are counted as individuals. For example, if two nests have five young initially, and one has five young alive for 10 days and the other has four young alive for one day and one alive for 10 days then the first nest will generate 50 young-days but the second only 14 young-days. Both nests will generate 10 nest-days.

Most of the nests included in this analysis were observed from the day of the first egg laid to the completion of the nesting attempt. Any manipulated nests (for example, from the 1990 and 1991 reciprocal transplant growth study) were excluded from any analysis of nestling mortality or nestling phase nest mortality.

We used two methods to compare groups of nests. The traditional method as outlined by Mayfield (1975) employs a contingency table analysis using numbers of observations from each group of nests as compared to the numbers that suffered mortality. The method presented by Hensler and Nichols (1981) employs maximum likelihood estimates and variances of survival probabilities to compare groups. Here we present results from 1993 followed by all years of the study (1985-1993) using both methods (Table 17, Table 18, Table 19, Table 20, Table 21).

The analysis of overall nest mortality (Table 17) compares test and control values for the number of nest-days observed without mortality with the number of nests where mortality occurred throughout the entire nesting attempt. The likelihood of mortality occurring was shown to be independent of treatment during 1993 ($\chi^2 = 0.501$, df = 1, $P = 0.479$). Likewise no significant differences were found between test and control plots in 1993 using the Hensler and Nichols method ($Z = 0.677$, $P = 0.248$). In terms of assessing overall nest mortality, the two methods are in complete agreement with one another during all years of the study. All years show either no

Table 17. Number of nest-days and nests lost to mortality factors during each year of the study. Plots are compared using the Hensler and Nichols (1981) (Z) and Mayfield (1975) (χ^2) methods

Operation Level	Year	Plot	Nest-Days[a]	Nests lost[b]	%	Hensler/Nichols Z	Hensler/Nichols P	Mayfield χ^2	Mayfield P
Full	1993	Test	2207	21	0.95	0.677	0.248	0.501	0.479
		Control	6443	51	0.79				
	1992	Test	2434	94	3.86	3.172	0.001	12.041	0.001[c]
		Control	6079	148	2.44				
	1991	Test	2509	38	1.52	0.502	0.309	0.263	0.608
		Control	6639	91	1.37				
	1990	Test	2727	37	1.36	2.070	0.019	5.270	0.022[c]
		Control	7242	61	0.82				
	1989	Test	2775	73	2.63	0.979	0.164	1.009	0.315
		Control	6077	138	2.27				
Level 1	1988	Test	3249	31	0.95	1.910	0.028	4.039	0.044[c]
		Control	4937	28	0.57				
	1987	Test	2485	46	1.85	2.478	0.007	7.077	0.008[c]
		Control	4397	47	1.07				
Pre	1986	Test	1735	45	2.59	0.312	0.378	0.097	0.756
		Control	2321	64	2.76				
	1985	Test	1082	11	1.02	2.452	0.007	6.376	0.012[c]
		Control	917	23	2.51				

[a] days of observations of nests with at least one egg or young alive

[b] number of nests which suffered complete mortality of eggs and (or) young

[c] Significant at 0.05 or greater

significant differences between test and control, or if there is a difference (1987, 1988, 1990 and 1992), the probability of nest mortality is higher on the test plot. The only exception to this is in 1985 when the probability of nest mortality was higher on the control plot. It must be noted here that sample sizes in 1985 were small compared to all other years, most likely due to the fact that we established the control plots in 1985. Nesting activity is comparatively low for the first year or two following the establishment of plots. We speculate this was a contributing factor to the contrasting differences observed in mortality.

It is of interest to break down the overall nest mortality data into two time periods. The first represents the time span of egg laying and incubation (hereafter termed incubation phase) and the second is the period of time following hatching of the eggs when adults are actively feeding the young (hereafter termed young phase). These two time periods are characterized by differing behavioral patterns exhibited by the two parents. During the incubation phase only the female incubates the eggs, spending a majority of her time sitting on the eggs once the clutch is completed. Following hatching, the female is the main contributor in brooding of the young for several days and then there is approximately equal time and effort invested by both parents feeding the young thereafter.

Incubation phase nest mortality (Table 18) during 1993 showed no differences between test and control plots for either method of analysis ($\chi^2 = 1.245$, $P = 0.265$; $Z = 1.028$, $P = 0.154$). During all years of the study the two methods are in complete agreement with one another. During preoperational antenna status, one of the two years (1985) showed a significant difference between treatments, with probability of nest failure being lower on the test plots. For one year of level 1 antenna testing (1987) the probability of nest mortality was higher on test plots than on controls. No differences were shown between test and control when the antenna was fully operational.

Young phase nest mortality (Table 19) during 1993 did not differ between test and control plots ($\chi^2 = 0.050$, $P = 0.823$; $Z = 0.229$, $P = 0.409$), and once again, the two methods of analysis are in agreement during all years of the study. No differences were shown between test and control plots during the two preoperational years. During level 1 antenna testing, the probability of mortality during the young phase was higher on the test plot in 1988. While the antenna was fully operational, one of five years showed a higher probability of nest failure on the test plot.

Table 18. Incubation phase nest-days and nests lost to mortality factors during each year of the study. Plots are compared using Hensler and Nichols (1981) (Z) and Mayfield (1975) (χ^2) methods

Operation Level	Year	Plot	Nest-days[a]	Nests lost[b]	%	Hensler/Nichols Z	Hensler/Nichols P	Mayfield χ^2	Mayfield P
Full	1993	Test	1290	14	1.09	1.028	0.154	1.245	0.265
		Control	3467	26	0.75				
	1992	Test	1755	29	1.65	0.970	0.166	1.023	0.312
		Control	3763	49	1.30				
	1991	Test	1458	21	1.44	0.048	0.480	0.002	0.961
		Control	3586	51	1.42				
	1990	Test	1467	21	1.43	1.490	0.068	2.695	0.101
		Control	3843	35	0.91				
	1989	Test	1803	27	1.50	1.361	0.087	2.106	0.147
		Control	3925	41	1.05				
Level 1	1988	Test	1717	18	1.05	1.260	0.104	1.737	0.188
		Control	2660	18	0.68				
	1987	Test	1598	38	2.38	2.531	0.006	7.281	0.007[c]
		Control	2492	31	1.24				
Pre	1986	Test	1221	21	1.72	1.338	0.090	1.710	0.191
		Control	1589	39	2.45				
	1985	Test	576	7	1.22	2.081	0.019	4.325	0.038[c]
		Control	562	17	3.03				

[a] days of observations of nests with at least one egg or young alive
[b] number of nests which suffered complete mortality of eggs and (or) young
[c] Significant at 0.05 or greater

In addition to comparing the probability of nest failure between test and control plots, it is of interest to look at mortality probabilities of individual eggs and individual young. These analyses use egg-days or young-days as the unit of exposure rather than nest-days.

During 1993 there were no differences detected in the probability of individual egg mortality between test and control plots (Table 20, $\chi^2 = 1.310$, $P = 0.252$; $Z = 1.109$, $P = 0.134$). For egg exposure data we found that the two methods of analysis gave slightly different results during both 1992 and 1989. In both cases the Hensler and Nichols method reveals a significant difference between test and control plots whereas the χ^2 method does not. In all cases where a significant

Table 19. Young phase nest-days and nests lost to mortality factors during each year of the study. Plots are compared using Hensler and Nichols (1981) (Z) and Mayfield (1975) (χ^2) methods

Operation Level	Year	Plot	Nest-days[a]	Nests lost[b]	%	Hensler/Nichols Z	Hensler/Nichols P	Mayfield χ^2	Mayfield P
Full	1993	Test	917	7	0.76	0.229	0.409	0.050	0.823
		Control	2976	25	0.84				
	1992	Test	679	65	9.75	4.220	0.000	25.608	0.000[c]
		Control	2343	99	4.23				
	1991	Test	1051	17	1.62	0.689	0.245	0.524	0.469
		Control	3053	40	1.31				
	1990	Test	1260	16	1.23	1.434	0.076	2.570	0.109
		Control	3399	26	0.77				
	1989	Test	962	46	4.78	0.314	0.378	0.101	0.751
		Control	2150	97	4.51				
Level 1	1988	Test	1151	13	1.13	2.059	0.020	5.732	0.017[c]
		Control	2342	10	0.43				
	1987	Test	885	8	0.90	0.166	0.443	0.028	0.867
		Control	1904	16	0.84				
Pre	1986	Test	515	24	4.66	1.045	0.147	1.145	0.285
		Control	732	25	3.42				
	1985	Test	506	4	0.79	1.128	0.129	1.435	0.231
		Control	355	6	1.69				

[a] days of observations of nests with at least one egg or young alive

[b] number of nests which suffered complete mortality of eggs and (or) young

[c] Significant at 0.05 or greater

result occurs, the probability of egg mortality is higher on the test plots, with the exception of 1986 where mortality is higher on the control plots.

During 1993 there were significant differences in the probability of young mortality (Table 21) detected by the Hensler and Nichols method ($Z = 1.826$, $P = 0.034$), but not by the χ^2 method ($\chi^2 = 2.825$, $P = 0.093$). During the remaining years of the study the two methods are in agreement. For the preoperational years of 1985 and 1986 there were significant differences in the probability of mortality of young, yet the direction of these differences switched with years. During 1985 mortality was higher on the control plots, whereas mortality was higher on the test-plot in 1986. The level 1 testing phase showed a higher probability of mortality on the test plots during

Table 20. Number of egg-days and eggs lost to mortality during each year of the study. Plots are compared using Hensler and Nichols (1981) (Z) and Mayfield (1975) (χ^2) methods

Operation Level	Year	Plot	Egg-days[a]	Eggs lost[b]	%	Hensler/Nichols Z	Hensler/Nichols P	Mayfield χ^2	Mayfield P
Full	1993	Test	5398	98	1.82	1.109	0.134	1.310	0.252
		Control	15366	243	1.58				
	1992	Test	7508	179	2.38	1.765	0.039	3.306	0.069
		Control	16173	325	2.01				
	1991	Test	6300	134	2.13	0.713	0.239	0.494	0.482
		Control	15045	344	2.29				
	1990	Test	6619	145	2.19	3.266	<0.001	12.437	<0.001[c]
		Control	17071	259	1.52				
	1989	Test	7964	179	2.25	1.729	0.043	3.174	0.075
		Control	17656	336	1.90				
Level 1	1988	Test	8077	135	1.67	2.764	0.003	8.115	0.004[c]
		Control	12140	144	1.19				
	1987	Test	6418	219	3.41	7.056	<0.001	57.417	<0.001[c]
		Control	9864	153	1.55				
Pre	1986	Test	5682	139	2.45	3.509	<0.001	11.847	<0.001[c]
		Control	7017	248	3.53				
	1985	Test	2806	37	1.32	0.132	0.448	0.017	0.895
		Control	2661	34	1.28				

[a] days of observations of eggs still alive
[b] number of eggs which suffered mortality
[c] Significant at 0.05 or greater

one year (1988) and no difference in the other (1987). Two of the five years of full operation phase showed test plots mortality higher than controls; two years showed no differences; and one year showed mortality higher on the control. Only the Hensler and Nichols method detected this last difference during 1993.

In conclusion, overall nest mortality was significantly higher on the control plots during only one year of the preoperation period (1985), and then there were either no differences detected (four years) or nest failure was significantly higher on the test plots (four years) in level 1 and full operation years (Table 22). The number of significant differences in mortality is considerably less when the nesting cycle is broken down into the incubation and young phases (Table 22). Seven of

Table 21. Number of young-days and young lost during each year of the study. Plots are compared using Hensler and Nichols (1981) (Z) and Mayfield (1975) (χ^2) methods

Operation level	Year	Plot	Young-days[a]	Young lost[b]	%	Hensler/Nichols		Mayfield	
						Z	P	χ^2	P
Full	1993	Test	3442	36	1.05	1.826	0.034	2.825	0.093
		Control	11935	170	1.42				
	1992	Test	2767	298	10.77	7.324	<0.001	70.032	<0.001[c]
		Control	9201	531	5.77				
	1991	Test	4243	98	2.31	0.625	0.268	0.404	0.525
		Control	11547	247	2.14				
	1990	Test	5017	108	2.15	3.627	<0.001	16.376	<0.001[c]
		Control	14095	186	1.32				
	1989	Test	3388	226	6.67	0.910	0.181	0.846	0.358
		Control	6569	405	6.17				
Level 1	1988	Test	4640	115	2.48	5.180	<0.001	34.620	<0.001[c]
		Control	10043	116	1.56				
	1987	Test	3115	42	1.35	0.967	0.166	1.012	0.315
		Control	7715	86	1.12				
Pre	1986	Test	2242	135	6.02	4.047	<0.001	17.421	<0.001[c]
		Control	2996	104	3.47				
	1985	Test	1927	14	0.73	2.105	0.018	4.881	0.027[c]
		Control	1441	22	1.53				

[a] days of observations of young still alive
[b] number of young which suffered mortality
[c] Significant at 0.05 or greater

the nine years of the study have equal mortality on test and control plots in each phase. From the data presented on eggs and young we found that the probability of mortality was higher on the test plots for individual eggs five of nine years and for individual young four of nine years (Table 23). However, egg mortality was higher on the control plot during the preoperational year of 1986, and young mortality was higher on the control plot during 1985 and 1993. Test and control plots did not differ in egg and young mortality in three of the nine years of the study (Table 23).

The general pattern of these data which emerges from the analysis of all five variables is that mortality is not clearly associated with the operation of the Communications System. While there are 15 instances (42%) of higher mortality on test plots during level 1 and full operation of the

Table 22. Summary of nest-day mortality study on test and control plots. Significance is based on the Hensler and Nichols Z value (1981). Years with significant differences are checked

Operation level	Year	Total Nest Mortality			Incubation Phase Mortality			Young Phase Mortality		
		T>C[a]	T<C[b]	T=C[c]	T>C	T<C	T=C	T>C	T<C	T=C
Full	1993			✓			✓			✓
	1992	✓					✓	✓		
	1991			✓			✓			✓
	1990	✓					✓			✓
	1989			✓			✓			✓
Level 1	1988	✓					✓	✓		
	1987	✓			✓					✓
Pre	1986			✓			✓			✓
	1985		✓			✓				✓
	Total:	4	1	4	1	1	7	2	0	7

[a] mortality greater on test than control plot
[b] mortality less on test than control plot
[c] mortality on test plot equal to control plot

system, there are 19 instances (53%) where test and control plots had equal mortality. There was no consistent trend of mortality with operation of the Communications System, but mortality was higher on test plots more often (16 instances; 36%) than mortality was higher on control plots (5 instances; 11%). There are likely many possible factors which contribute to this relationship, but we have found none that can clearly be assigned as the causal factor. The greater forest edge on test plots may have increased interference by house wrens (*Troglodytes aedon*). Their depredation on tree swallow eggs has been shown to be a significant factor influencing tree swallow nesting success in other localities (Rendell and Robertson 1990). However, there was very little, if any, evidence of house wren activity on our study plots as one moved away from the edges. It has also been difficult to distinguish between house wren depredation and other forms of nest failure with any quantifiable degree of confidence. Other factors which may have influenced higher mortality on test plots

Table 23. Summary of egg-day and young-day mortality on test and control plots 1985 through 1993. Results are based on the Hensler and Nichols Z (1981). Check marks signify the results of each year

Operation level	Year	Egg Mortality			Young Mortality		
		T>C[a]	T<C[b]	T=C[c]	T>C	T<C	T=C
Full	1993			✓		✓	
	1992	✓			✓		
	1991			✓			✓
	1990	✓			✓		
	1989	✓					✓
Level 1	1988	✓			✓		
	1987	✓					✓
Pre	1986		✓		✓		
	1985			✓		✓	
	Total:	5	1	3	4	2	3

[a] mortality greater on test than control plot
[b] mortality less on test than control plot
[c] mortality equal on test and control plot

include better access to nest boxes by predators and differential impact of local weather patterns. At this time, we can not attribute the higher mortality on test plots to any of the factors with any confidence. Overall, probabilities of mortality are variable, and although mortality was more often higher on the test plots than controls, particularly once the antenna was activated, just as often the plots did not differ in levels of mortality. We can therefore not conclude with any certainty that ELF electromagnetic fields are the cause of the observed differences.

Growth. Curve fitting to growth data for individual nestlings for body mass, tarsus length and ulna length was accomplished using the logistic model. Wing growth, which was still proceeding at fledging, was fit by the exponential model. These models produced the highest R^2 values, on average, compared to other growth models (see Methods). The maximum values attained for mass, tarsus length and ulna length, and the ages at which they were attained, were also used to assess growth of nestlings on control and test plots. Maximum values have been found by other researchers to be less variable than curve fitted ones (Zach, 1988), as we have also found. We include these more sensitive measures along with the curve-fit values.

The logistic model was fitted to the individual nestling growth data (Ricklefs 1983) using procedure NONLIN in SYSTAT (Wilkinson 1988). The procedure estimated values for the growth rate constant and the inflection point for body mass, tarsus length and ulna length. The NONLIN procedure was also used to fit wing growth data to an exponential model. A growth constant was estimated, but not an inflection point. The data were analyzed using a nested analysis of variance (ANOVA model), with main effects of operational period and treatment plot, and operation and plot interaction, and with the effect of years nested within operational period. The appropriate mean square ratio for computing the value of F for the operation effect is the mean square due to operation divided by the mean square due to years within operation (Zar, 1984). Prior to analysis by ANOVA, each variable was tested for normality by the procedure of D'Agostino *et al.* (1990). Each variable was transformed, if necessary, to render the distribution normal. Summarized below are the findings for the years 1985-1991. Data were not taken for 1992 since nearly all nestlings died in a prolonged cold weather episode.

ELF Exposure During Growth Studies. The hours of operation and field strengths of the antenna system during growth studies are presented in Figure 15. Low level testing began in 1987 and 1988, and full operation occurred from 1989 through 1991.

Body Mass. The growth constant (Figure 16), inflection points (Figure 17), maximum mass attained (Figure 18) and age at maximum mass (Figure 19) showed no significant operational period effects (Table 24). A plot effect was apparent for inflection point (Figure 17) and maximum mass attained (Figure 18), but not for the other variables (Table 24). The significant plot effect observed for mass inflection point cannot be interpreted straightforwardly when the plot-period interaction is significant, but it could be due to the control plot means being higher than the test plot means

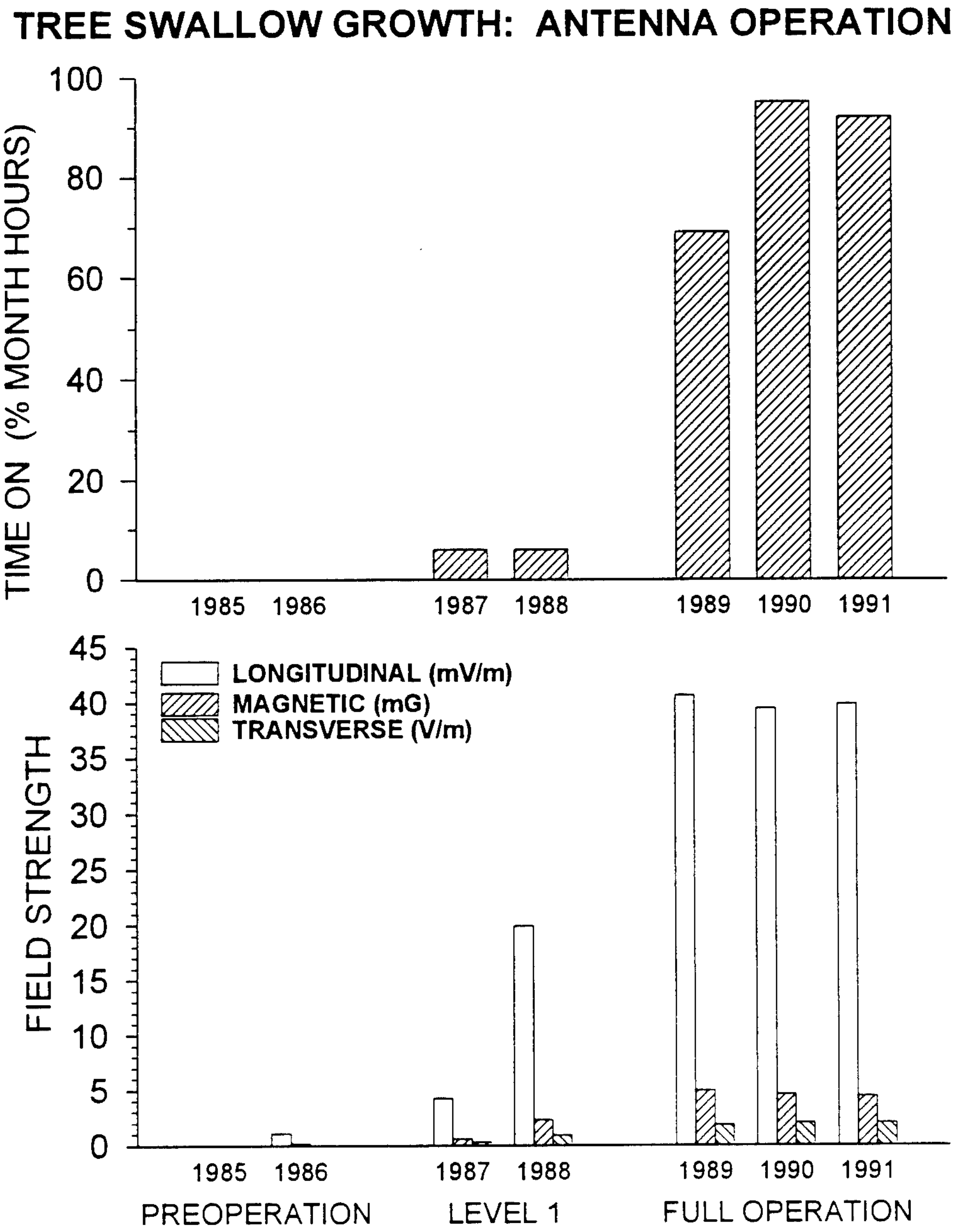


Figure 15. ELF electromagnetic field exposure during growth studies

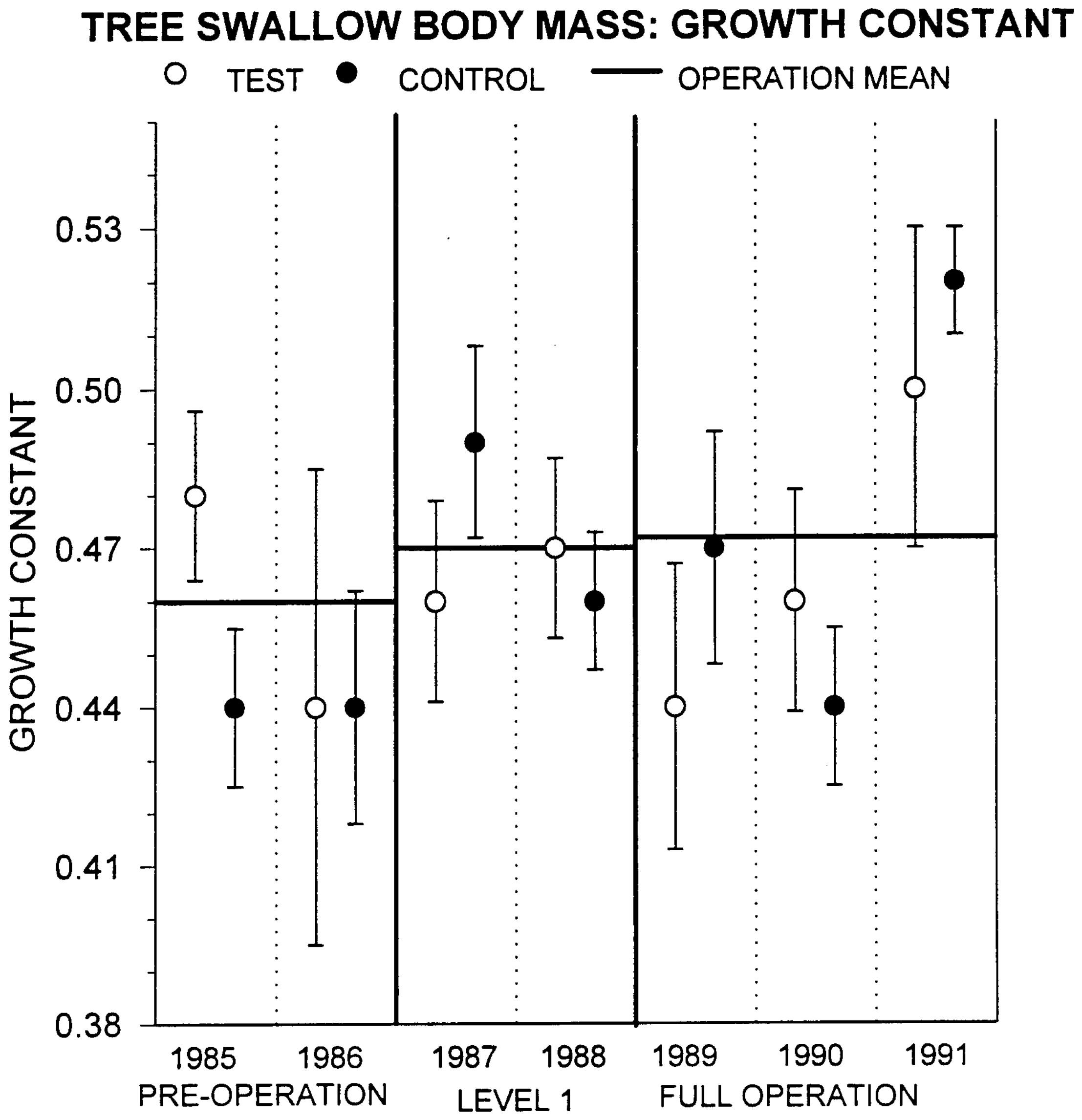


Figure 16. Mass growth constants (mean±95% confidence interval) of nestling tree swallows observed on test and control sites for 1985 through 1991.

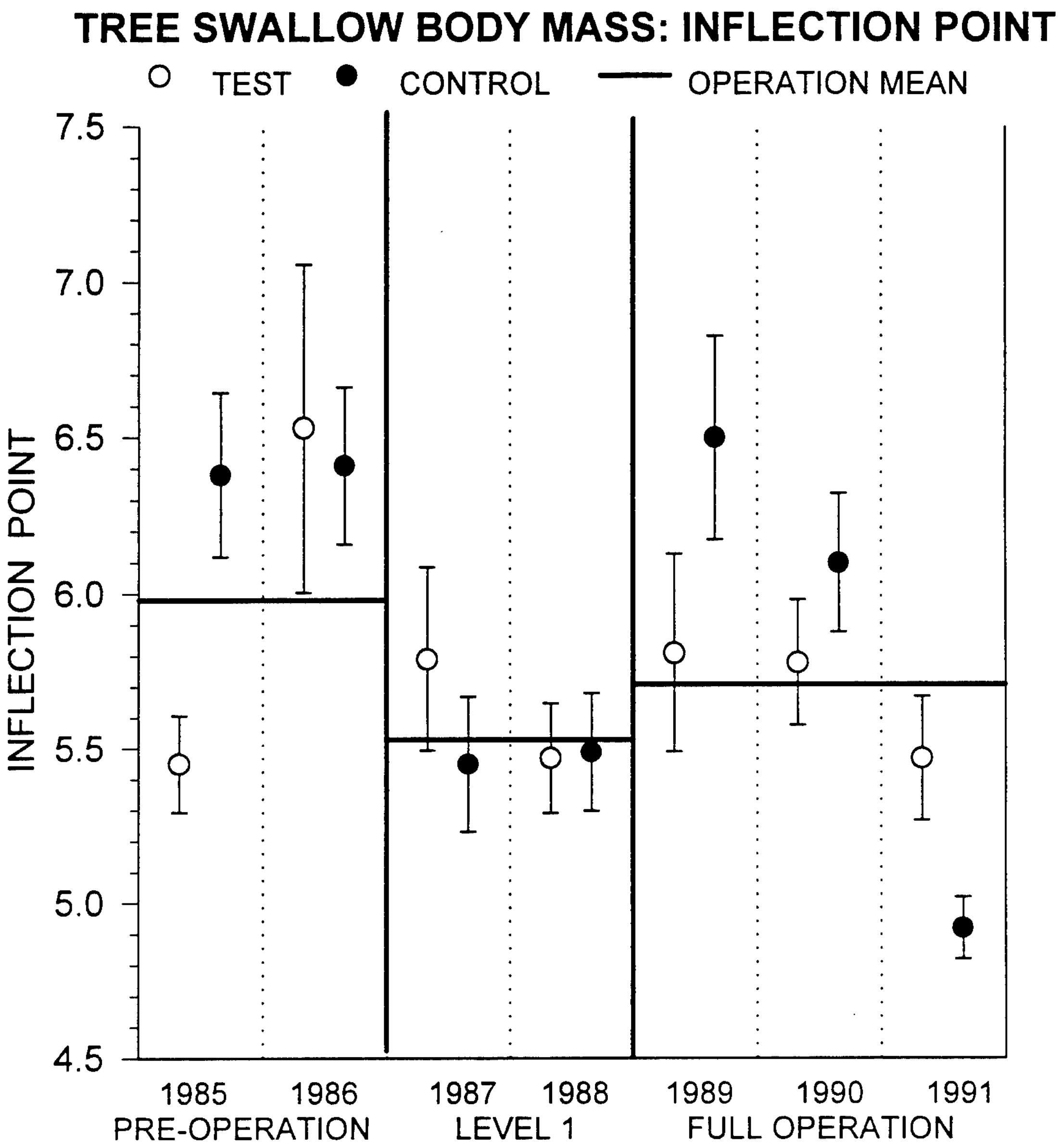


Figure 17. Mean inflection points (age in days±95% confidence interval) for tree swallow growth of body mass

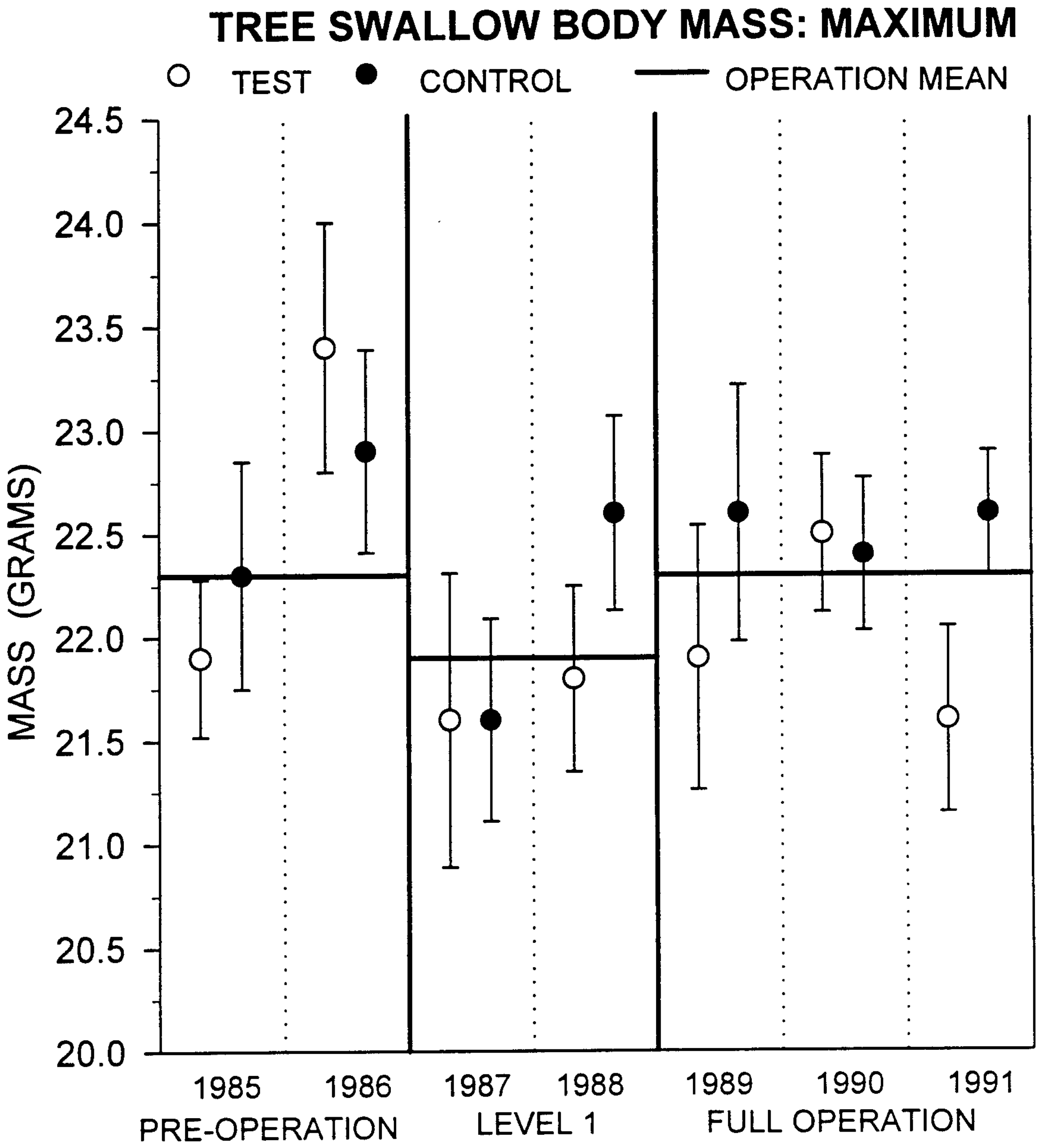


Figure 18. Maximum mass (grams, mean±95% confidence interval) attained by nestling tree swallows observed on test and control sites for 1985 through 1991

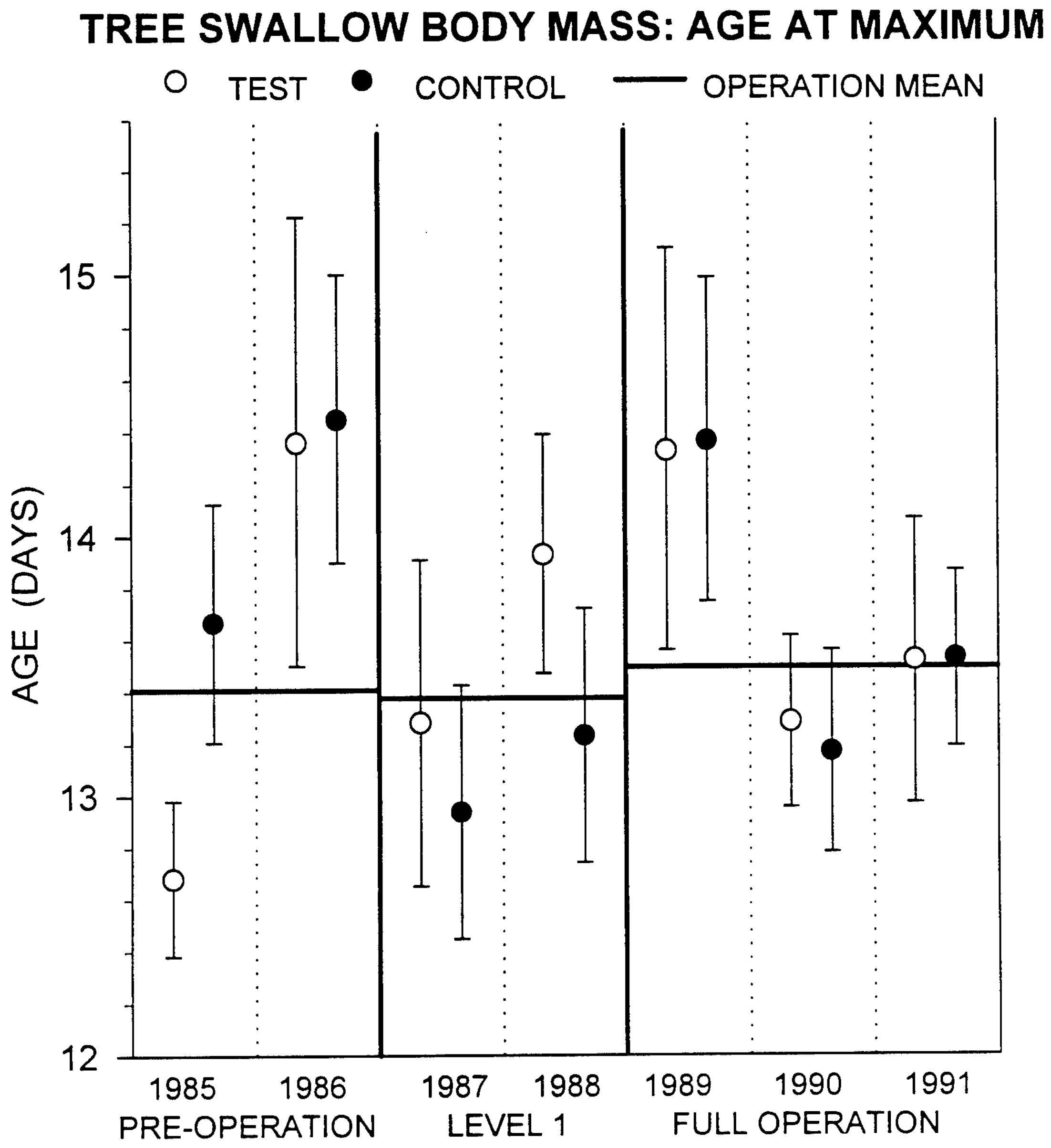


Figure 19. Age at maximum body mass (mean±95% confidence interval) for tree swallow nestlings for 1985 through 1991

during the first year of preoperation (1985) and the first year of full operation (1989), and also to the control plot mean being much lower than the test plot mean in 1991 (Figure 17). The plot effect for maximum mass attained was due to larger mean values on control plots in four of seven years. These differences in means were not associated with operation level.

A highly significant effect was noted for years within operation for all variables, which may be due to weather events. Cold weather often leads to nestlings of reduced mass due to parents spending considerable effort to maintain their own energy levels in the cold weather. Also, insect abundance is low during cold weather events.

A significant interaction of operation and plot was noted for all but maximum weight. Since this could be indicative of an effect of the Communications System, the interaction for each variable is examined in detail. For mass growth constant (Figure 20), the significant interaction was due to lower control-plot means compared to test-plot means during the preoperational period followed by an increase to the level of test plot means in level 1 and full operation periods. Means for test plots remained stable over the same periods. The reverse direction of change occurred for body mass inflection point on the control plot (Figure 21), with the means on the test plot again remaining stable. There was not a significant operation-by-plot interaction for maximum body mass (Table 24), but there was for age at maximum body mass (Figure 22). Age at maximum body mass was lower on the test plot in the preoperation period. Both means converge and are not significantly different in level 1 and full operation periods.

In each of the significant interactions for body mass growth constant, inflection point, and age at maximum body mass, the means for test and control plots were different in the preoperation phase of the study. The means converge and are not significantly different during level 1 and full operation. In all but age at maximum mass, the control plot means converge on test plot means, which remain relatively constant. In age at maximum mass, means on both plots converge. This pattern could be interpreted as due to the Communications System in the case of test plot means,

Table 24. Nested analysis of variance for measures of mass in nestling tree swallows

Nested ANOVA for mass growth constant, transformed to the 1.25 power.

SOURCE	DF	SS	MS	F	P
OPERATION	2	0.0404	0.0202	0.32	0.7452
PLOT	1	0.0073	0.0073	1.54	0.2148
YEAR(OPER)	4	0.2548	0.0637	13.48	<0.0001[a]
OPER*PLOT	2	0.0443	0.0222	4.69	0.0095[a]
ERROR	706	3.3360	0.0047		

Nested ANOVA for mass inflection point, log transformed.

SOURCE	DF	SS	MS	F	P
OPERATION	2	0.9180	0.4590	1.04	0.4315
PLOT	1	0.1810	0.1810	9.08	0.0027[a]
YEAR(OPER)	4	1.7577	0.4394	22.05	<0.0001[a]
OPER*PLOT	2	0.5065	0.2532	12.70	<0.0001[a]
ERROR	691	13.7724	0.0199		

Nested ANOVA for maximum mass, transformed to the 2.4 power.

SOURCE	DF	SS	MS	F	P
OPERATION	2	14585.0*E2	729296.1	1.49	0.3279
PLOT	1	852041.1	852041.1	7.33	0.0069[a]
YEAR(OPER)	4	19543.0*E2	488594.8	4.21	0.0022[a]
OPER*PLOT	2	76581.2	38290.6	0.33	0.7193
ERROR	873	101428.0*E3	116183.2		

Nested ANOVA for age at maximum mass.

SOURCE	DF	SS	MS	F	P
OPERATION	2	19.727	9.863	0.33	0.737
PLOT	1	0.794	0.794	0.23	0.630
YEAR(OPER)	4	119.435	29.859	8.73	0.000[a]
OPER*PLOT	2	51.320	25.660	7.50	0.001[a]
ERROR	873	2986.576	3.421		

[a] Significant at 0.05 or less

since the age at maximum mass increased during level 1 operation compared to the control plot. However, no further increase in the test plot mean occurred in full operation, raising the possibility of a threshold, rather than incremental, effect of the Communications System. Furthermore, older ages at maximum mass in the preoperation period were followed by younger ages on the control plot in level 1 and full operation at the same time that means on the test plot were increasing. The

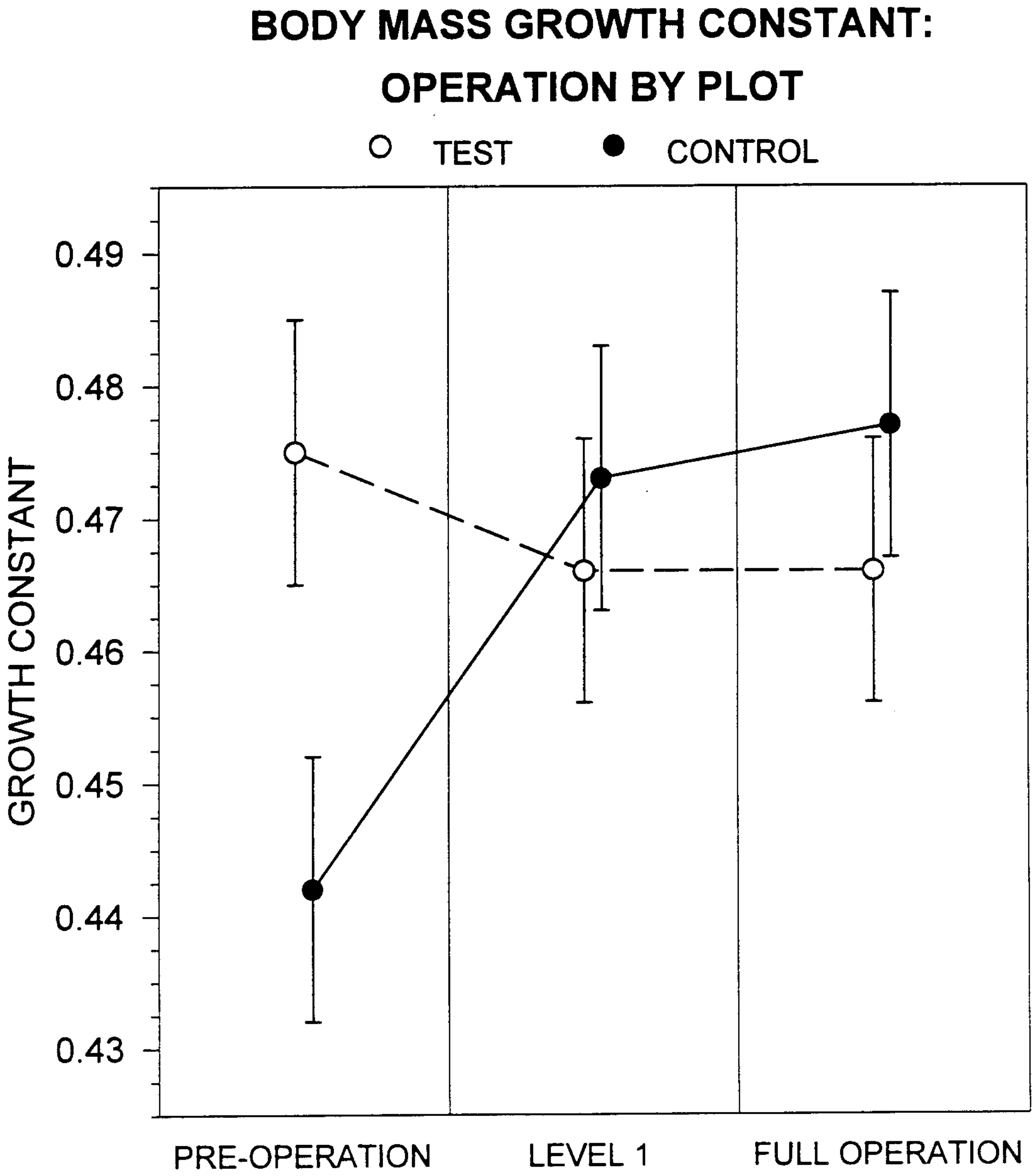


Figure 20. Mean growth constant (±95% confidence interval) for body mass for tree swallows. Shown are the test and control plot means pooled over years within operation level

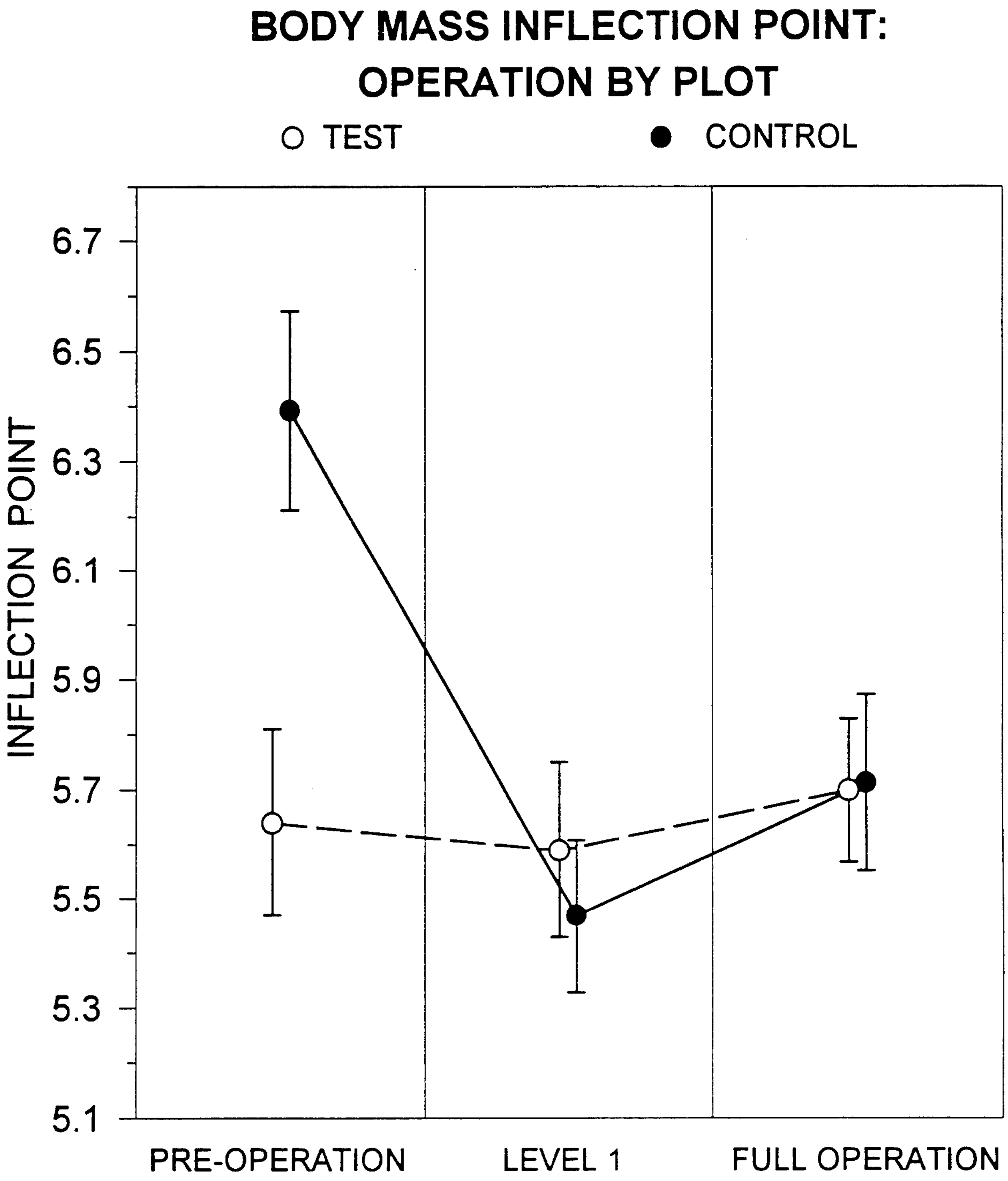


Figure 21. Mean inflection points (age in days ±95% confidence interval) for body mass for tree swallows. Shown are mean for operation by plot interaction

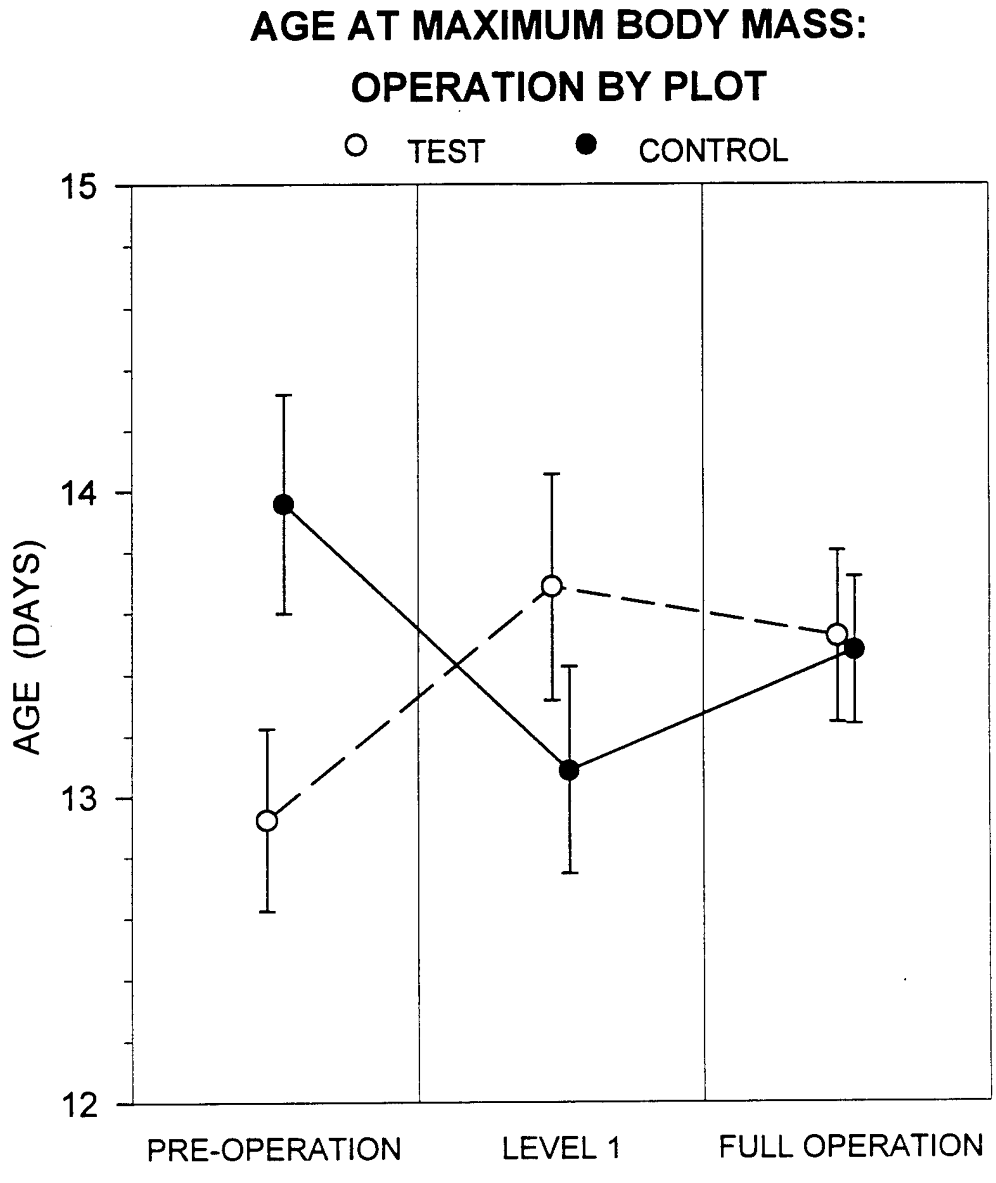


Figure 22. Mean age of maximum body mass (±95% confidence interval) for tree swallows showing the interaction of operation by plot

means converge during full operation.

The power of test and minimum detectable differences are noted in Figure 23. The actual detectable differences for operation effect were about 7% for mass growth constant but less than 5% for inflection point, maximum mass and age at maximum value (Figure 23). However, the power of all these tests was below 30%, meaning we have relatively low certainty we could have found such small differences in means as significant with our current sample size. If we increase the power to 70%, then the minimum detectable differences increase to just under 10% for all but the growth constant, which increases to about 18%. Therefore, our current data would have allowed us to detect a difference in operation means of about 18% for mass growth constant and about 10% for the other variables (Figure 23).

Minimum detectable differences and power of tests performed on plot means are also shown in Figure 23. The actual detectable differences are less than 4% for all variables, and the power is greater than 70% for mass inflection point and maximum mass, which we found to be significantly different in the ANOVA test. Therefore, we could and did detect differences as small as indicated with high certainty. Mass growth constant and age at maximum mass had powers of less than 30%. At 70% power, we would still have been able to detect differences in the means of these variables as small as about 2%.

Tarsus. Yearly plot means for growth constant (Figure 24), inflection point (Figure 25), maximum tarsus length attained (Figure 26), and age at maximum tarsus length (Figure 27) were tested for operation and plot effects. Effects of operation were not apparent for any of the measurements (Table 25), although maximum tarsus length approached significance. The means for maximum tarsus length increased from preoperation to the first year of full operation in 1989, then decreased in 1990 and 1992 (Figure 26).

A significant plot effect was observed for tarsus inflection point and for age at maximum tarsus, but not the other variables. For tarsus inflection point, the effects seems to be due solely to

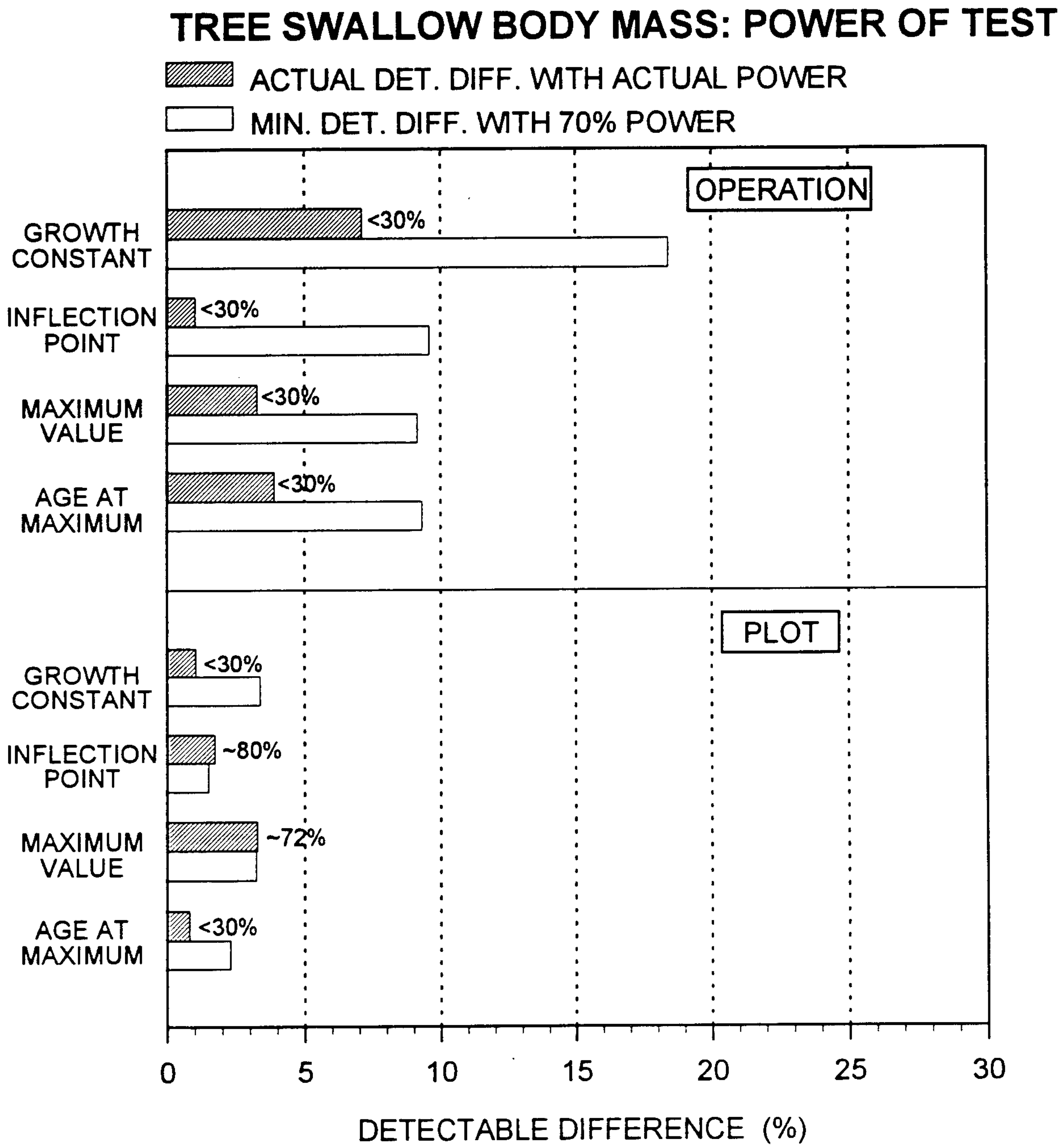


Figure 23. Detectable differences of tree swallow mass variables for operation and plot effects

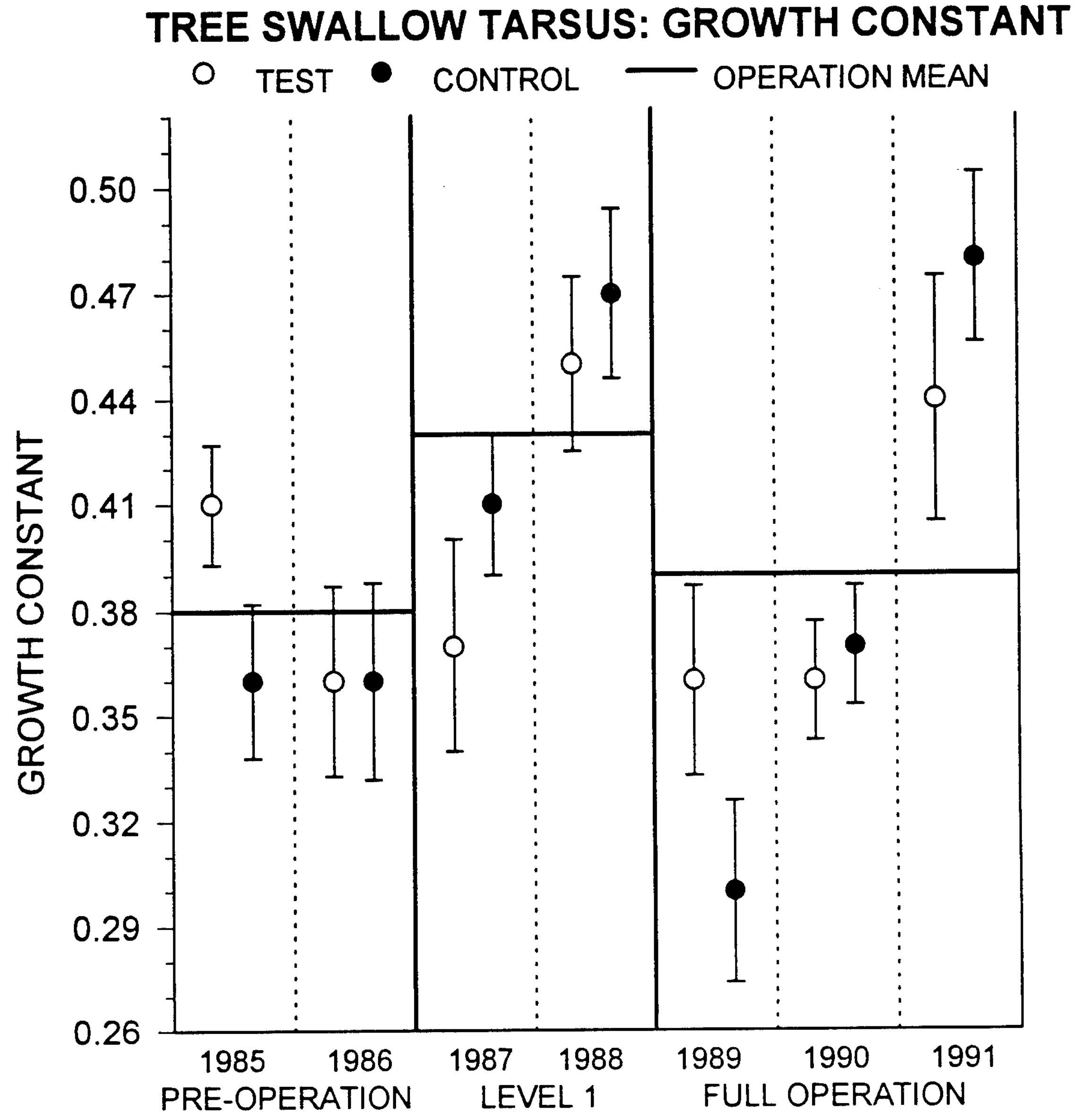


Figure 24. Tarsus length growth constants (mean±95% confidence interval) of nestling tree swallows observed on test and control sites for 1985 through 1991

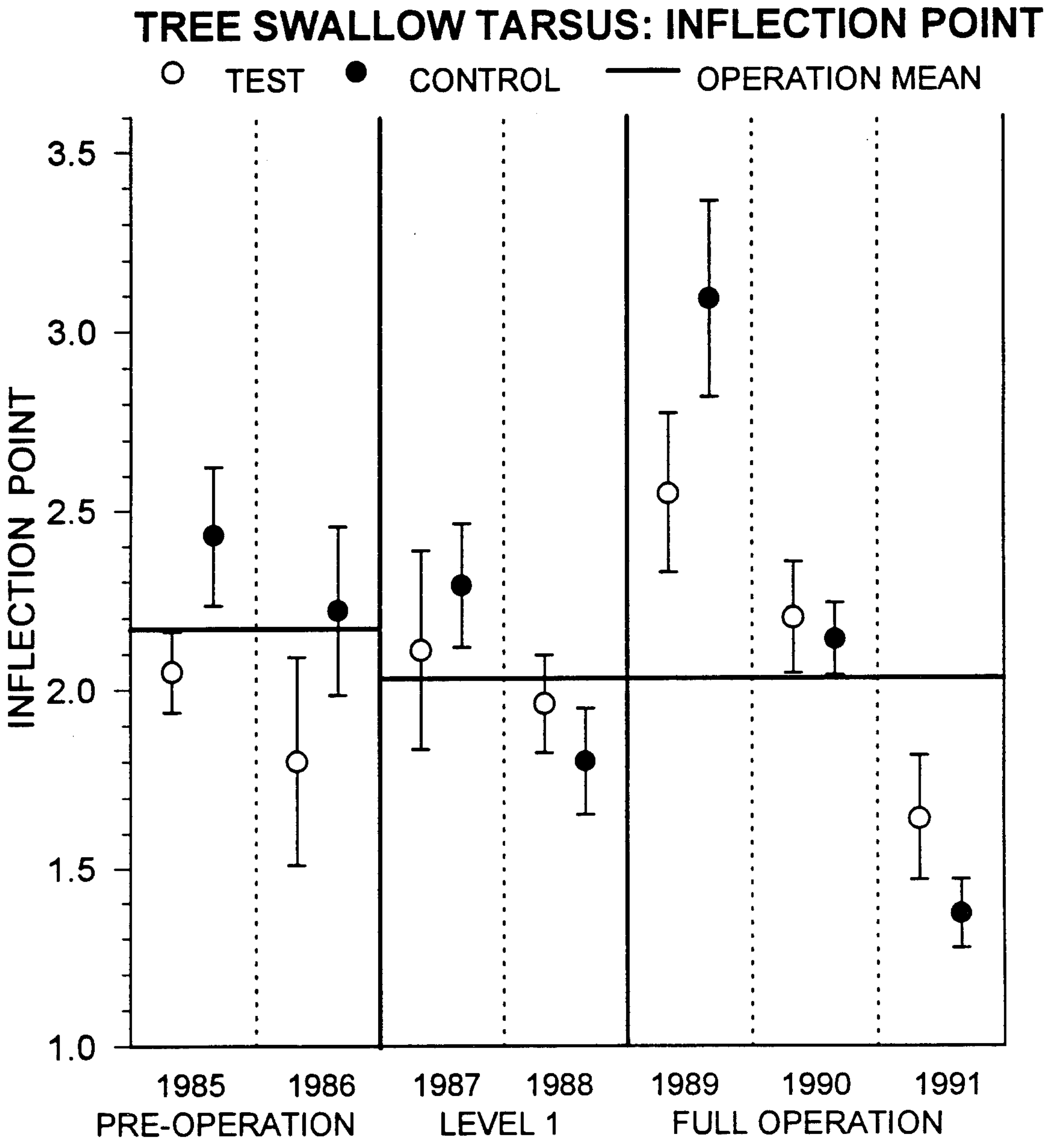


Figure 25. Mean inflection points (age in days ±95% confidence interval) for tarsus growth for nestling tree swallows for 1985 through 1991

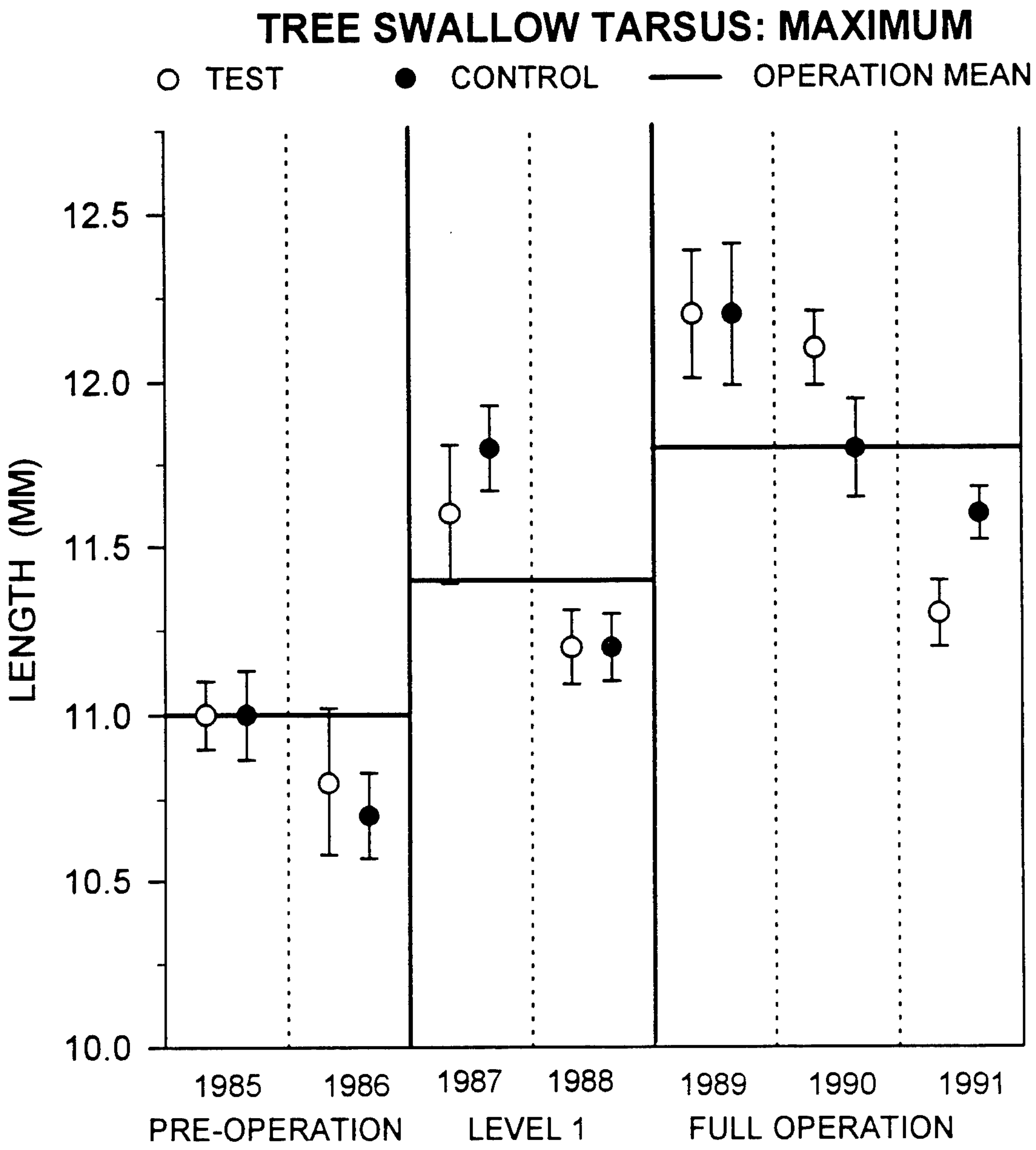


Figure 26. Maximum tarsus length (mm, mean ±95% confidence interval) attained by nestling tree swallows observed on test and control sites for 1985 through 1991

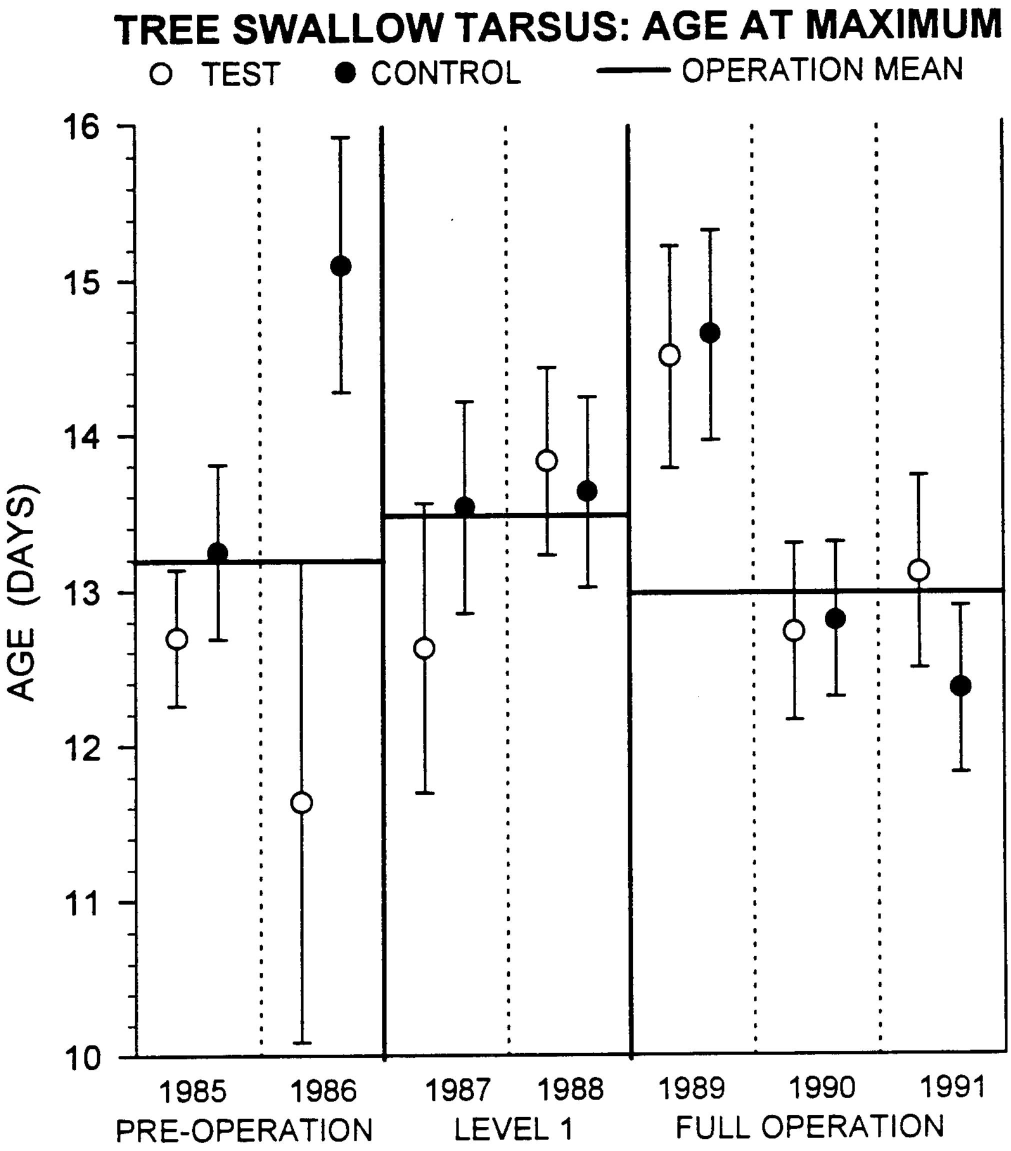


Figure 27. Mean age at maximum tarsus length (days ±95% confidence interval) for nestling tree swallows for 1985 through 1991

differences in plot means in 1989 (Figure 25). The plot effect for age at maximum tarsus length seems to be due solely to plot means in 1986 (Figure 26).

As with mass, highly significant year within operation effects were found for tarsus variables. The same factors of weather, and food abundance related to weather, are suspected as causing the observed effects. Tarsus length growth constant and body mass growth constant follow a similar annual pattern (compare Figure 16 and Figure 24), but maximum tarsus length and body mass do not (compare Figure 18 and Figure 26).

Significant interaction of operation and plot means, which could imply an effect of the Communications System, occurred for tarsus growth constant, inflection point and age at maximum tarsus length (Table 25). The significant interaction of operation and plot for tarsus growth constant appears due to an initially lower mean for the control plot in the preoperation period which then increased to test levels in the level 1 and full operation periods, while the test plot means remained relatively constant over the entire operation period (Figure 28). The change in control-plot birds is reversed for inflection point (Figure 29). For age at maximum tarsus, the control plot mean was higher in the preoperation period than the test plot, and then both means converged in level 1 and full operation periods (Figure 30). As was found for body mass operation-by-plot interactions, the significant effects were due to changes on the control plot, not the test plot, or both plots converged during level 1 and full operation periods.

Detectable differences for tarsus variables are noted in Figure 31. Actual detectable differences for the operation effect varied from about 3% to over 16%, with the power being less than 30% for all but maximum tarsus length, which was about 65%. Minimum detectable differences in operation means at 70% power indicate we could expect to detect differences in means of operation level of about 34% for tarsus growth constant and inflection point, but about 13% for age at maximum tarsus length and about 3% for maximum tarsus length.

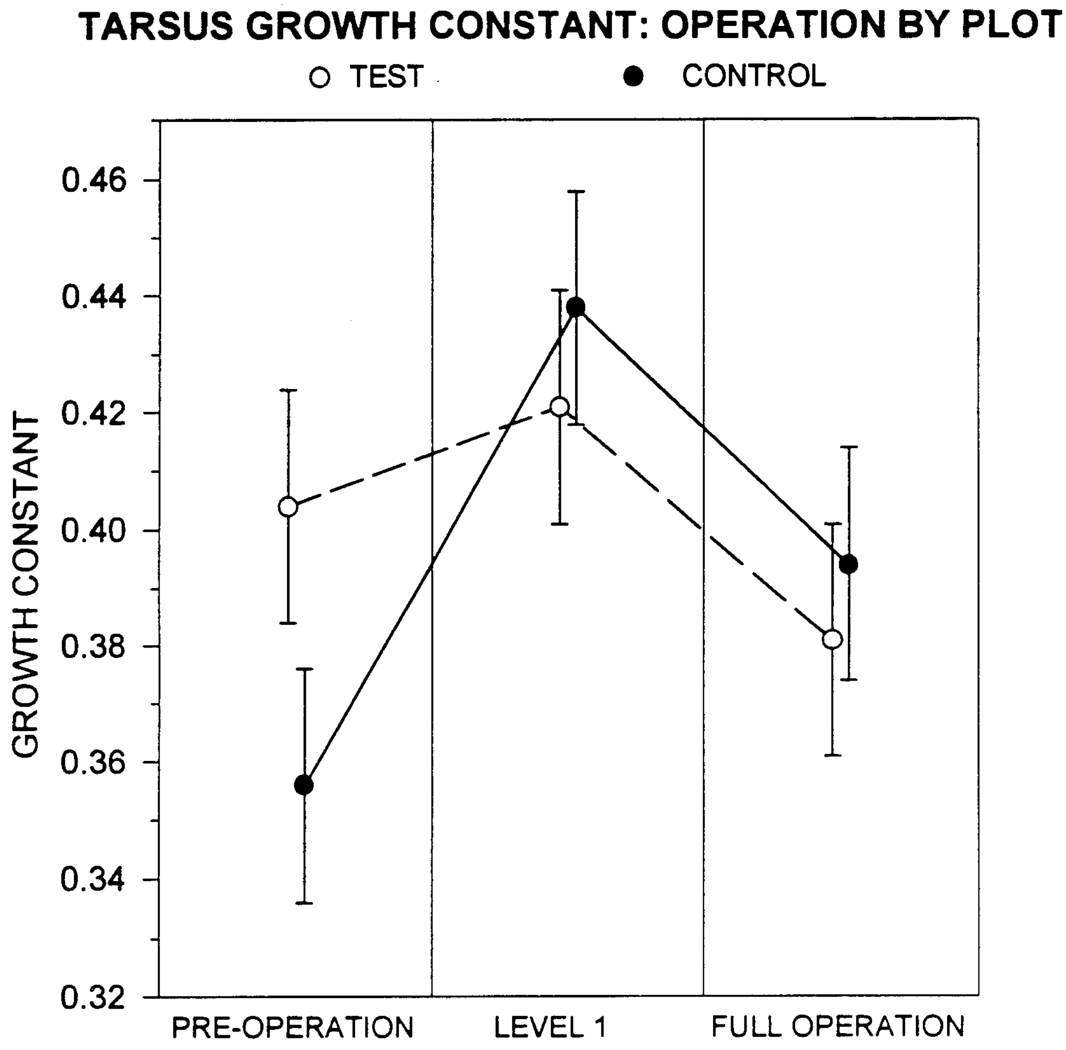


Figure 28. Mean tarsus growth constant (±95% confidence interval) for nestling tree swallows. Shown are means for operation by plot interaction

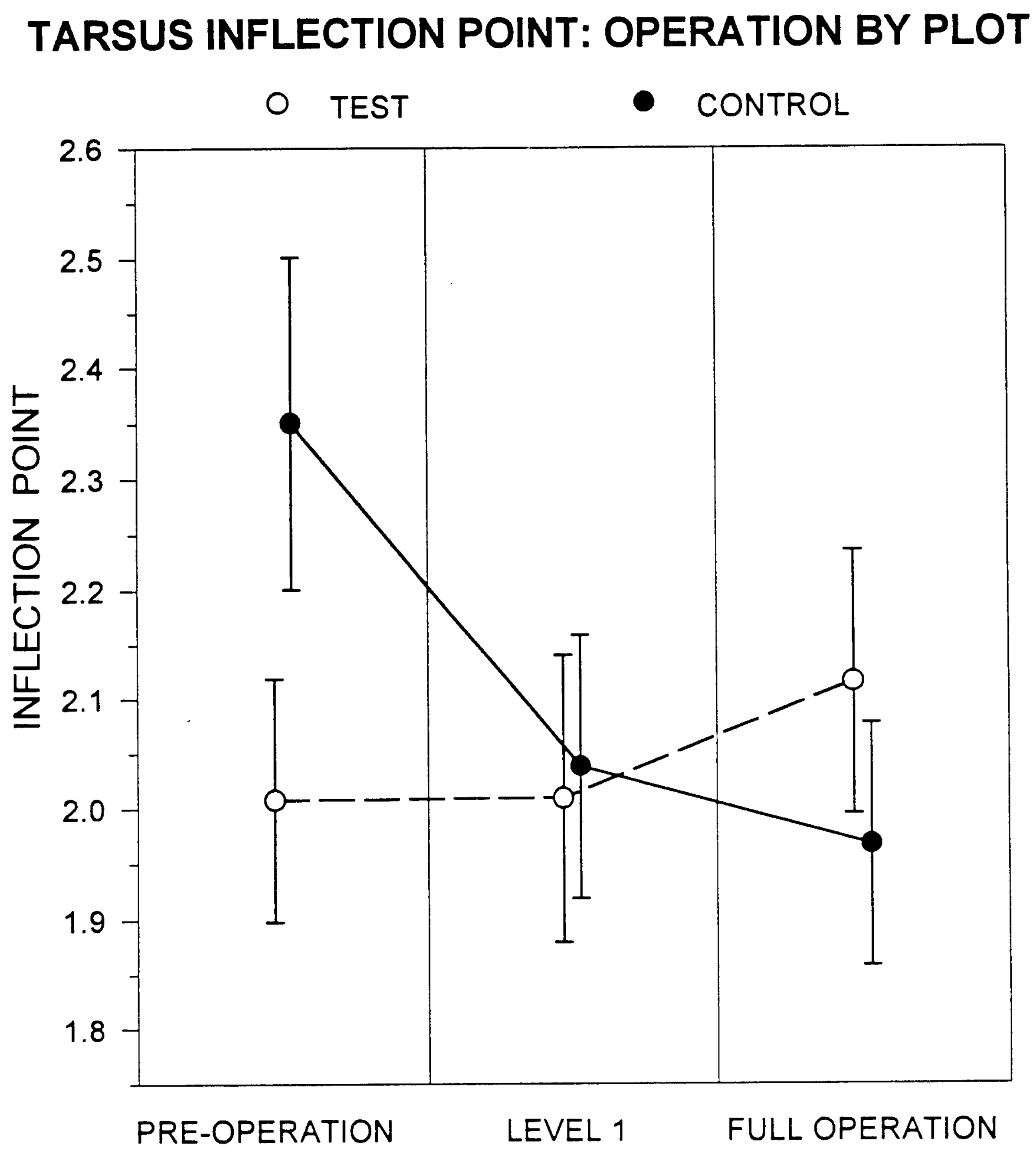


Figure 29. Mean tarsus inflection point (age in days ±95% confidence interval) for nestling tree swallows. Shown are means for operation by plot interaction

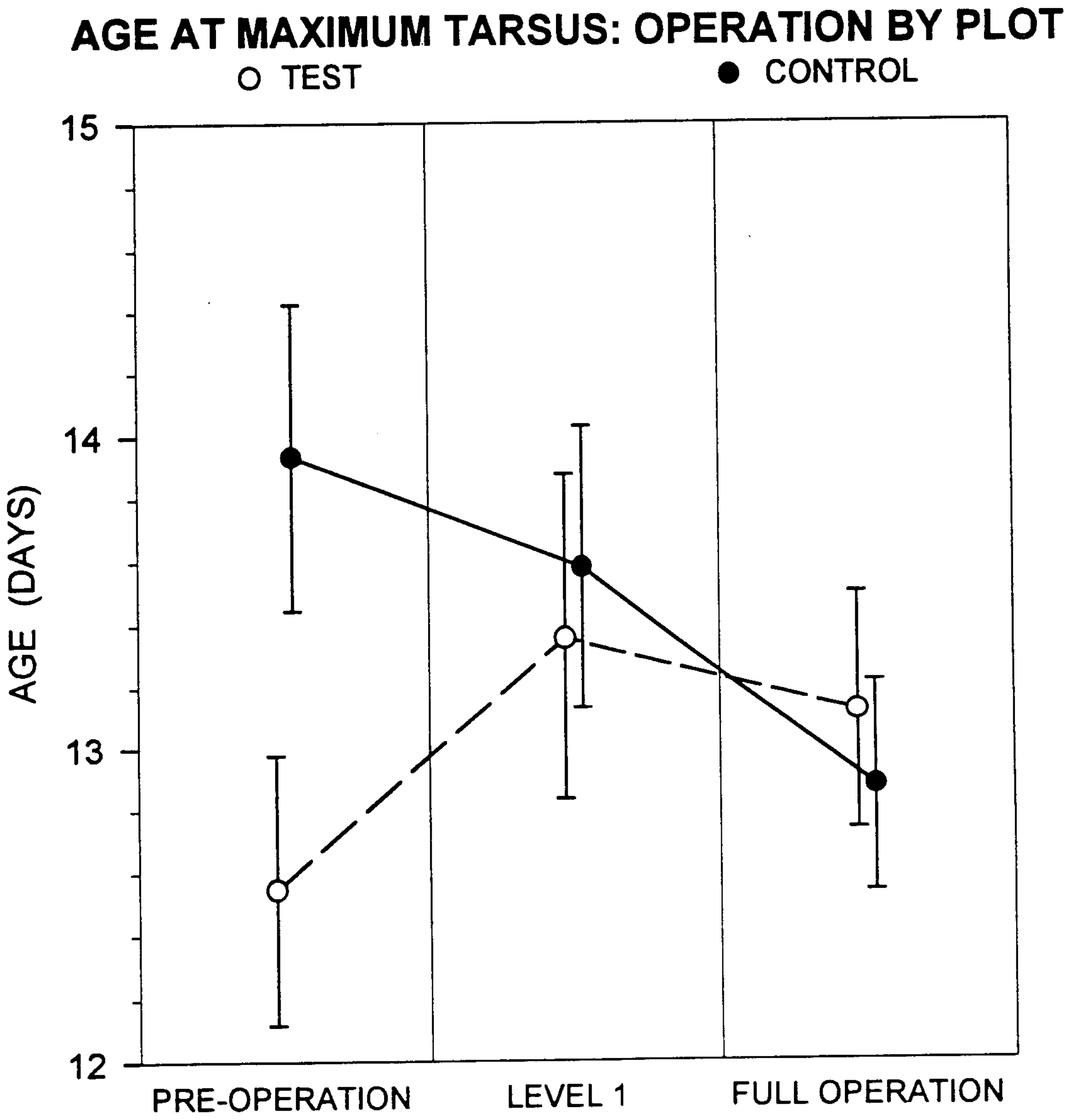


Figure 30. Mean values of age of maximum tarsus length (days ±95% confidence interval) for nestling tree swallows. Shown are means for operation by plot interaction

Actual detectable differences and power for plot means (Figure 31) indicate we could have detected differences from about 4% to less than 1% for tarsus variables, but the power of the test ranged from less than 30% to about 57%. With power set at 70%, minimum detectable differences increase to less than 1% to about 4%. This analysis indicates we could have detected very small differences in plot means, if they had existed, with our current data.

Ulna. An examination of ulna growth indicates there were no operation or plot effects (Table 26). We again find consistent, highly significant effects due to years within operation.

Yearly plot means for growth constants (Figure 32), inflection point for the growth constant (Figure 33), maximum ulna length (Figure 34) and age at maximum ulna (Figure 35) show patterns similar to tarsus growth.

The interaction of operation and plot, which could indicate an effect of the Communications System, was significant for ulna inflection point and age at maximum ulna, but not for other variables (Table 26). The control plot mean for ulna inflection point was higher than the test plot in the preoperation period (Figure 36). Means on both plots then decreased and converged in level 1 and full operation periods. However, the test plot mean for age at maximum ulna was lower than the control plot in the preoperation period and then converged to the control plot value during level 1 and full operation periods (Figure 37). This pattern is what would be expected if an effect of the Communications System was to occur, and we must conclude that the effect is coincident with antenna operation.

Detectable differences are noted in Figure 38. Actual detectable differences for operation means ranged from about 4% to 15% for operation means. The power of these tests was less than 30% for all except maximum ulna length, which was about 48%. With power set at 70%, minimum detectable differences for operation means ranged from about 10% to about 21%.

Actual detectable differences for plot means ranged from less than 1% to about 2%. The power of these tests was all less than 30%. With the power set at 70%, the minimum detectable

Table 25. Nested analysis of variance for measures of tarsus length growth in nestling tree swallows

Nested ANOVA for tarsus growth constant, log transformed.

SOURCE	DF	SS	MS	F	P
OPERATION	2	1.9164	0.9582	0.55	0.6150
PLOT	1	0.0469	0.0469	0.98	0.3222
YEAR(OPER)	4	6.9657	1.7414	36.47	<0.0001[a]
OPER*PLOT	2	1.1391	0.5695	11.93	<0.0001[a]
ERROR	744	35.5275	0.0478		

Nested ANOVA for tarsus inflection point, transformed to the 0.7 power.

SOURCE	DF	SS	MS	F	P
OPERATION	2	0.3343	0.1671	0.03	0.9675
PLOT	1	0.6548	0.6548	5.29	0.0218[a]
YEAR(OPER)	4	20.0510	5.0127	40.47	<0.0001[a]
OPER*PLOT	2	1.9146	0.9573	7.73	0.0005[a]
ERROR	723	89.5554	0.1239		

Nested ANOVA for maximum tarsus length, transformed log(x + 1).

SOURCE	DF	SS	MS	F	P
OPERATION	2	0.6845	0.3423	4.75	0.088
PLOT	1	0.0003	0.0003	0.13	0.714
YEAR(OPER)	4	0.2882	0.0721	37.98	<0.001[a]
OPER*PLOT	2	0.0041	0.0021	1.08	0.339
ERROR	881	1.6715	0.0019		

Nested ANOVA for age at maximum tarsus length.

SOURCE	DF	SS	MS	F	P
OPERATION	2	0.981	0.490	0.01	0.991
PLOT	1	36.364	36.364	5.54	0.019[a]
YEAR(OPER)	4	214.487	53.622	8.17	<0.001[a]
OPER*PLOT	2	73.280	36.640	5.58	0.004[a]
ERROR	881	5783.338	6.565		

[a] Significant at 0.05 or less

difference for plot means ranged from 2% to about 4.5%

Wing. Growth of the wing was examined by fitting data to an exponential model to produce a growth constant. The wing does not have a linear phase during growth in the nest, and growth is still underway when nestlings fledge. Accordingly, we have only measures of the fitted growth constant to examine for possible ELF effects. No effects of operation were detected

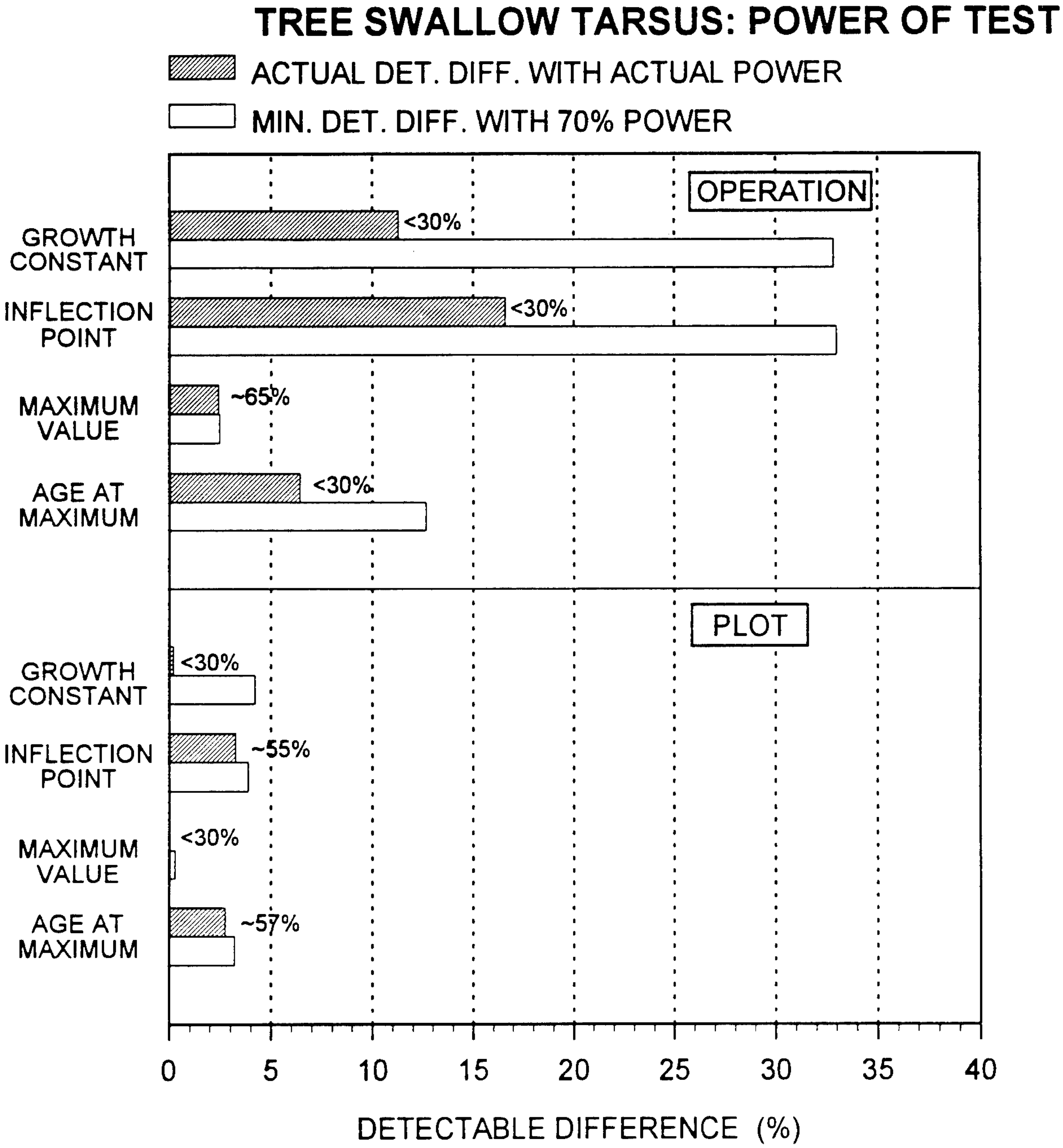


Figure 31. Detectable differences of tree swallow tarsus length variables for operation and plot effects

Table 26. Nested analysis of variance for measures of ulna length growth in nesting tree swallows

Nested ANOVA for ulna growth constant (K), transformed to the 1.25 power.

SOURCE	DF	SS	MS	F	P
OPERATION	2	0.0604	0.0302	0.60	0.5939
PLOT	1	0.0006	0.0006	0.24	0.6269
YEAR(OPER)	4	0.2028	0.0507	21.53	<0.001[a]
OPER*PLOT	2	0.0008	0.0004	0.16	0.8529
ERROR	679	1.5988	0.0024		

Nested ANOVA for ulna inflection point, log transformed.

SOURCE	DF	SS	MS	F	P
OPERATION	2	1.7527	0.8764	1.72	0.2895
PLOT	1	0.0146	0.0146	0.70	0.4047
YEAR(OPER)	4	2.0412	0.5103	24.38	<0.001[a]
OPER*PLOT	2	0.3218	0.1609	7.69	0.0005[a]
ERROR	661	13.8348	0.0209		

Nested ANOVA for maximum ulna, transformed to the 6.4 power.

SOURCE	DF	SS	MS	F	P
OPERATION	2	3996.0*E15	1998.0*E15	3.33	0.1410
PLOT	1	7512.0*E13	7512.0*E13	1.10	0.2942
YEAR(OPER)	4	2402.0*E15	6006.0*E14	8.81	<0.001[a]
OPER*PLOT	2	9086.0*E13	4543.0*E13	0.67	0.5140
ERROR	861	5872.0*E16	6819.0*E13		

Nested ANOVA for age at maximum ulna length.

SOURCE	DF	SS	MS	F	P
OPERATION	2	26.053	13.026	0.38	0.707
PLOT	1	7.368	7.368	2.27	0.133
YEAR(OPER)	4	137.438	34.360	10.57	<0.001[a]
OPER*PLOT	2	55.246	27.623	8.50	<0.001[a]
ERROR	861	2799.096	3.251		

[a] Significant at 0.05 or less

(Table 27). Significant effects were noted for plot and years within operation, and the interaction of operation and plot was nearly significant.

Yearly plot means for wing growth constants are shown in Figure 39. The significant plot effect appears to be due to larger mean values of wing growth constant for the control plot in 1988 and in 1990. In other years, the means are nearly identical, except for the test plot in 1986. In that

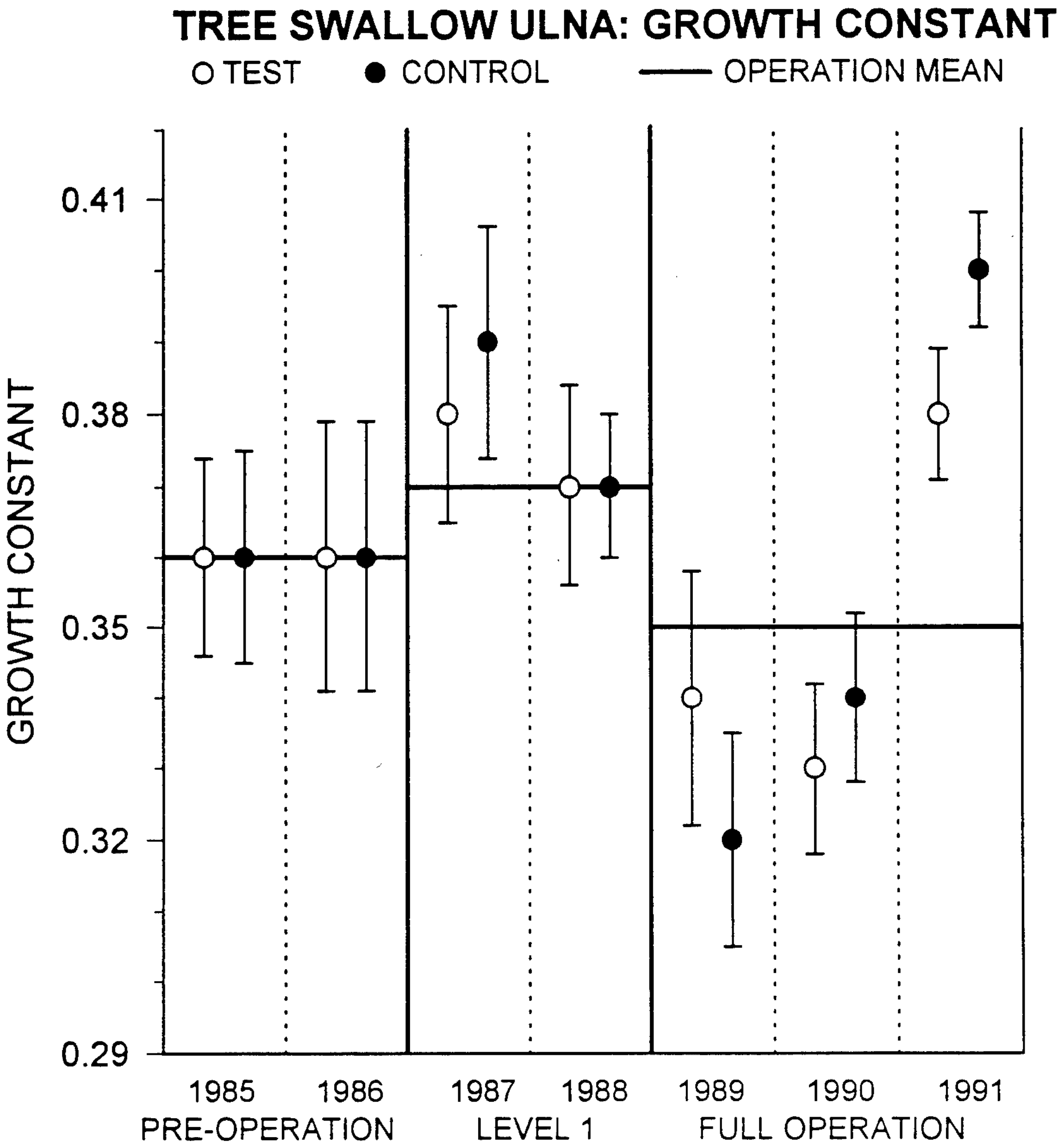


Figure 32. Ulna length growth constants (mean ±95% confidence interval) of nestling tree swallows observed on test and control sites for 1985 through 1991

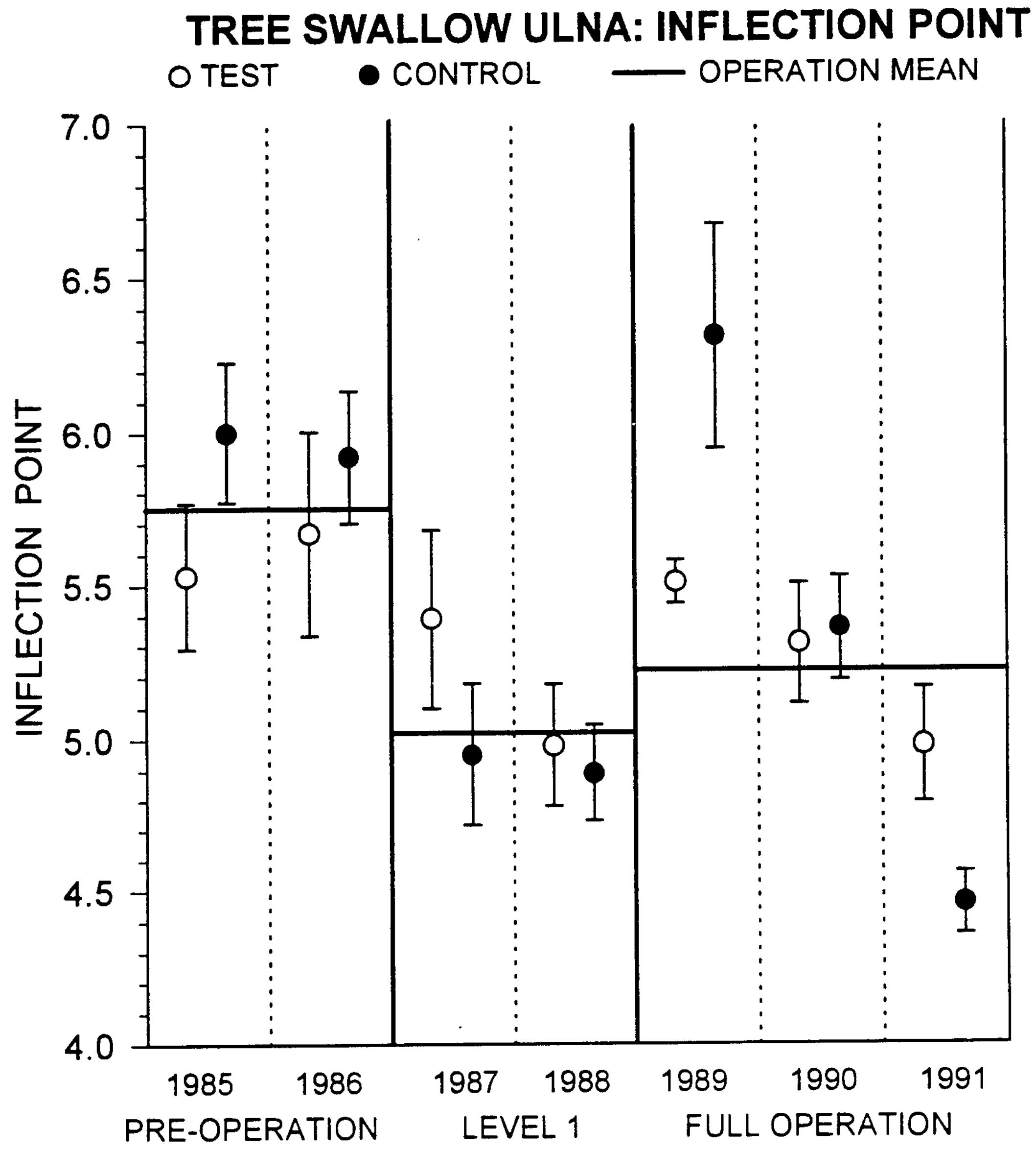


Figure 33. Mean inflection point for ulna growth (age in days ±95% confidence interval) for nestling tree swallows observed on test and control sites for 1985 through 1991

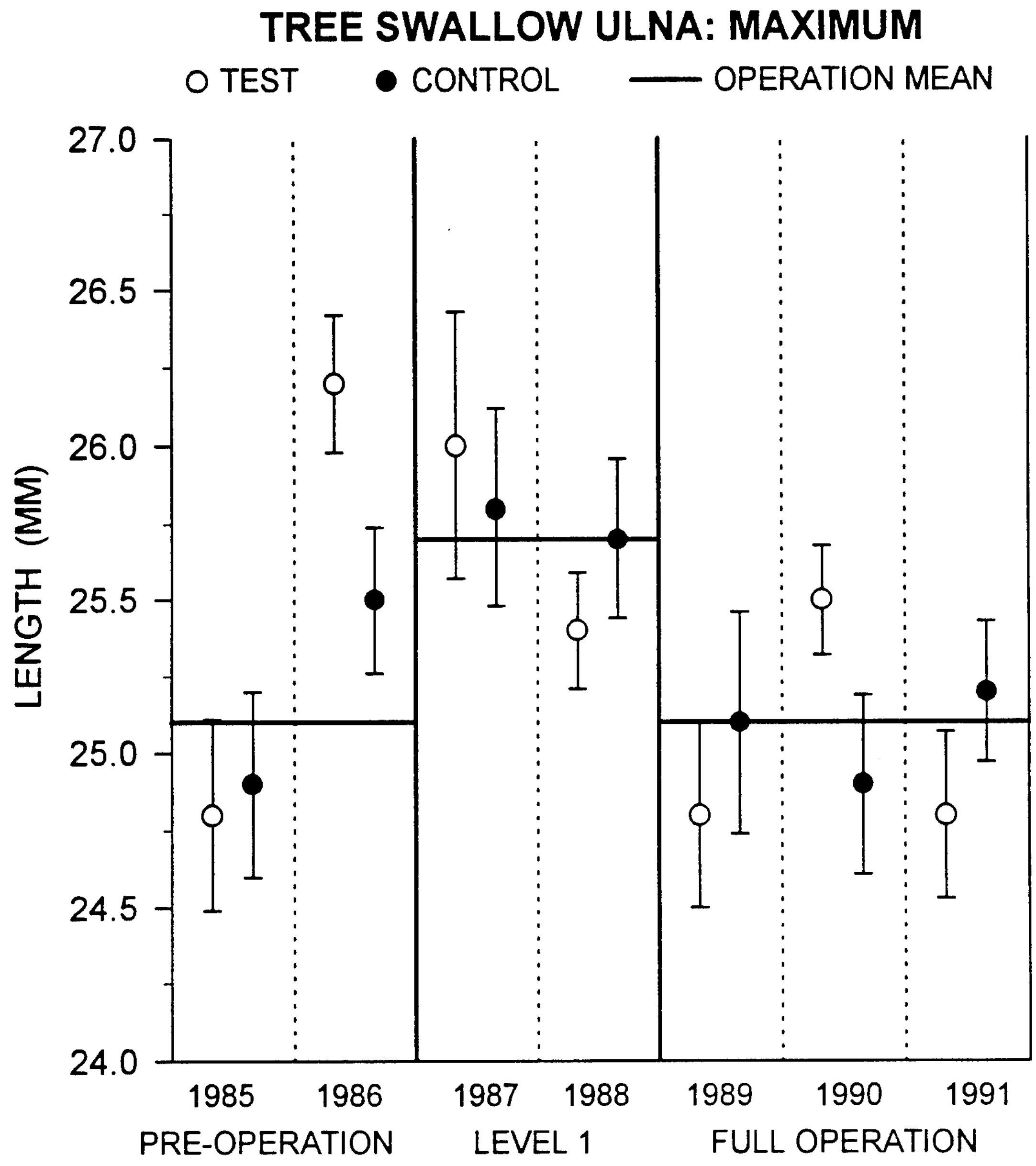


Figure 34. Maximum ulna length (mm, mean ±95% confidence interval) attained by nestling tree swallows observed on test and control sites for 1985 through 1991

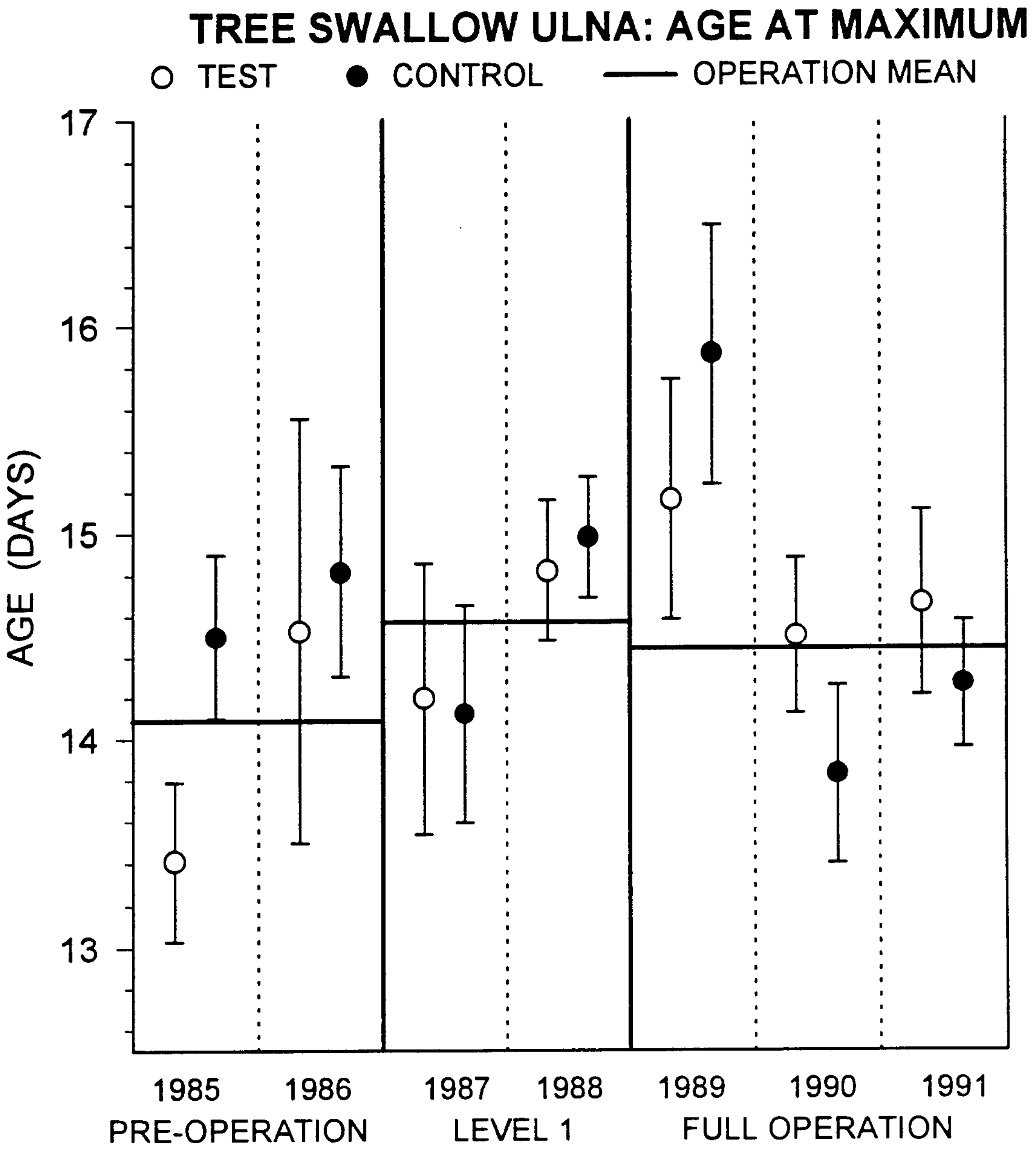


Figure 35. Age at maximum ulna (days ±95% confidence interval) for nestling tree swallows observed on test and control sites for 1985 through 1991

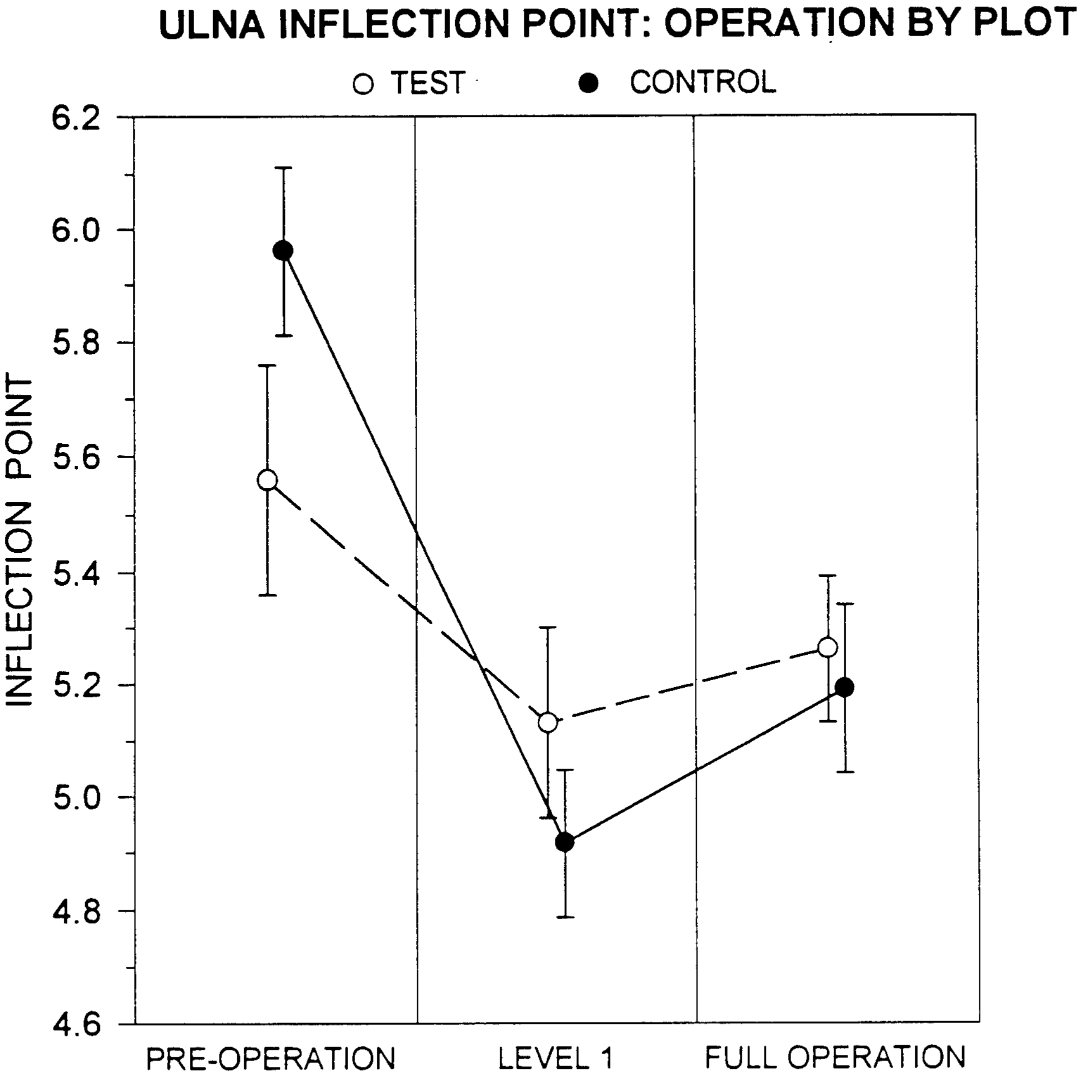


Figure 36. Mean ulna inflection point (age in days ±95% confidence interval) for nestling tree swallows. Shown are means for operation by plot interaction

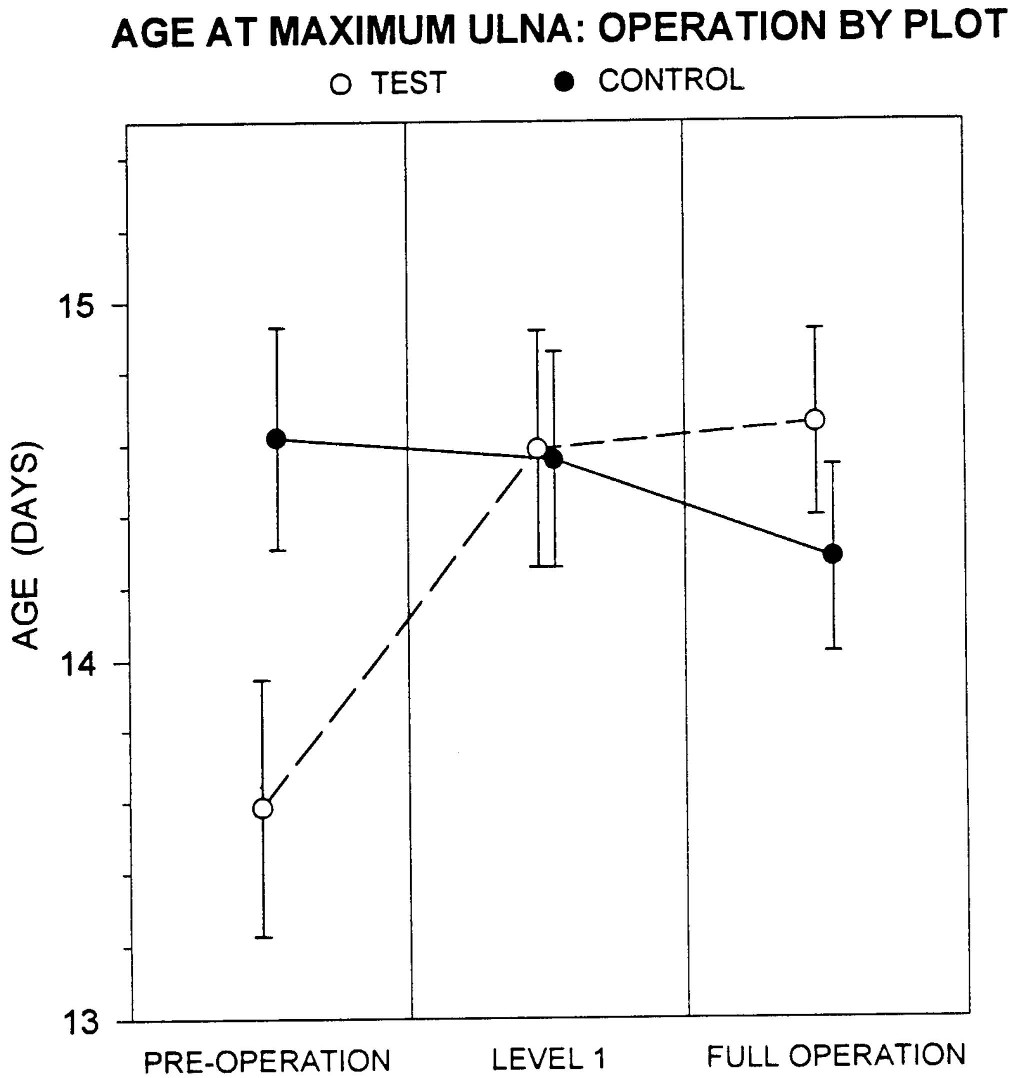


Figure 37. Mean age at maximum ulna length (days ±95% confidence interval) for nestling tree swallows. Shown are means for operation by plot interaction

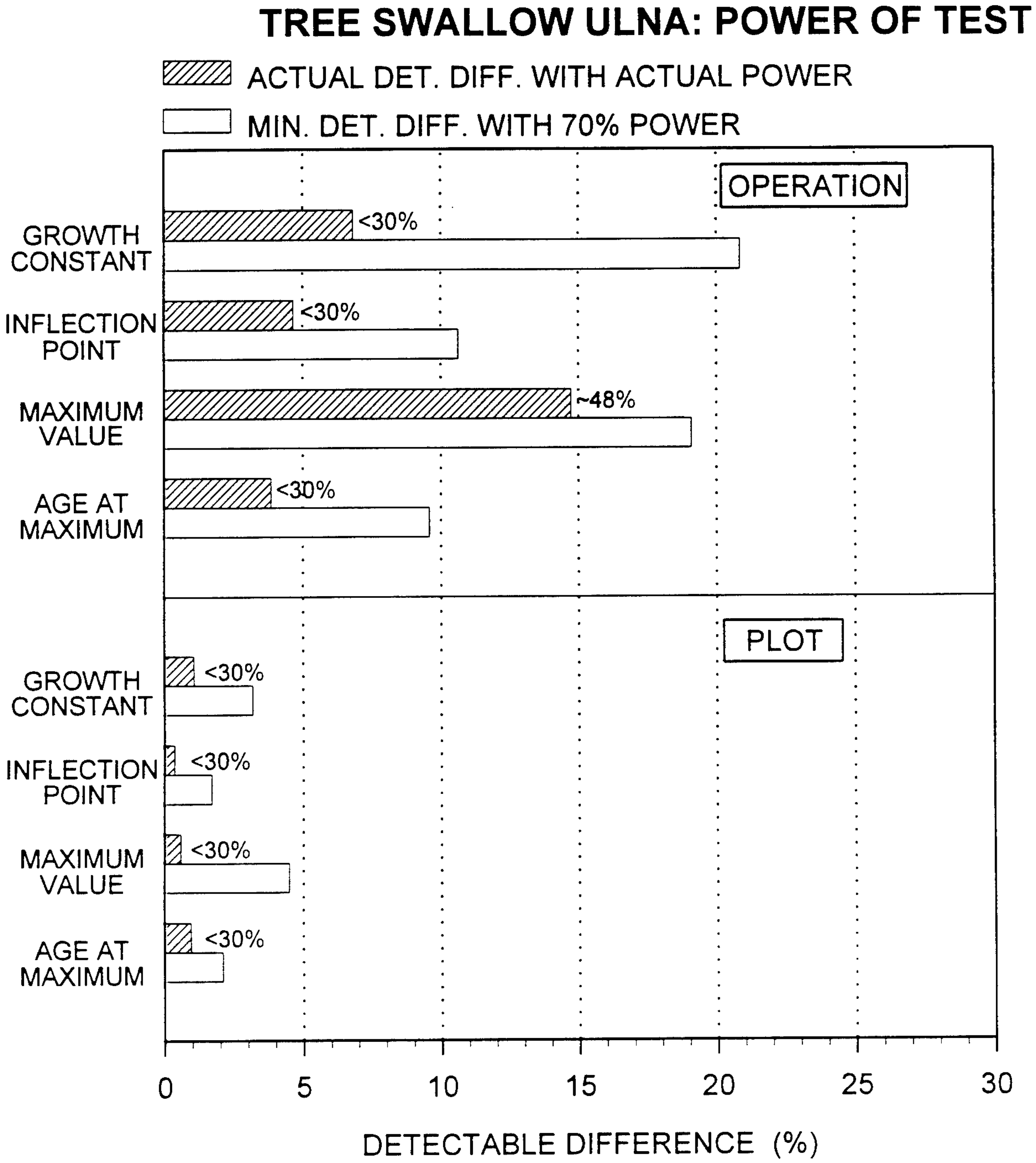


Figure 38. Detectable differences of tree swallow ulna length variables for operation and plot effects

Table 27. Nested analysis of variance for measures of wing length growth in nestling tree swallows

Nested ANOVA for wing growth constant (K), transformed to the -3.0 power.

SOURCE	DF	SS	MS	F	P
OPERATION	2	733931.0	366965.0	0.61	0.5858
PLOT	1	60549.3	60549.3	4.47	0.0348
YEAR(OPER)	4	2394380.0	598595.0	44.22	<0.0001
OPER*PLOT	2	75538.7	37769.3	2.79	0.0621
ERROR	737	9976260.0	13536.3		

year, the test plot mean was higher than the control, but variation in growth constants was also very high. Differences in plot means do not appear to be related to operation levels. As with the other growth variables, a pronounced year effect occurs.

Interaction of operation and plot was nearly significant (Table 27) and appears to be due to test mean becoming slightly larger than control mean from pre-operation to level 1. The test-plot mean then remained slightly smaller than control means during full operation (Figure 40).

Detectable differences are noted in Figure 41. Actual detectable difference for operation means was about 17% but at a power of less than 30%. With power set at 70%, the minimum detectable difference increases to about 54%. A fairly large difference in operation means would have had to occur for us to be able to detect it with 70% power using our current sample size.

Actual detectable difference for plot means was about 4% with a power of about 45%. With power set at 70%, the minimum detectable difference increases to about 5%. Since plot means were significantly different in the ANOVA, we demonstrated that we could detect these very small differences in plot means.

Landmark Events. The landmark growth events of age at eye opening (days) and age at feather eruption (days) were analyzed by analysis of variance. Effects of operation were not apparent for either event; however, a plot effect was noted for age at feather eruption (Table 28). A strong year within operation effect was noted which we attribute to inclement weather. These

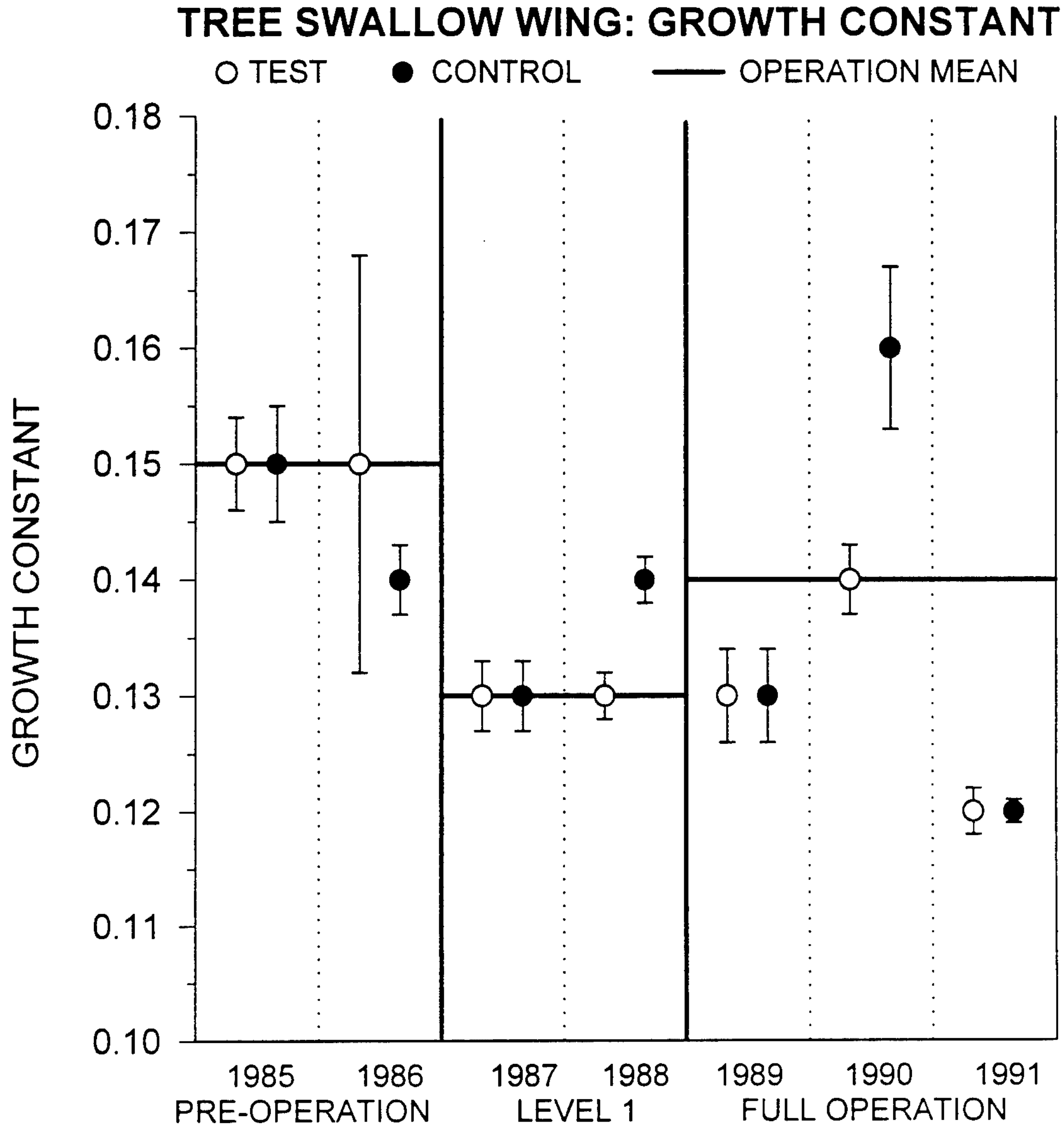


Figure 39. Wing growth constants (mean ±95% confidence interval) of nestling tree swallows observed on test and control sites for 1985 through 1991.

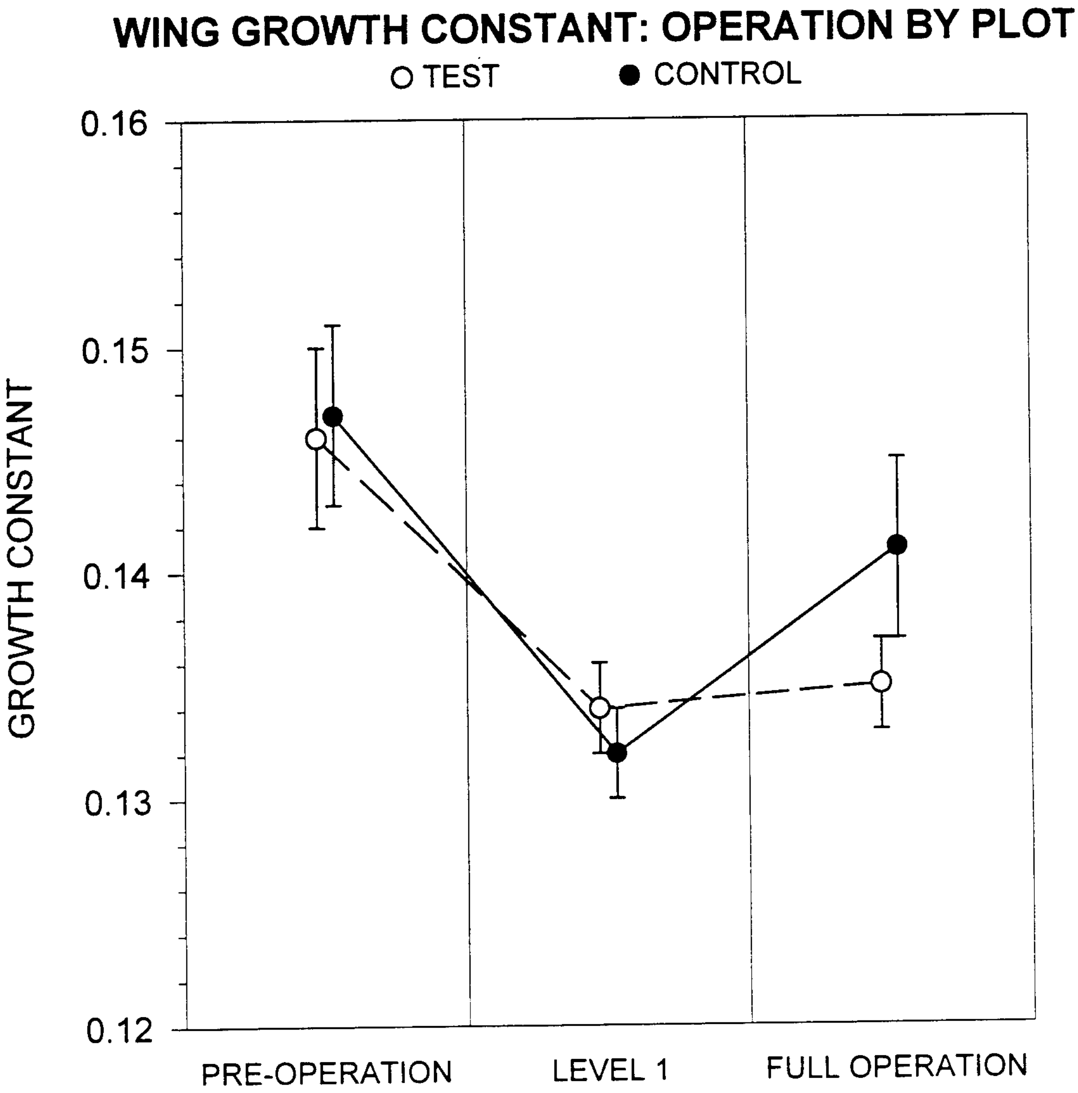


Figure 40. Mean wing growth constants (±95% confidence interval) for nestling tree swallow growth. Shown are means for operation by plot interaction

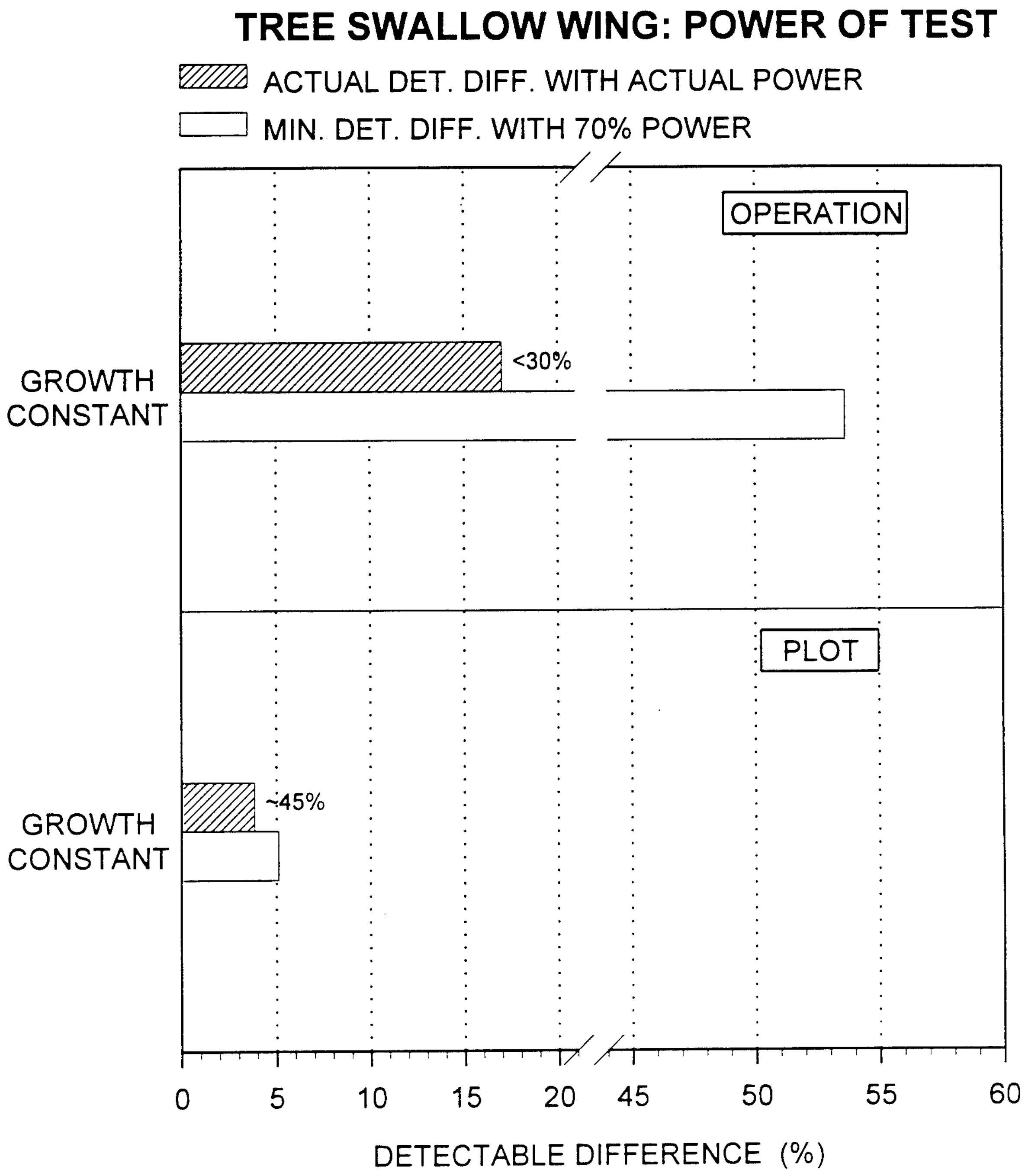


Figure 41. Detectable differences of tree swallow wing growth constants for operation and plot effects

effects are unrelated to ELF electromagnetic fields and appear to impact test and control plots equally (Figure 42).

Table 28. Nested analysis of variance for age of the landmark events of eye opening and primary feather eruption in nestling tree swallows

Nested ANOVA for tree swallow age at eye opening, transformed to the 0.7 power.

SOURCE	DF	SS	MS	F	P
OPERATION	2	15.2661	7.6330	0.39	0.7078
PLOT	1	0.0623	0.0623	0.22	0.6373
YEAR(OPER)	3	58.9169	19.6390	70.16	<0.0001[a]
OPER*PLOT	2	4.2577	2.1288	7.61	0.0005[a]
ERROR	593	165.9825	0.2799		

Nested ANOVA for tree swallow age at feather eruption.

SOURCE	DF	SS	MS	F	P
OPERATION	2	12.4526	6.2263	0.81	0.5236
PLOT	1	10.5820	10.5820	12.95	0.0004[a]
YEAR(OPER)	3	23.0861	7.6954	9.42	<0.0001[a]
OPER*PLOT	2	6.6942	3.3471	4.10	0.0172[a]
ERROR	515	420.8032	0.8171		

[a] Significant at 0.05 or less

The significant interaction of operation and plot suggests the possibility of a Communications System effect. However, examination of the plot means for age at eye opening (Figure 43) indicates that the interaction effect is due to a lower mean on the test plot in the pre-operation period that increased slightly above the control plot mean during the level 1 operation period. The means are about the same in full operation. This pattern does not suggest the means are changing in relation to the operation of the Communications System.

As with the age of eye opening, there is a significant effect of years within operation for age at feather eruption as well as a significant interaction between operation and plot (Table 28). We attribute the year effect to poor weather conditions during 1986 and 1989, although yearly plot means are highly variable every year (Figure 44). It is clear that variation in feather eruption is strongly influenced by weather and the nest (or parent) environment.

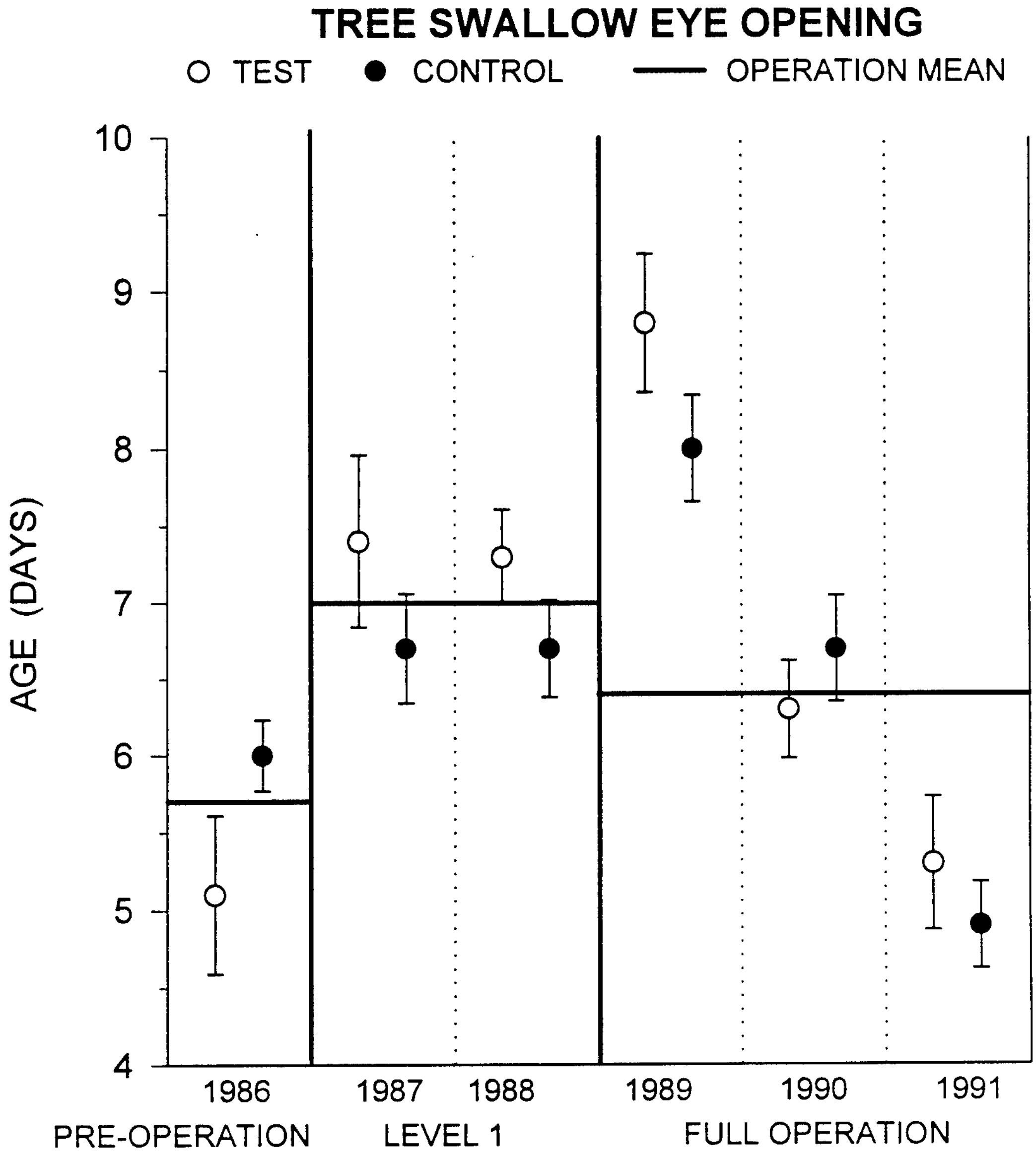


Figure 42. Age at eye opening (days, mean ±95% confidence interval) of nestling tree swallows observed on test and control sites for 1986 through 1991

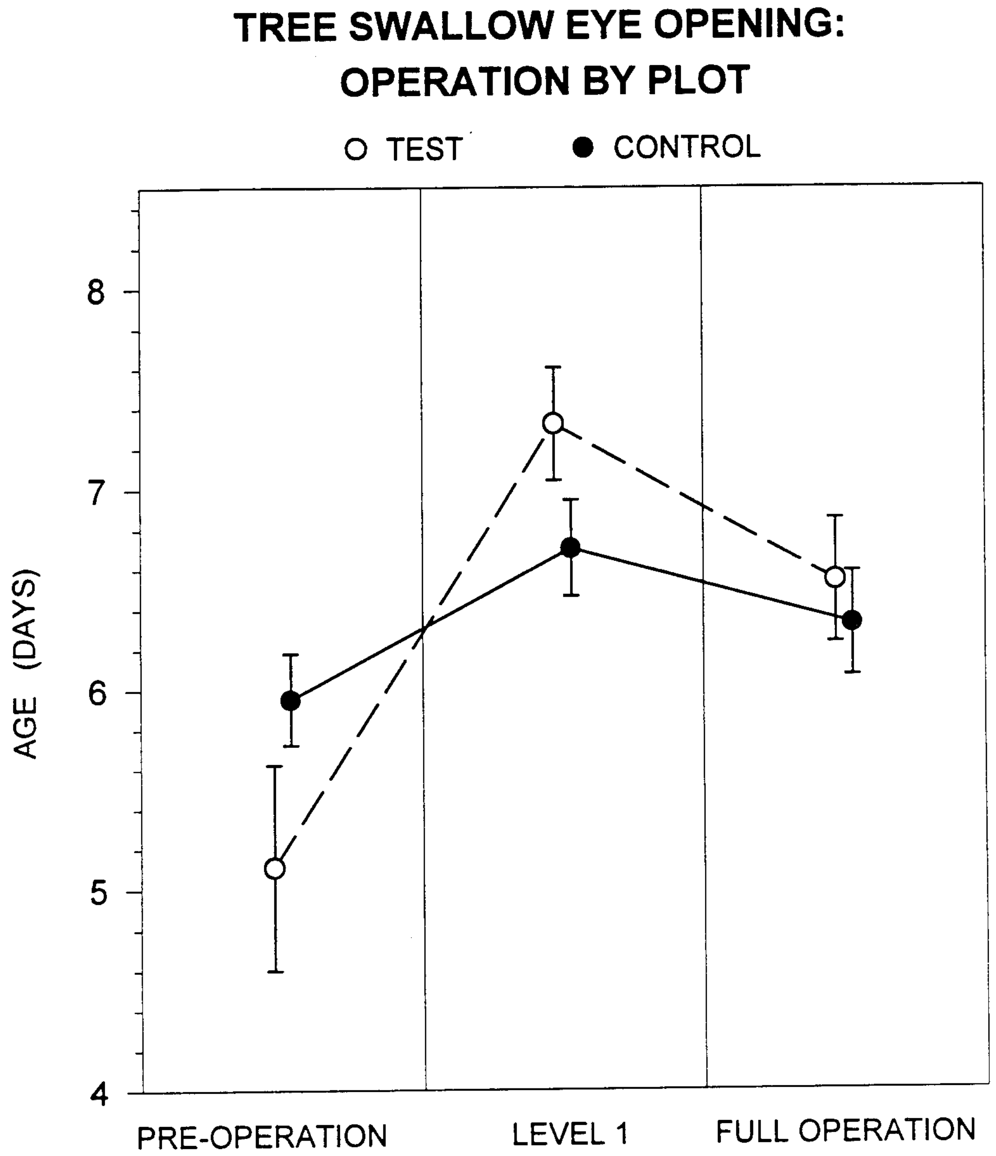


Figure 43. Mean age at eye opening (days, ±95% confidence interval) for nestling tree swallows. Shown are means for operation by plot interaction

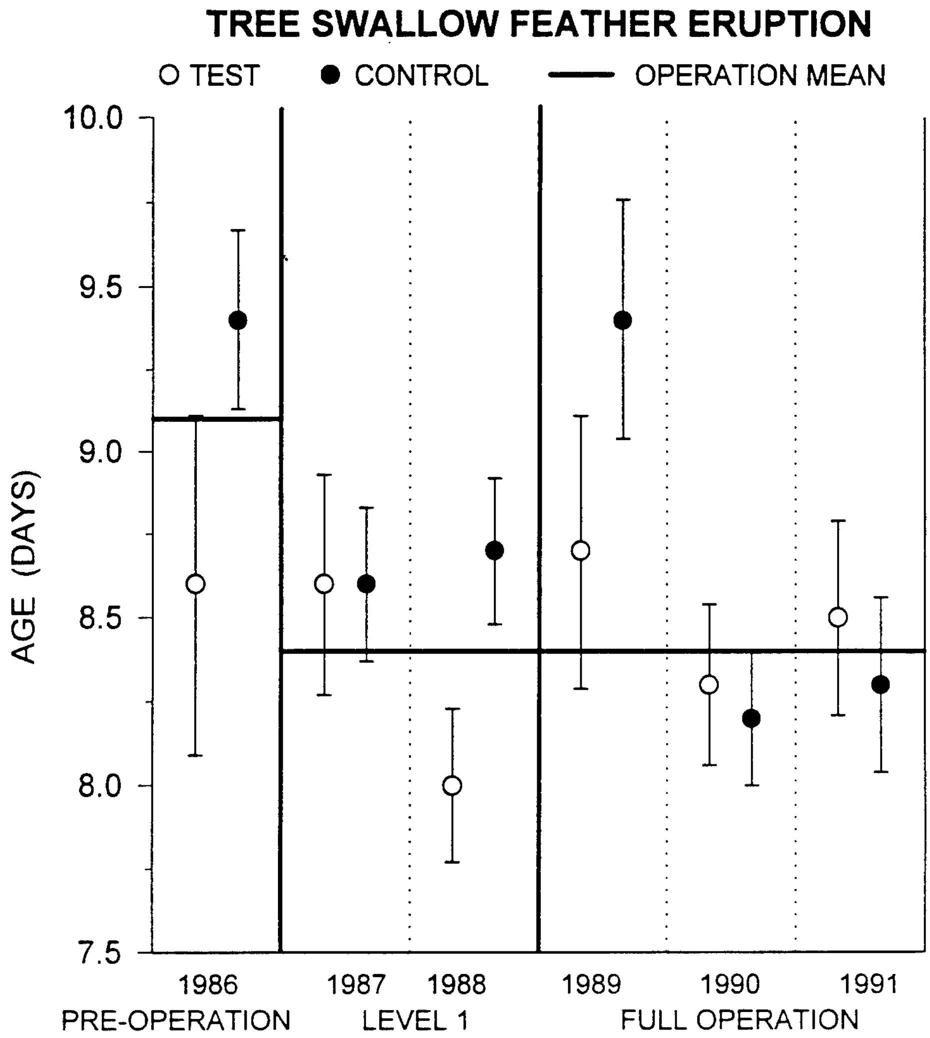


Figure 44. Age at feather eruption (days, mean ±95% confidence interval) of nestling tree swallows observed on test and control sites for 1986 through 1991

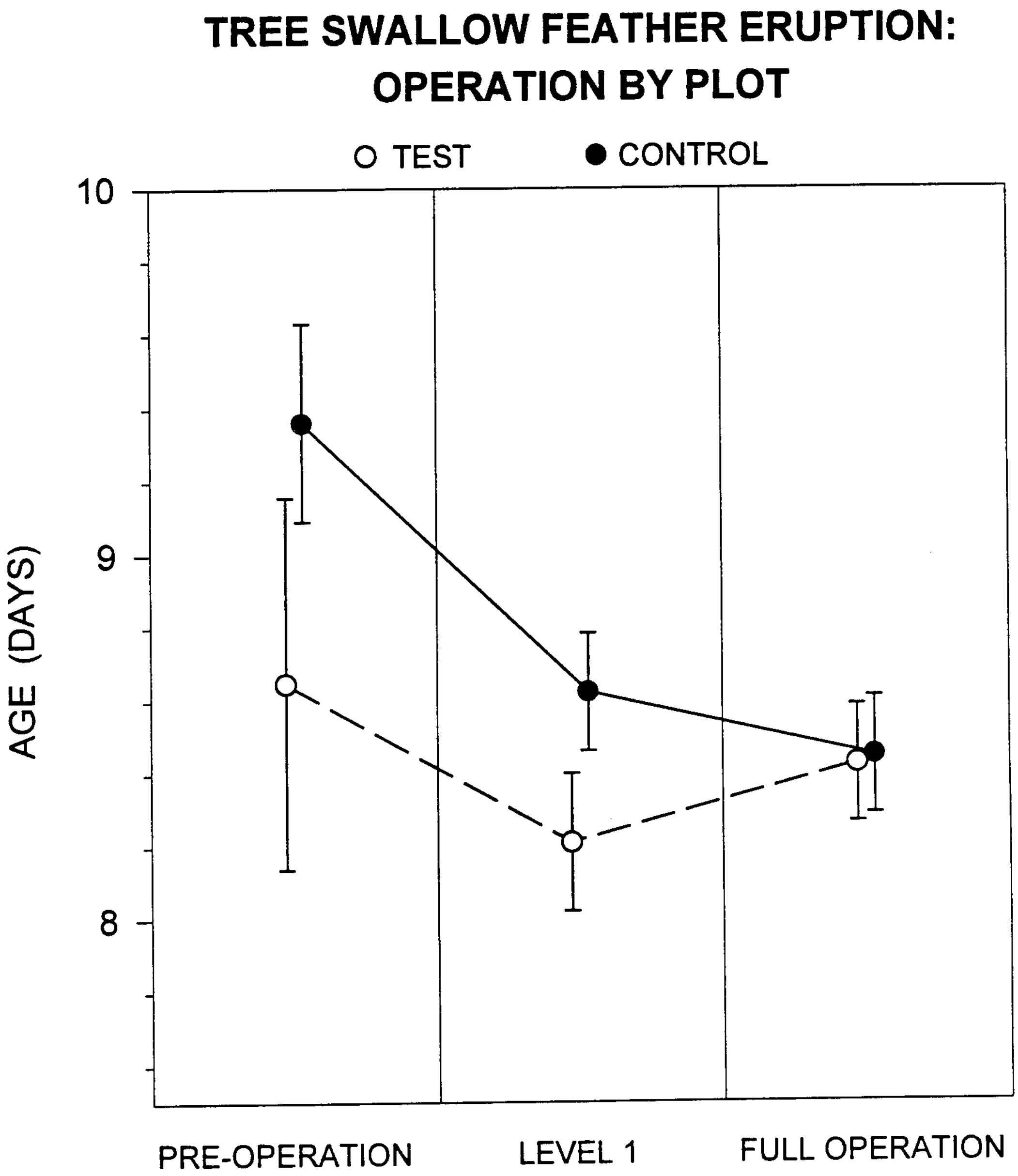


Figure 45. Mean age at feather eruption (days ±95% confidence interval) for nestling tree swallows. Shown are means for operation by plot interaction

The significance of the interaction of operation and plot does suggest a possible Communications System effect. However, the means for the control plot are higher in each operation period, except for full operation, and they converge on the means of the test plot, which are relatively stable across all levels of operation, from level 1 to full operation (Figure 45). This pattern suggests factors other than the Communications System are influencing the relation of control and test plot means.

We have examined the statistical power of test and detectable differences for the operation and plot effects on landmark growth events (Figure 46). The actual detectable differences for operation effect were about 15% for eyes open and about 3% for feather eruption. The power for these tests was less than 30%. With power set to 70%, the minimum detectable difference increases to over 35% for eyes open and to about 9% for feather eruption. We are therefore less able to detect an effect of the Communications System on eye opening than feather eruption.

Actual detectable differences for plot effect were less than 1% for eyes open and about 3% for feather eruption (Figure 46). The power of the test for eyes open was less than 30%, but it was about 93% for feather eruption. With power set to 70%, the minimum detectable difference we could have detected was about as small as the differences in plot means we did detect for either variable with our current sample sizes. We actually did detect these small differences for feather eruption, but as noted above, the differences were not due to the effects of the Communications System.

Results of Nestling Transfer Experiment. Nestling transfers were made in 1990 and 1991 following the methods described earlier (see page 31). Analysis of variance was used to examine the effect of TREATMENT, with six levels, and YEAR, with two levels, since the experiment was conducted over two years. The variables examined were the same as those used in the growth and maturation studies of the preceding section.

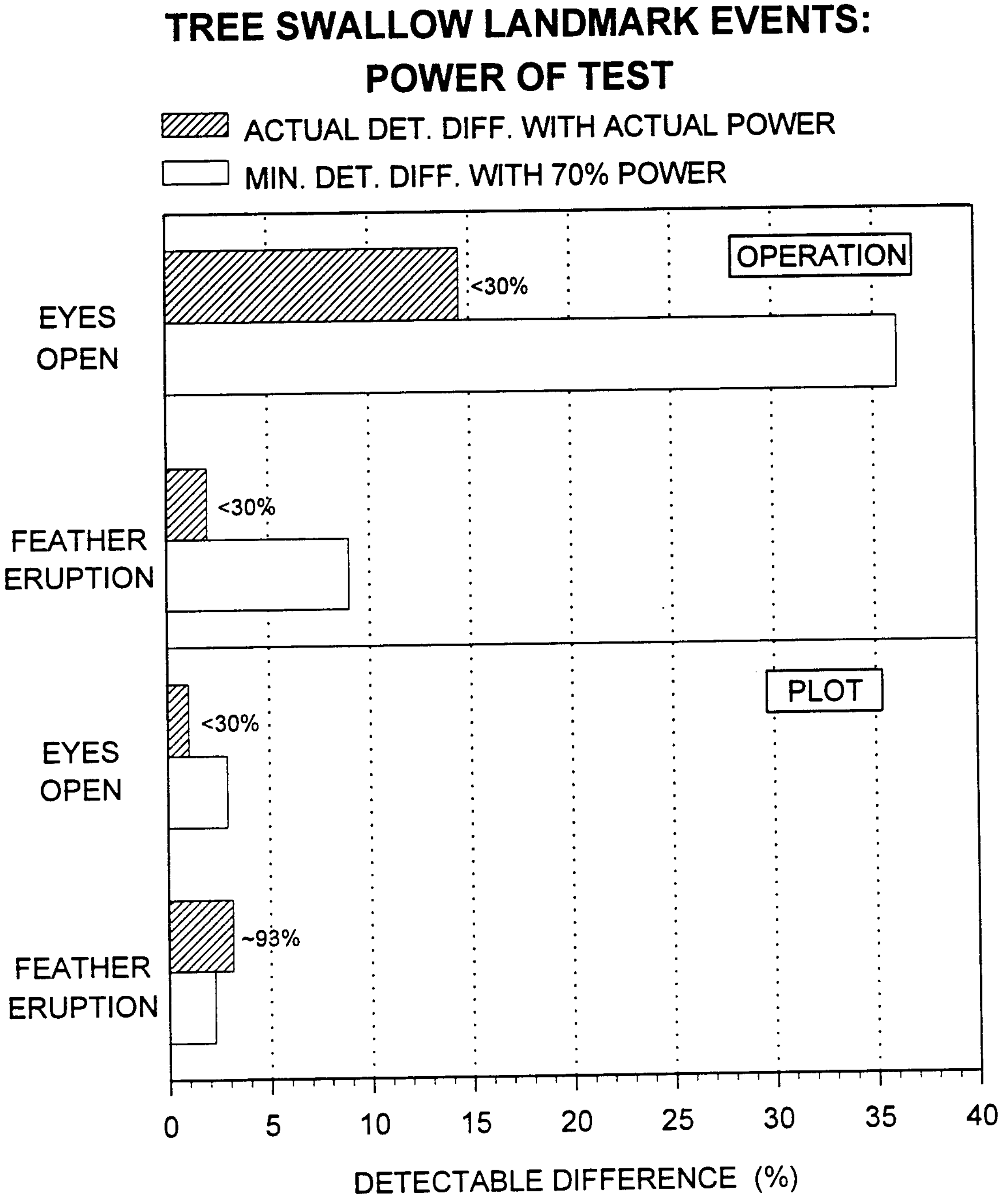


Figure 46. Detectable differences of tree swallow landmark events for operation and plot effects

No effect of the treatment could be detected for most variables, but significant effects were found for body mass growth constant and inflection point, maximum body mass, ulna inflection point and wing growth constant (Table 29). Examination of treatment means graphically (Figure 47 and Figure 48) and by Bonferroni *post hoc* tests indicated that while there were some significant differences in the treatment means, these differences cannot be unequivocally considered as due to the effect of the Communications System. In the discussion following, we use the coded names of the treatment levels when referring to treatment means (see page 31).

In the case of body mass growth constant, the **control** nestlings were significantly different from **young exposed**. The **control-swap** treatment was significantly different from **young exposed** and **test-swap** groups. Lastly, the **egg exposed** level was nearly significantly different from the **young exposed** group. Thus, while there are some significant differences in treatment means, the lack of a difference in other treatment means is difficult to reconcile with an hypothesis of a Communications System effect. Why did the **control** group not show significant differences when compared to the **test** and **test-swap** groups? Why was the **control-swap** group only different from the **test-swap** group and not also the **test** group? The most parsimonious explanation is that the differences noted were not due to the Communications System, but other, unrelated, factors.

The inflection point for body mass (Figure 47) showed the **control-swap** nestlings as different from **young exposed**. The **control-swap** group approached significance compared to the **test-swap** group. Here again there were no consistent differences that suggest an effect of the Communications System.

For ulna inflection point (Figure 47), only the **control** and **control-swap** means were significantly different. This difference is clearly not related to an effect of the Communications System.

The greatest number of differences in treatment means was found for wing growth constant (Figure 48). The treatment means for **control** and **control-swap** nestlings differed from the **test-**

swap mean, but not the **test** mean. The **control-swap** mean differed from both the **egg exposed** and **young exposed** groups but the **control** mean only differed from the **young exposed** group. Interestingly, the **test** group also differed from the **test-swap** group, and the **young exposed** group approached significance in being different from the **test-swap** group. Still, the **control** and **control-swap** groups did not differ from the **test** group, only the **test-swap** group. Except for this major inconsistency, the wing growth constant provides the strongest case of all growth and maturation variables for an effect of the Communications System.

The final variable showing a significant treatment effect in the analysis of variance was the age at eye opening (Figure 48). The only treatment means that approached significance in the Bonferroni *post hoc* test were the **control-swap** and the **test** groups. No other differences were detected. There is therefore little support for an effect of the Communications System on the age at eye opening.

For all growth and maturation variables except age at maximum body mass, age at maximum tarsus length and age at maximum ulna length, there was a highly significant year effect due to better growth during 1990 compared to 1991 (see two examples in Figure 49). The year effect was uniform across treatment means in 1991, but not in 1990. This resulted in significant interaction between treatment and year for all variables except body mass growth constant and maximum tarsus length. Unlike our earlier models of analysis of variance, the interaction of treatment and year does not indicate potential effects of the Communications System. Instead, the interaction seems to indicate that better growth in 1990 was accompanied by greater disparities among the treatment groups than in 1991 when growth was poorer. We do not know what factors are responsible for these growth patterns.

Overall, the nestling transfer experiment did not detect unequivocal effects on growth attributable to Communications System exposure. Of the five variables for which a significant treatment effect was found, *post hoc* tests of the means revealed that no consistent trend for control

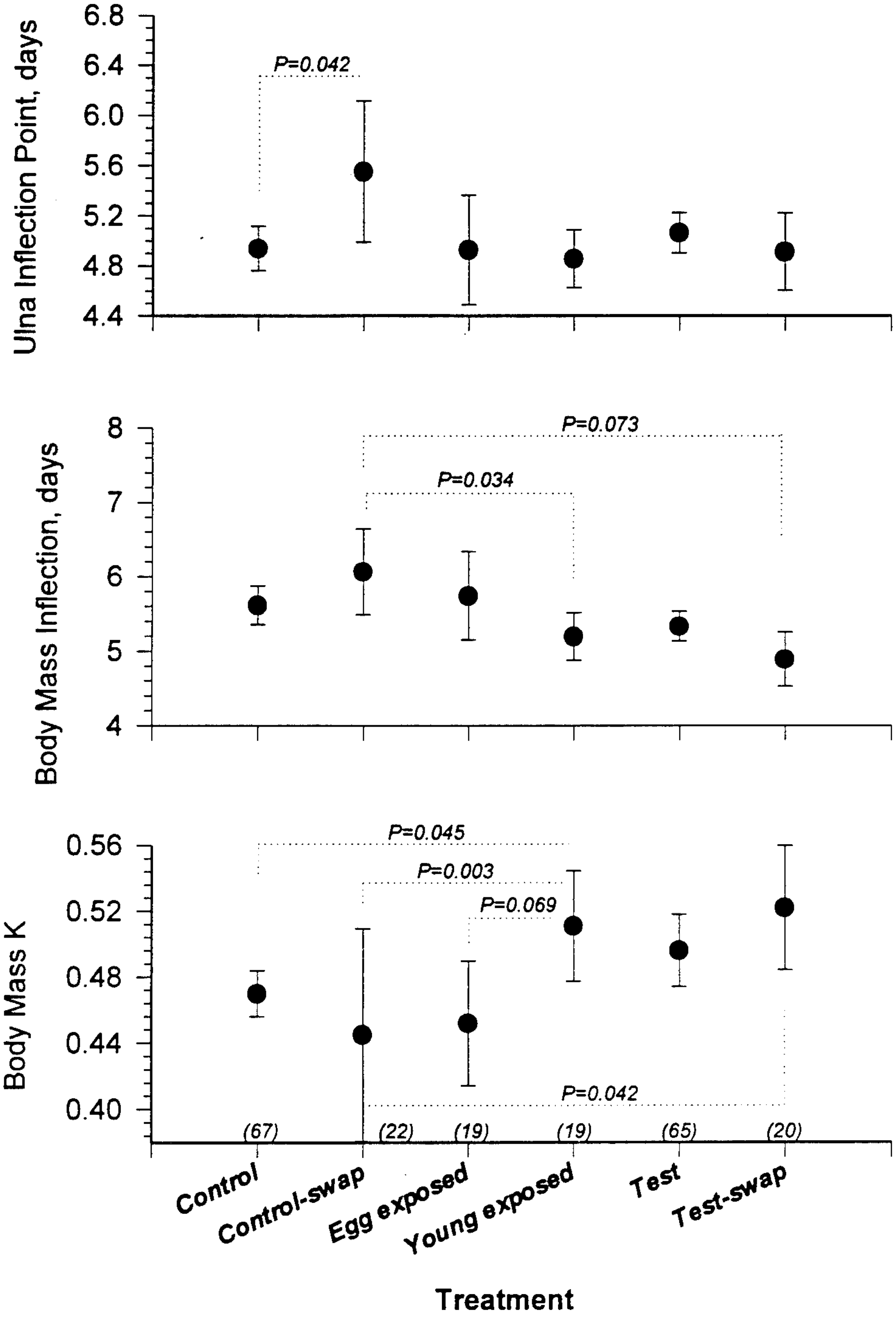


Figure 47. Mass growth constant, inflection point and ulna inflection point (±95% confidence interval) and (N) for nestling transfer experiment. *P* values are for *post hoc* tests

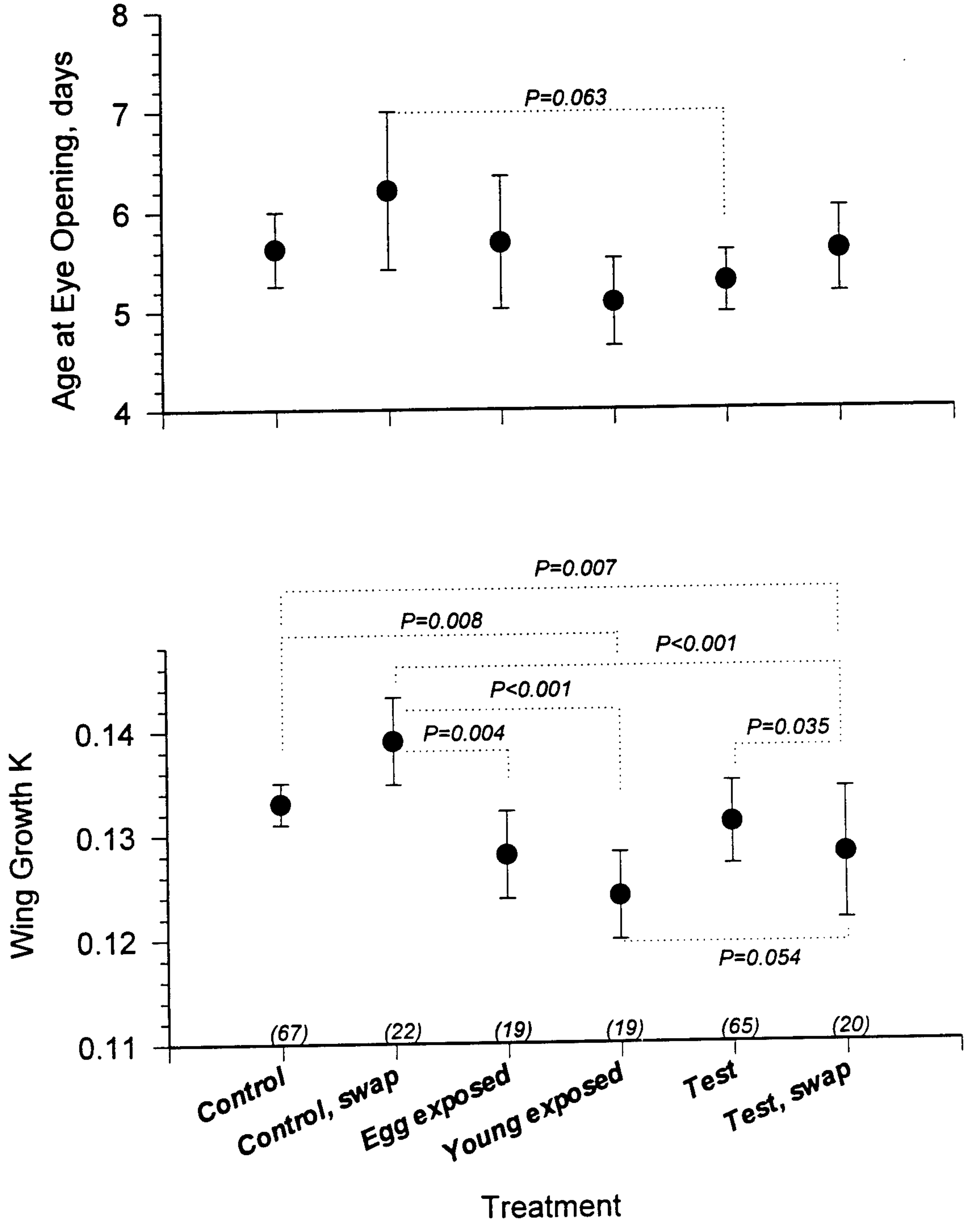


Figure 48. Eye opening and wing growth constant means (±95% confidence interval) and (N) for the nestling transfer experiment. *P* values are for Bonferoni *post hoc* tests

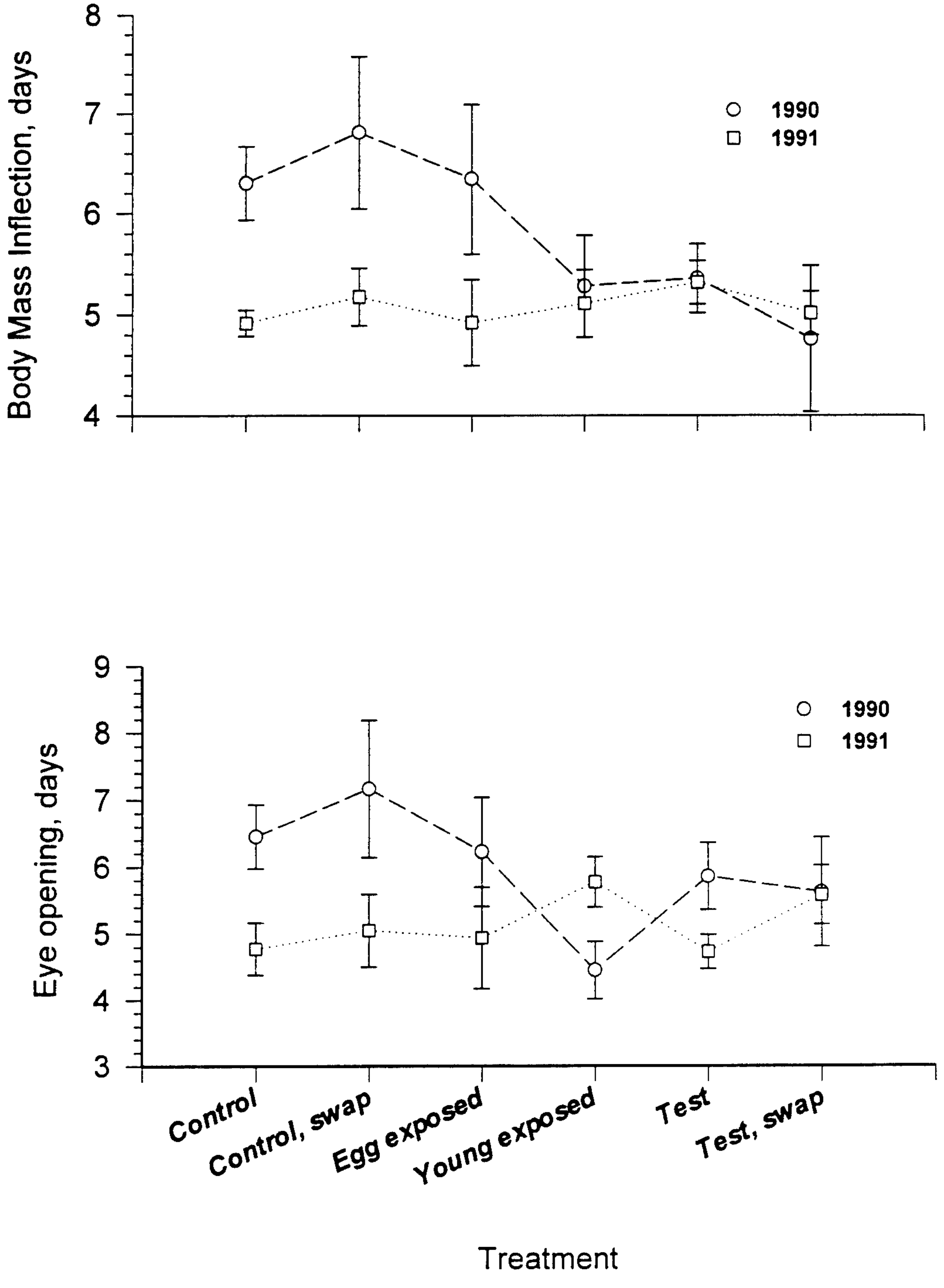


Figure 49. Examples of variables showing a treatment by year interaction (means ±95% confidence interval) during the nestling transfer experiment conducted in 1990 and 1991

Table 29. Analysis of variance for growth and maturation variables for the nestling transfer experiment done in 1990 and 1991. N=188 nestlings

Variable	Transform	F	P
Body Mass:			
Growth constant	$K^{1.25}$	4.072	0.002[a]
Inflection point	log(I)	2.619	0.026[a]
Maximum mass	none	1.982	0.083
Age at maximum mass	M^2	1.002	0.418
Tarsus Length:			
Growth constant	log(K)	1.956	0.087
Inflection Point	$I^{0.7}$	1.122	0.350
Maximum length	$T^{0.01}$	0.514	0.765
Age at maximum length	none	1.261	0.283
Ulna Length:			
Growth constant	$K^{1.25}$	1.204	0.309
Inflection Point	log(I)	2.222	0.054[b]
Maximum length	none	1.657	0.148
Age at maximum length	$U^{0.001}$	1.654	0.148
Wing Length:			
Growth constant	$K^{-3.0}$	7.839	<0.001[a]
Maturation Variables:			
Age at eye opening	log(AGE)	2.294	0.047[a]
Age at feather eruption	F^2	1.170	0.326

[a] Significant at 0.05 or less
[b] P between 0.1 and 0.05

nestlings to differ from test nestlings, with the possible exception of wing growth constant. Instead single instances of some treatment means differing from others were found. Only for wing growth constant was there a possible indication of an effect of exposure to the Communications System. However, there are inconsistencies in the differences in treatment means for wing growth constant that question this conclusion. It is especially puzzling that the **control** and **control-swap** treatments did not differ from the **test** mean.

It should be noted that the sample N was variable among treatments due to predation (*e.g.*, a bear destroyed some nests in 1990) and other accidents. In all treatments with swapped young, the original sample N was 12 young/year. In treatments without swapping, the sample N was 34 young on control plots and 26 young on test plots in each year. The higher mortality on the test plot was due primarily to predation in both years. Young that died due to predation or other causes were excluded from the analysis.

IV. Electromagnetic Field Strengths and Tree Swallow Growth

Growth Variables and Field Strengths. Our comparison of growth variables from test and control plots is based on the difference in field strengths produced by the antenna over a large distance, as was called for in the original request for proposals. Field strengths were an order of magnitude or greater higher on the test plot than on the control plot. However, detailed measures of the field strengths (by personnel from IITRI: We note here that measures were only made at selected boxes in a transect perpendicular to the antenna line. We have made the assumption that the same field strengths would occur at nest-boxes the same distance from the antenna at other location on the test plot.) indicated they were greatest directly underneath the antenna and that they rapidly decreased away from the antenna (Figure 50). Nest boxes on our test plots were placed in rows that varied from 30 to 200 m from the antenna. Nest boxes closest to the line on these plots received much stronger levels of all three fields than boxes farthest away. To study the possible effect of these gradients in electromagnetic fields within the test plot, we examine below the response of growth and maturation variables for nestling tree swallows on our test plot (Pirlot Road test plot).

Field strength varied at each nest box depending on the year and the distance of the box from the antenna. None of the boxes received electromagnetic fields during 1985 and 1986, which was prior to antenna construction and operation. Field strengths increased from 1987 to 1991, with boxes closest to the antenna receiving, in general, the highest levels. However, due to the fact that the closest nest boxes were 30 m from the line, and that both the longitudinal and transverse fields peaked at 0 m, then first decreased greatly in the first 20 meters only to increase again out to 80 m before decreasing again, nest boxes about 80 m from the antenna had higher exposure levels for the longitudinal and transverse fields than nest boxes closer to and farther away from the antenna line

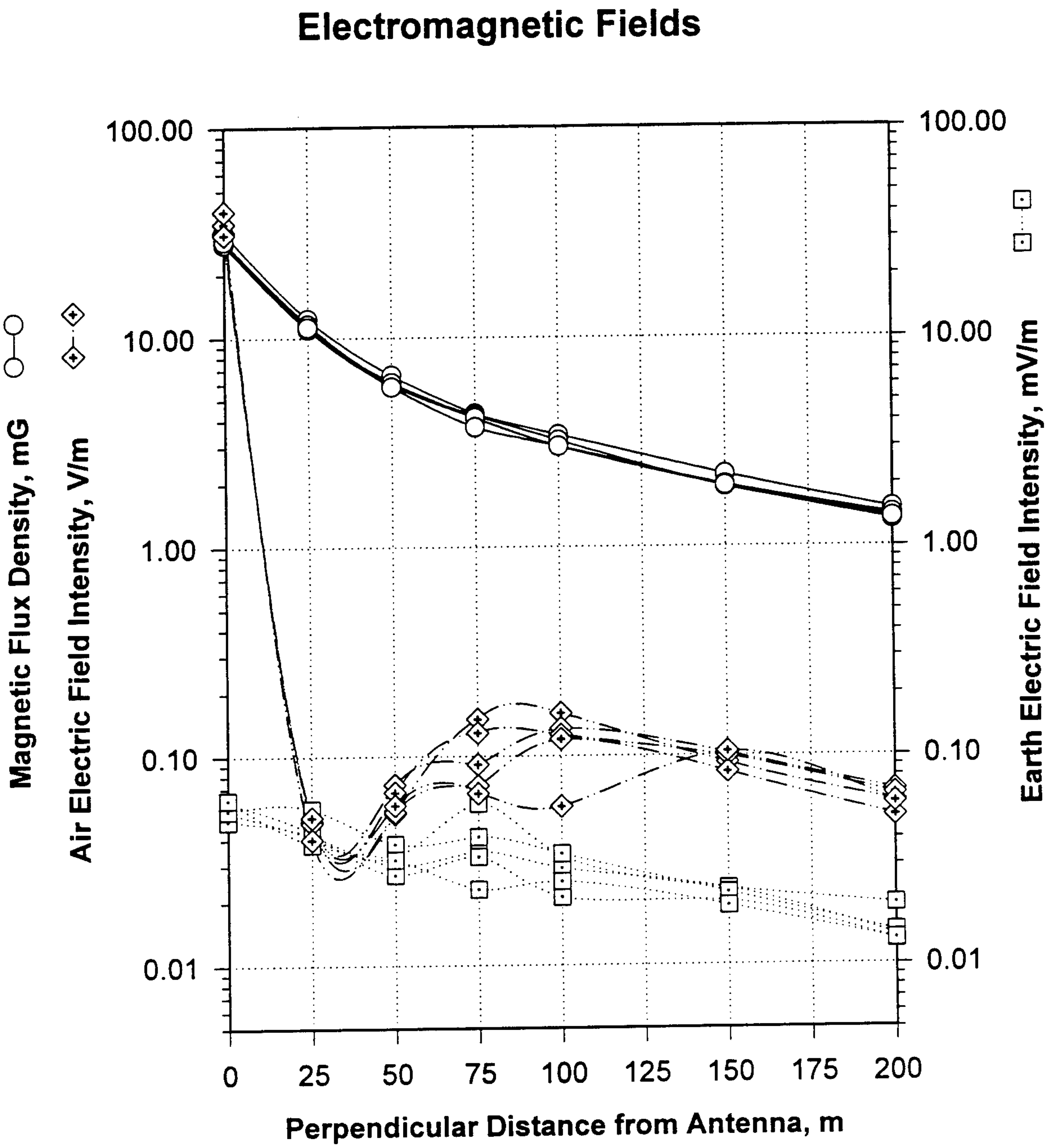


Figure 50. Strength of magnetic, longitudinal (earth electric) and transverse (air electric) fields in relation to distance from the antenna for the years 1989 through 1993. Individual years are not separately coded. Modified from Figures A-24 and A-31, IITRI Technical Report D06209-1, April, 1994

(Figure 51: magnetic field; Figure 52: longitudinal field; Figure 53: transverse field).

All variables used in the growth and maturation studies were used in this analysis. This approach allowed a comparison of findings of significant effects in the test-control plot growth study with a more detailed comparison of electromagnetic field strengths experienced by nestlings during growth only on the test plot.

The full range of strengths of each field measured at nest-boxes over all years and distances from the antenna was divided into approximately equal width categories. This approached worked well for all but the magnetic field, where the number of nests became too small to keep equal width categories at higher field strengths. Thus, the last category for the magnetic field had about four times great field strength than the next lower category. This procedure resulted in five categories for the transverse field, six for the longitudinal field and seven for the magnetic field. These categories were used as treatment levels in an analysis of variance. A nested effect for years within treatment level was included to take account of annual variation in weather patterns. As we have shown above for growth studies, year effects on growth are usually very pronounced.

Growth and maturation variables were tested for normality using the procedure of D'Agostino *et al.* (1990), and for homogeneity of variances using Bartlett's test (Zar 1984). Data were transformed where necessary. Data for maximum ulna could not be transformed to produce homogeneous variances, so the analysis of variance was run on untransformed data, assuming that the test is robust to heterogeneous variances.

Magnetic Field. As an example of how average values for growth variables compared to electromagnetic field strengths, maximum values for ulna length, body mass and tarsus length were plotted against mean magnetic field strength. There was little correspondence between field strength and the growth variables, although means for ulna and body mass increased with the highest magnetic category (Figure 54). Analysis of variance for these variables and all other growth and maturation variables indicated there was no significant effect of magnetic field category on the

MAGNETIC FIELD STRENGTH BY YEARS AND DISTANCE FROM THE ANTENNA

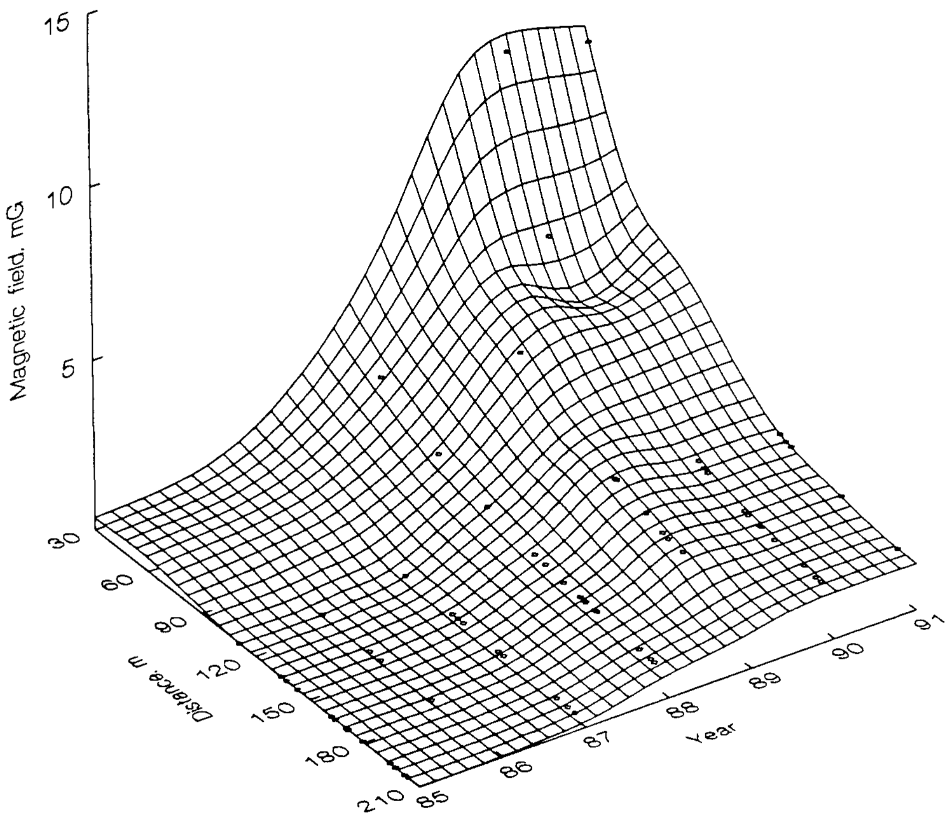


Figure 51. Magnetic field strengths at occupied nest boxes by year of study and distance from the antenna

LONGITUDINAL FIELD STRENGTH BY YEAR AND DISTANCE FROM THE ANTENNA

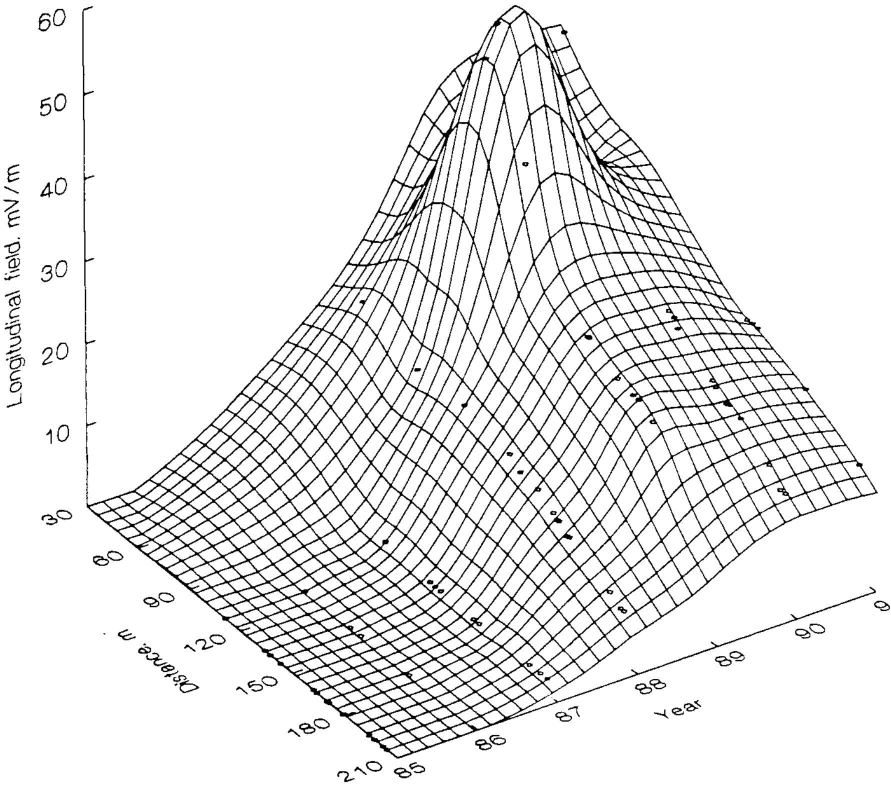


Figure 52. Longitudinal field strength at occupied nest boxes for years of the study and distance from the antenna

TRANSVERSE FIELD STRENGTH BY YEARS AND DISTANCE FROM THE ANTENNA

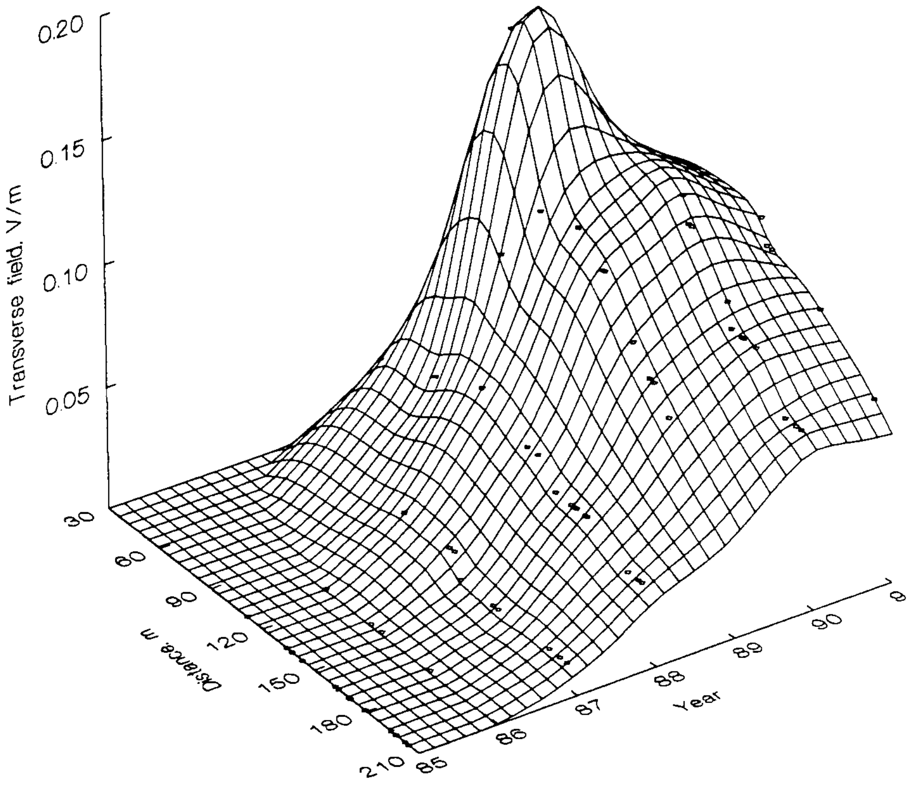


Figure 53. Transverse field strength at occupied nest boxes for years of the study and distance from the antenna

response variables (Table 30, growth constants; Table 31, inflection points; Table 32, maximum values; Table 33, age at maximum value; and Table 34, maturation variables), but there was a significant effect of year. A Bonferonni *post hoc* test for variables that approached significance revealed no significant differences in any treatment means.

Table 30. Analysis of variance of growth constants for body mass, tarsus, ulna and wing growth as a function of categories of electromagnetic field strengths. Data are for the Pirlot Road test plot, 1986 through 1991

Growth Constant for:	Mean Square	df	F	P
Magnetic Field				
Body mass	0.010	6	0.415	0.85
Tarsus length	0.141	6	0.655	0.69
Ulna length	0.009	6	2.041	0.15
Wing length	2409.78	6	0.041	0.99
Longitudinal Field				
Body mass	0.009	5	0.360	0.86
Tarsus length	0.148	5	0.630	0.68
Ulna length	0.015	5	2.795	0.09
Wing length	24433.16	5	0.418	0.83
Transverse Field				
Body mass	0.005	4	0.165	0.95
Tarsus length	0.384	4	1.382	0.32
Ulna length	0.018	4	2.988	0.09
Wing length	9993.41	4	0.132	0.97

Longitudinal Field. Again using the example growth variables of maximum values for ulna length, body mass and tarsus length, plotted against mean longitudinal field strength in each category, a pattern emerged for the longitudinal field that is similar to magnetic field strength (Figure 55). There is again an apparent increase in mean ulna length and body mass for the highest category. Analysis of variance showed no significant effect of longitudinal field category for any growth or maturation variables (Table 30, growth constant; Table 31, inflection points; Table 32, maximum values; Table 33, age at maximum value; and Table 34, maturation variables) but

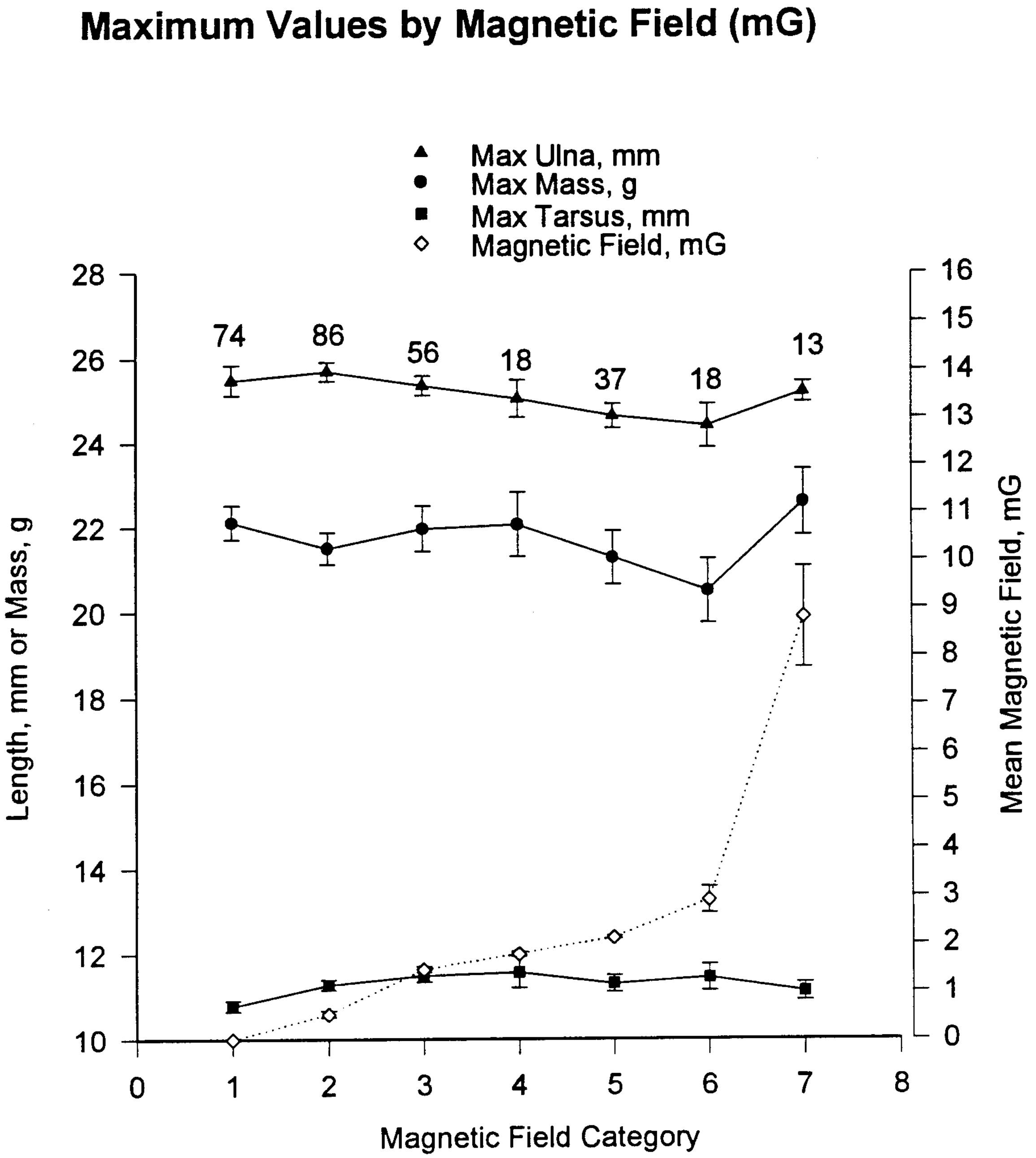


Figure 54. Means for maximum growth values (±95% confidence interval) plotted by magnetic field category and the average (±95% confidence interval) field strength (mG) for the magnetic field in each category

Table 31. Analysis of variance of inflection points for body mass, tarsus, ulna and wing growth as a function of categories of electromagnetic field strengths. Data are for Pirlot Road test plot, 1986 through 1991

Inflection Point for:	Mean Square	df	F	P
Magnetic Field				
Body mass	0.036	6	0.035	0.89
Tarsus length	0.083	6	0.212	0.97
Ulna length	0.074	6	1.332	0.32
Wing length[a]				
Longitudinal Field				
Body mass	0.038	5	0.366	0.86
Tarsus length	0.637	5	2.075	0.16
Ulna length	0.096	5	2.418	0.12
Wing length[a]				
Transverse Field				
Body mass	0.029	4	0.241	0.91
Tarsus length	0.314	4	0.529	0.72
Ulna length	0.114	4	2.833	0.10
Wing length[a]				

[a] An inflection point can not be calculated for wing growth

approached significance for ulna length growth constant and age at maximum ulna length (Table 30, growth constant; Table 33, age at maximum value). A Bonferonni *post hoc* test of means was performed for each of these variables. For ulna growth constant, category 2 versus 3 and 4 had the largest differences, but neither pair was significantly different in the test (2 vs 3: P=0.18; 2 vs 4: P=0.084). In the case of age at maximum ulna, only category 1 versus 4 means showed a large difference, and they were not significantly different in the test (P=0.089). All other means were not significantly different.

Transverse Field. As examples of growth variable response to the transverse electric field, maximum values for ulna length, body mass and tarsus length were plotted against mean transverse field strength in each category. Little correspondence between the variables and mean field strength of categories could be seen (Figure 56), although maximum body mass declined in category 5.

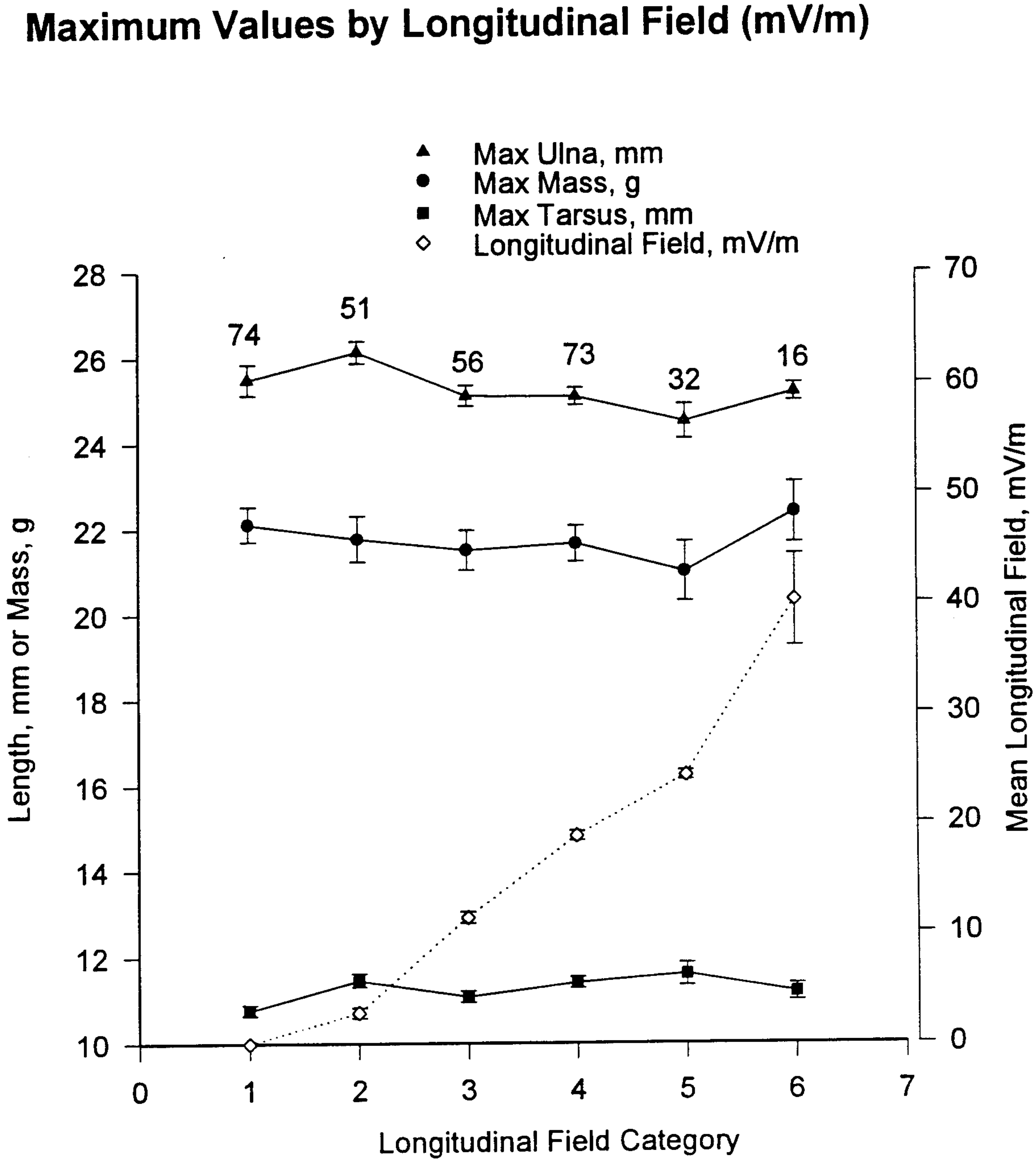


Figure 55. Average (±95% confidence interval) maximum growth values plotted against longitudinal field strength category and the average (±95% confidence interval) longitudinal field strength (mV/m) for each category

Analysis of variance showed no significant effect of field strength category for any growth or maturation variables, although ulna growth constant and inflection point approached significance (Table 30, growth constant; Table 31, inflection points; Table 32, maximum values; Table 33, age at maximum value; and Table 34, maturation variables). A Bonferonni *post hoc* test of means showed no significant difference between any means for maximum ulna growth constant, although one pair, category 2 versus 5 approached significance (P=0.11). Ulna inflection point means for category 1 versus 3 approached significance (P=0.15). No other means were even close to significantly different.

Table 32. Analysis of variance of maximum values for body mass, and tarsus and ulna length growth as a function of electromagnetic field strengths. Data are for Pirlot Road test plot, 1986 through 1991

Maximum values for:	Mean Square	df	F	P
Magnetic Field				
Body mass	309345.9	6	2.103	0.14
Tarsus length	0.011	6	0.674	0.67
Ulna length	0.34E18	6	1.405	0.30
Wing length[a]				
Longitudinal Field				
Body mass	177116.3	5	0.912	0.51
Tarsus length	0.020	5	1.445	0.30
Ulna length	0.27E18	5	1.934	0.18
Wing length[a]				
Transverse Field				
Body mass	541750.5	4	2.444	0.13
Tarsus length	0.024	4	1.386	0.32
Ulna length	0.41E18	4	1.876	0.21
Wing length[a]				

[a] A maximum value cannot be estimated for wing growth because growth is not complete at fledging

Power of the performed analyses of variance for selected variables (Figure 57) revealed that most tests had powers of less than 30% and minimum detectable differences ranging from about 5%

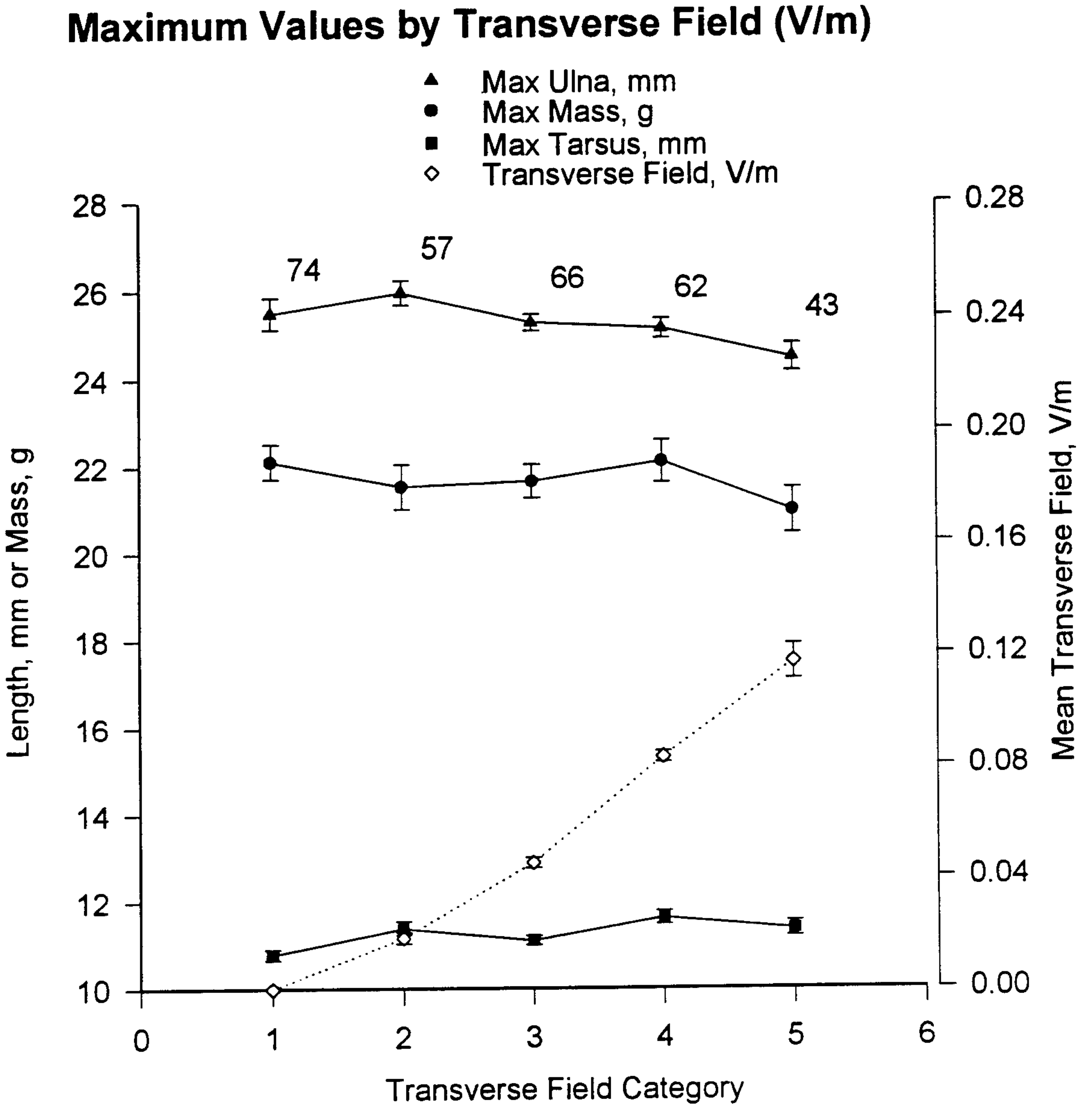


Figure 56. Average (±95% confidence interval) maximum growth values plotted against transverse field category and the average (±95% confidence interval) transverse field strength (V/m) by category

to 11.5%. With power set at 70%, minimum detectable differences ranged from about 8% to nearly 20%. If there had been differences in treatment means within this range, we could have detected them with the standard of 70%, or greater, power.

Table 33. Analysis of variance of age at maximum value for body mass, and tarsus and ulna growth as a function of categories of electromagnetic field strengths. Data are for Pirlot Road test plot, 1986 through 1991

Age at maximum values for:	Mean Square	df	F	P
Magnetic Field				
Body mass	6.078	6	0.528	0.78
Tarsus length	18.636	6	1.773	0.19
Ulna length	6.215	6	1.129	0.41
Wing length[a]				
Longitudinal Field				
Body mass	4.195	5	0.492	0.78
Tarsus length	19.304	5	1.222	0.37
Ulna length	10.474	5	3.099	0.07
Wing length[a]				
Transverse Field				
Body mass	1.219	4	0.092	0.98
Tarsus length	18.842	4	1.222	0.37
Ulna length	6.833	4	1.658	0.25
Wing length[a]				

[a] the wing is still growing at fledging and cannot be used in this analysis

In summary, none of the variables tested showed any response that could be attributed unequivocally to an effect of one of the electromagnetic fields. The greatest amount of variation in the data was due to yearly effects, which we attribute to weather.

V. Conclusions for tree swallow growth studies

Before leaving the section on tree swallow growth, it is important to summarize and contrast the findings in the sections dealing with tests of growth variables on test and control plots, the nestling transfer experiment and the nest box-electromagnetic field study. Each study presents analyses that provide different insights on the possible effects of the Communications System. In

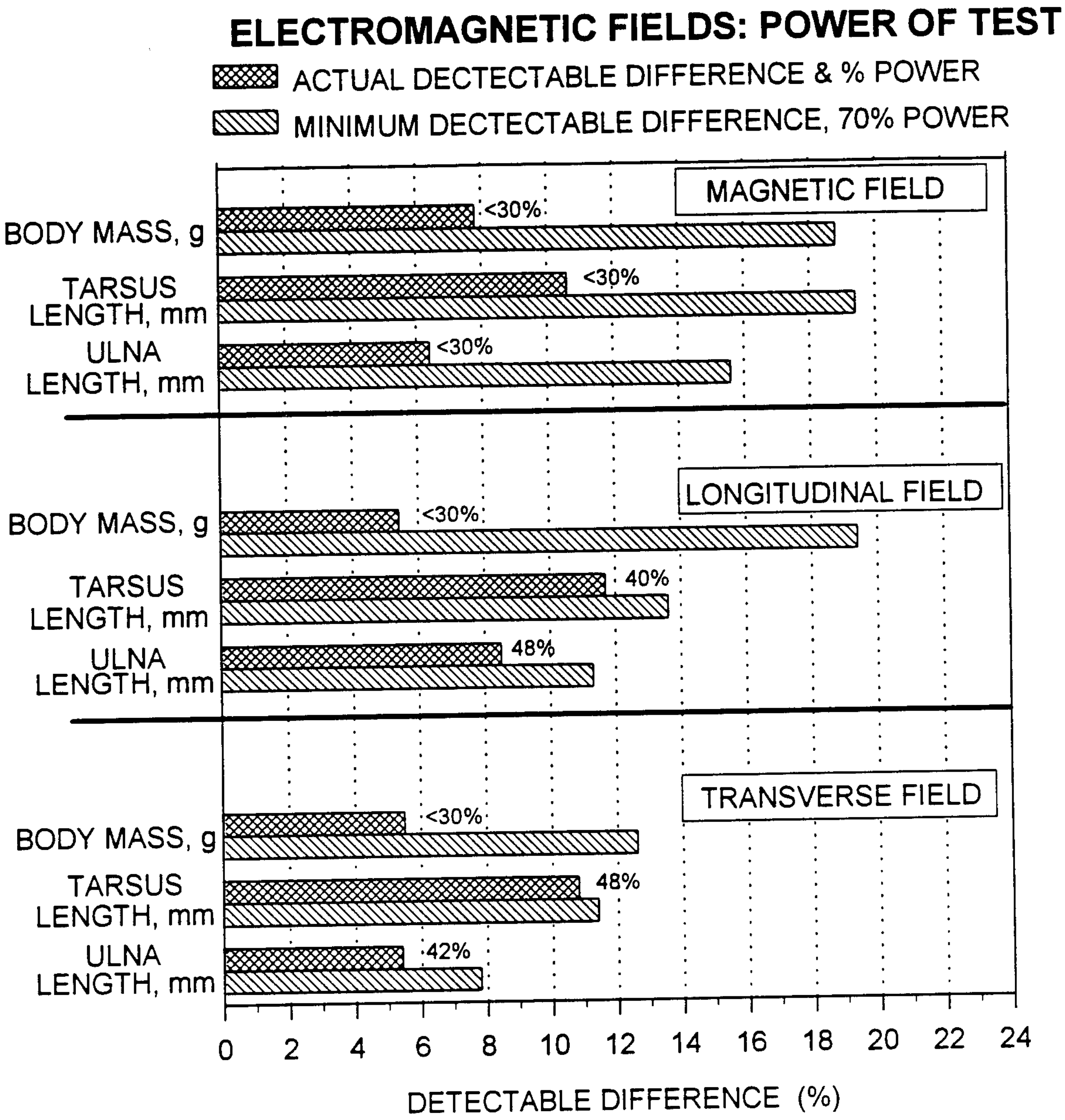


Figure 57. Power of performed analyses of variance for maximum values by type of electromagnetic field. Dara are from Pirlot Road test plot

Table 34. Analysis of variance for age at eye opening and feather eruption for tree swallows as a function of electromagnetic field strengths. Data are from Pirlot Road test plot, 1986 through 1991

Maturation values for:	Mean Square	df	F	P
Magnetic Field				
Age at eye opening	6.996	6	2.285	0.11
Age at feather eruption	0.002	6	1.296	0.34
Longitudinal Field				
Age at eye opening	5.150	5	2.066	0.15
Age at feather eruption	0.0004	5	0.533	0.75
Transverse Field				
Age at eye opening	5.187	4	1.411	0.31
Age at feather eruption	0.0008	4	1.295	0.35

the growth studies on test and control plots, we found possible effects of the Communications System, as indicated by the significant interaction of operation and plot levels in the analysis of variance, for growth of body mass as measured by the fitted growth constant, inflection point and age at maximum mass, tarsus length, as measured by the fitted growth constant, inflection point and age at maximum length, and ulna length, as measured by the inflection point of the fitted growth constant and age at maximum length. We did not find any of these variables to be significant in the nestling transfer experiment or the study of actual electromagnetic field strengths on nestling growth on the test plot. Instead, means in the treatment levels for body mass and wing growth constants in the nestling transfer study exhibited effects that could have been due to the Communications System, while no effects were found for any variable in the electromagnetic field strength study of nestling growth on the test plot. How can we reconcile these differences in our findings?

A first step is to compare the relative strengths of each study. The plot comparison study had the advantage of large numbers of nestlings followed each year over a number of years. Studies began prior to the construction and operation of the Communications System and continued into full operation.

The nestling transfer study was probably the most powerful test of the short term effects of the Communications System. Exposures to electromagnetic fields were controlled for eggs and nestlings, as were the effects of parental care and the procedure for transferring nestlings to other nests (the swap effect). The study was conducted for two years, allowing for year effects in the model.

The test of growth and maturation variables for nestlings raised in nest-boxes exposed to a gradient of electromagnetic field strengths on the test plot was more focused on the possibility of a graded or threshold response than either of the other two approaches. In this study growth was related directly to exposure to each electromagnetic field of the Communications System.

With the strengths of each study in mind, we can now give an educated opinion about the significance of findings of a possible effect of the Communications System on a number of growth variables in the test-control plot study, just two, different, variables in the nestling transfer study, and none in the electromagnetic field strength study.

First, the findings of the test-control plot study were not supported by the findings in the nestling transfer and the electromagnetic field levels studies. None of the variables for which we found significant interaction effects in the test-control plot study were also significant in the other two studies. This suggests that differences found in the test-control plot study are not due to the Communications System. If there was an effect on growth, why did we not detect it in the more focused and controlled studies? The most likely explanation is that other factors, not those due to the Communications System, were causing the observed differences.

Second, the nestling transfer study suggested a possible effect of the Communications System on the body mass and wing growth, as measured by the fitted growth constant. For each variable, at least one control mean was different from a test mean. Yet there were also always control means that did not differ from test means, suggesting that unknown factors, specific to each treatment level, were influencing growth. This suggestion is supported by the observation that the test-control plot study and the electromagnetic field strength study on the test plot did not find any effects for these same variables. Still, the findings of the nestling transfer study are the strongest evidence we have found for a Communications System effect on growth variables for tree swallows.

Finally, the electromagnetic field strength study did not yield any significant effects on growth and maturation variables. We expected that gradient, or possibly threshold, responses in growth and maturation variables would have been observed if there was a Communications System effect. The few variables that approached significance in the analysis of variance did not exhibit any pairs of means as significant in *post hoc* tests, and furthermore, the pairs that were identified as approaching significance were not the ones expected if either a gradient or threshold response had occurred.

It is therefore our considered opinion that, taken as a whole, none of our studies of growth and maturation of tree swallows exhibits an unequivocal effect of the Communications System. Instead, there are hints of an effect, weakly supported at best, in parts of test-control plot study and the nestling transfer study.

GROWTH AND MATURATION STUDIES - DEER MICE

I. Purpose

The purpose of these studies was to characterize growth and maturation in nestling deer mice at test and control sites and to test for possible effects of the ELF Communications System on these variables. Specifically, the rates of growth and development of nestlings were compared between test and control sites and for each site from year to year.

II. Methods

These studies were conducted within enclosures because free-ranging mice were known not to remain resident in nest boxes for long enough periods for us to obtain the data desired. The enclosures were large: 6.1 by 5.8 m. Ten enclosures were constructed within mixed deciduous forests at both the test and control plots. They were open at the top to allow free passage of atmospheric electromagnetic fields and free exposure to weather. Furthermore, they were constructed primarily of acrylic plastic sheeting, which is permeable to atmospheric electric fields according to IITRI engineers. Briefly, the walls of the enclosures consisted of acrylic sheeting attached to cedar posts extending about 60 cm above ground and projecting about 15 cm below ground to prevent mice from digging out. A 51-cm-wide sheet of acrylic placed horizontally along the top of each wall prevented animals from climbing over the wall. Tree trunks were sheathed with sheets of high-density polyethylene to prevent mice from climbing in or out of the enclosures via the trees. Each enclosure was provided with a nest box and a feeding and watering station. The nest box could be opened to permit access to the mice.

Small enclosures (termed holding facilities or "hotels") built according to the same design, but measuring just 1.2 by 1.2 m, were also constructed at the same sites. These enclosures were used as holding facilities for mice awaiting study in the large enclosures. The mice to be studied were captured in mixed deciduous forest near the enclosure sites. Females were transferred into the large enclosures when visibly pregnant. They gave birth in the large enclosures and, barring problems, reared their young there to the age of weaning.

Newborn young were toe-clipped for identification when 4 days old. From then until they were 22 days old, their growth was followed by weighing every other day to an accuracy of 0.1 g using a Pesola scale. Initial litter size and any subsequent deaths were recorded. The ages of eye-opening and incisor eruption were recorded as indices of developmental rate.

III. Results

ELF Electromagnetic Exposure During Small Mammal Growth Studies. The antenna was not operational during the small mammal growth studies in 1986, was on at low field strengths and relatively few hours during 1987 and 1988, and was fully operational during 1989-1991 (Figure 58).

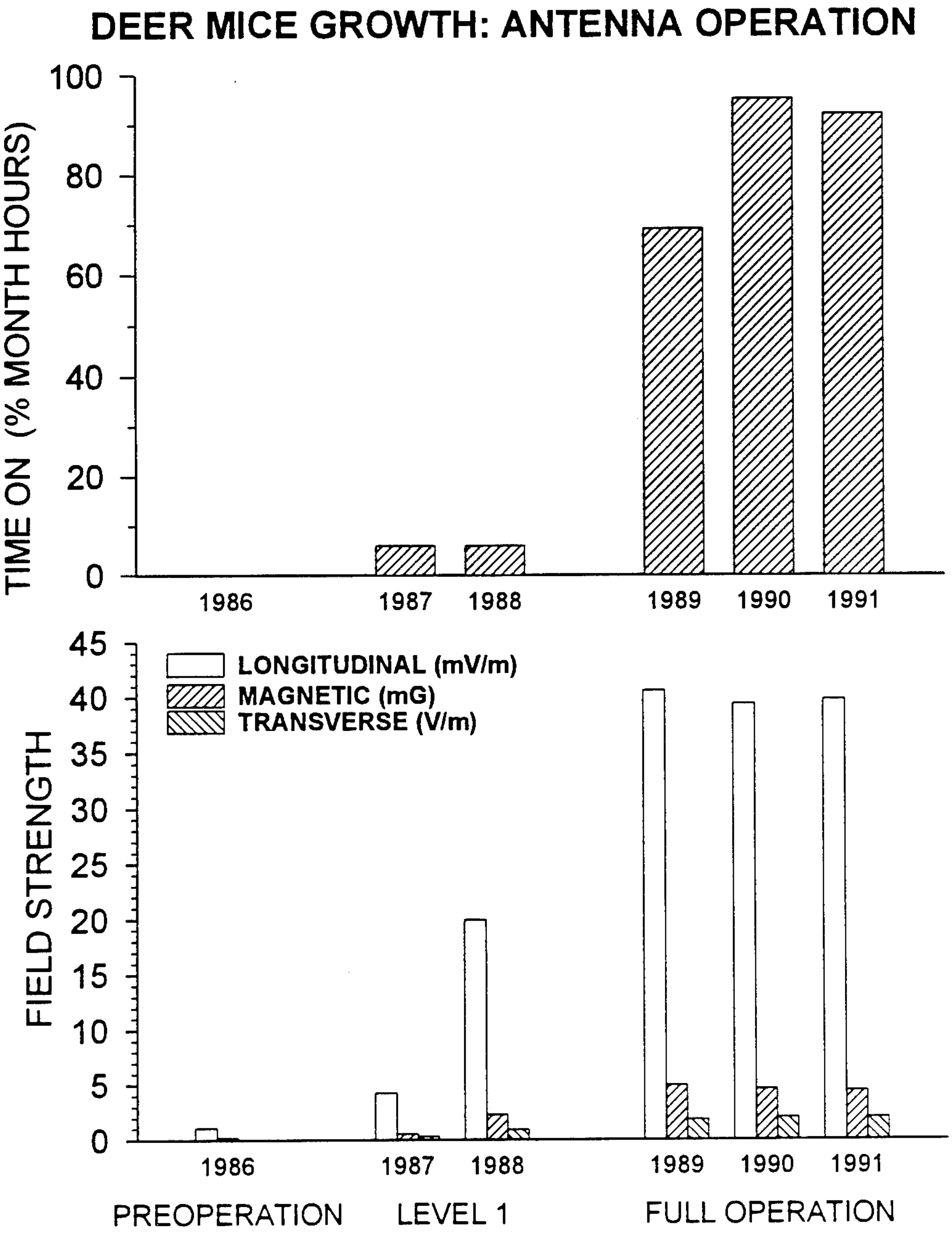


Figure 58. Antenna operation hours (% month-hours) and field strengths during deer mice growth studies

Termination of Studies in 1991. The study of growth and development of nestling deer mice was ended with the 1991 season. We had intractable problems with disease (Tyzzer's disease), which resulted in high female mortality rates and subsequent high death rates among litters. Also, we observed a fairly high incidence of behavioral abnormalities where females improperly cared for their young or cannibalized them. In addition to difficulties associated with the study animals, we encountered problems with damage to the enclosure systems by vandals, bears and storms. Efforts to decrease mortality through partial burying of nest boxes to reduce heat stress, improving ventilation in the nest boxes, dosing the adult females with antibiotics, and keeping the area clean to reduce disease met with minimal success. Cool weather during April and May appeared to substantially increase our chances of obtaining complete data sets on litters born in the enclosures, but we had very few field seasons that had favorable weather beyond the end of May. As a result of these problems, we have a limited data set.

Growth of Young. A perusal of our data for growth in body mass of nestlings indicated that growth curves often appear non-linear. Although litter mates consistently exhibit similarly shaped growth curves, there are apparent differences in curves among litters of different females as well as differences between litters of the same female (*i.e.*, some are exponential, some sigmoidal, etc.). While this variability in the shape of growth curves among (but not within) litters is interesting, it precludes the use of any particular non-linear model (*e.g.*, logistic growth model) to estimate and compare growth rates in these mice. Therefore, growth rates have been estimated using linear regression analyses for growth of each individual up to the time of weight recession which appears to be correlated with weaning.

Analysis of variance of growth rate yielded no significant effect of antenna operation (Table 35). However, significant effects due to plot, year nested within operation period and interaction of plot and operation were found.

The significant plot effect seems to be due to annual weather patterns rather than operation of the Communications System. Means on the control plots were significantly higher in 1986 and 1990, whereas the reverse was true in 1989. The other three years the means were not different (Figure 59). This pattern does not coincide with operation levels of the Communications System.

The year within operation effect may be due to severe drought experienced in 1989 and 1990 and other unknown factors in 1986.

The interaction of plot and operation means is potentially the strongest indication of a Communications System effect. Examination of the means for these factors (Figure 60) reveals that the interaction is due to lower means on the test plot in the preoperation period which increase to the level of the control means in level 1 and full operation periods. The control means remain nearly constant across all levels of operation. This pattern could be evidence for a Communications System effect, but only if one assumes *any* operation of the system causes a full potential effect (*i.e.*, a threshold response occurs) since it does not continue into the full operation period.

Table 35. Nested analysis of variance for deer mouse mass growth constant for years 1986-1991. Data are log transformed to achieve normality (D'Agostino 1990)

Nested ANOVA for deer mouse mass growth constant, log transformed

SOURCE	DF	SS	MS	F	P
OPERATION	2	1.0543	0.5272	3.51	0.1636
PLOT	1	0.2387	0.2387	7.22	0.0075
YEAR(OPER)	3	0.4499	0.1500	4.54	0.0039
OPER*PLOT	2	0.5271	0.2636	7.98	0.0004
ERROR	386	12.7562	0.0331		

Maturation of Young. Analysis of age at eye opening of nestlings indicated a non-significant effect of operation period (Table 36), although a trend toward increasing age at eye opening is present (Figure 61). A significant effect due to plot was found with earlier ages of eye opening occurring on the test plot. This trend began in 1988 and continued in 1990 and 1991 with no significant difference occurring 1989.

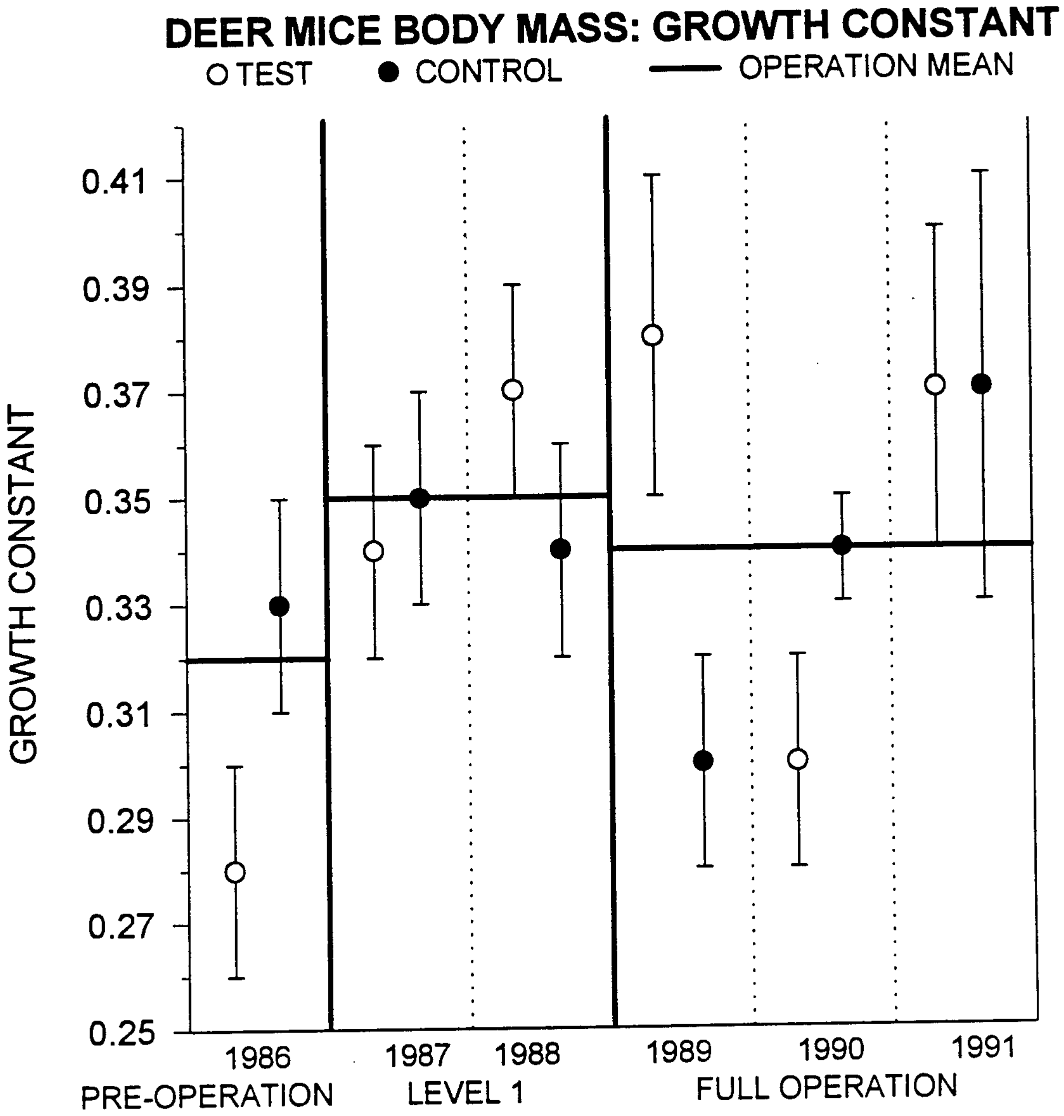


Figure 59. Mass growth constants (grams/day, mean ±95% confidence interval) of young deer mice observed on test and control sites for 1986 through 1991

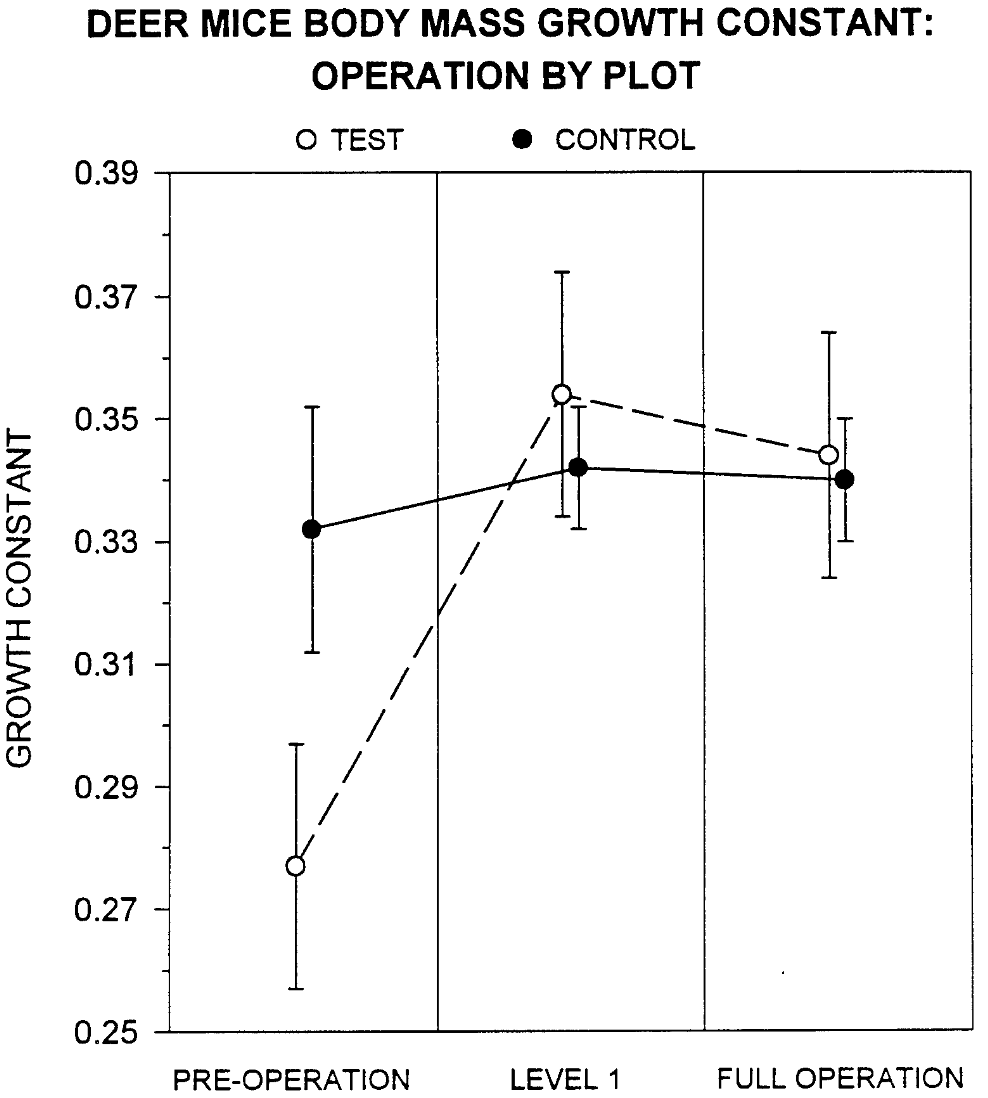


Figure 60. Mean growth constants (grams/day, ±95% confidence interval) for nestling deer mice. Shown are means for operation by plot interaction

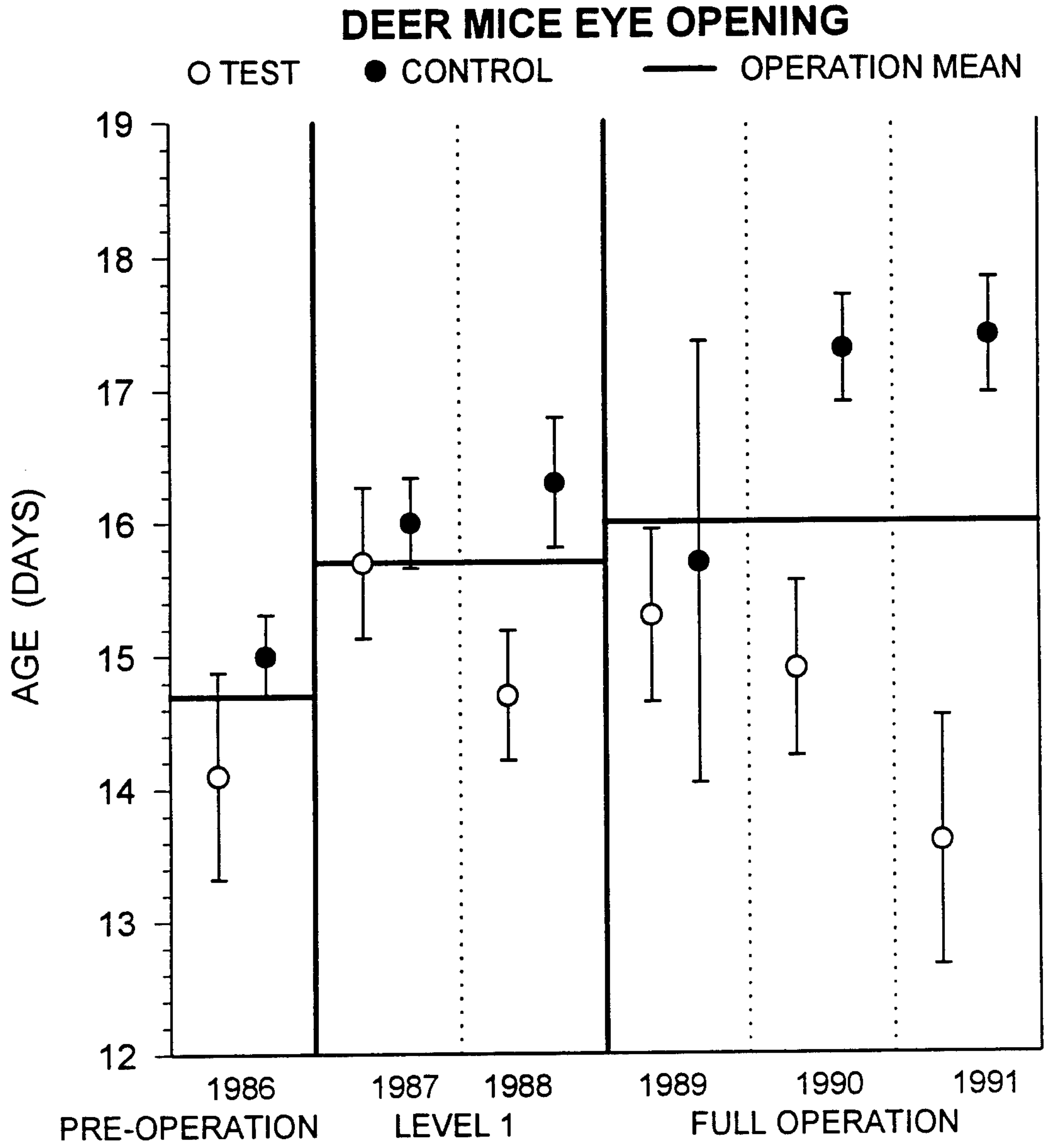


Figure 61. Age at eye opening (days, mean ±95% confidence interval) and sample N of young deer mice observed on test and control sites for 1986 through 1991

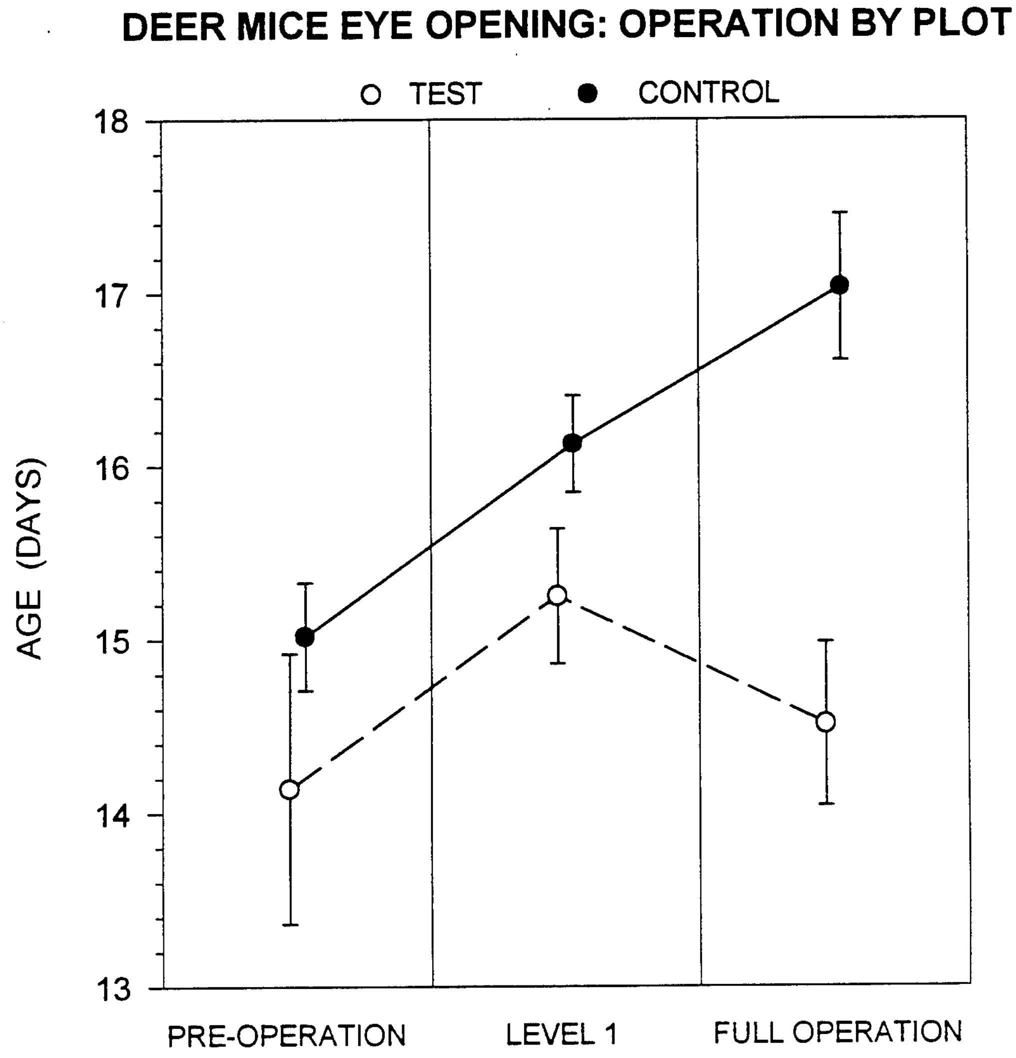


Figure 62. Mean age at eye opening (days, ±95% confidence interval) for nestling deer mice. Shown are means for operation by plot interaction

The diverging pattern of age at eye opening during the full operation period for test and control plots resulted in a significant interaction between of plot and operation period. The diverging pattern of the means (Figure 62), especially during the full operation period, strongly supports an effect of the Communications System. At this time, we do not know how ELF electromagnetic fields would produce the pattern of earlier eye opening on test plots. Further study would be required to elucidate the mechanism. The impact this effect may have on young deer mice is also not clear and open to speculation.

One possible explanation for the earlier opening of the eyes for young from the test plot is that they may have come from smaller litters, on average. Mothers may be able to provide more parental care to smaller litters, resulting in earlier maturation. We examined this possibility by plotting the average litter size for each plot over the years of the study (Figure 63). Analysis of variance of these data showed a significant effect of year ($F=7.21$, $P < 0.001$), plot of origin ($F=6.139$, $P=0.014$) and a year-by-plot interaction ($F=15.603$, $P<0.001$). The year effect is readily apparent by examining the means in Figure 63. Litter size was much lower in 1988 and 1989 than 1986 and 1987. The plot effect cannot be discerned in this figure since there is no simple way to view the plot effect when there is an interaction effect. The interaction of year and plot is especially of interest here since this could show a pattern that coincides with the increasing operation strength of the antenna. The pattern is, however, not unequivocally relatable to the operation of the antenna. The average litter size on the control plot is closely similar (overlapping 95% confidence intervals) to the test plot in 1986, 1988, 1989, 1990, and 1991, but is much larger in 1987. Furthermore, a trend for the average litter size on the control plot to be larger than the test plot in the years from 1987 through 1989 is reversed in 1990 and 1991. None of these findings points to a clear trend that could explain the earlier opening of the eyes of young deer mice on the test plot.

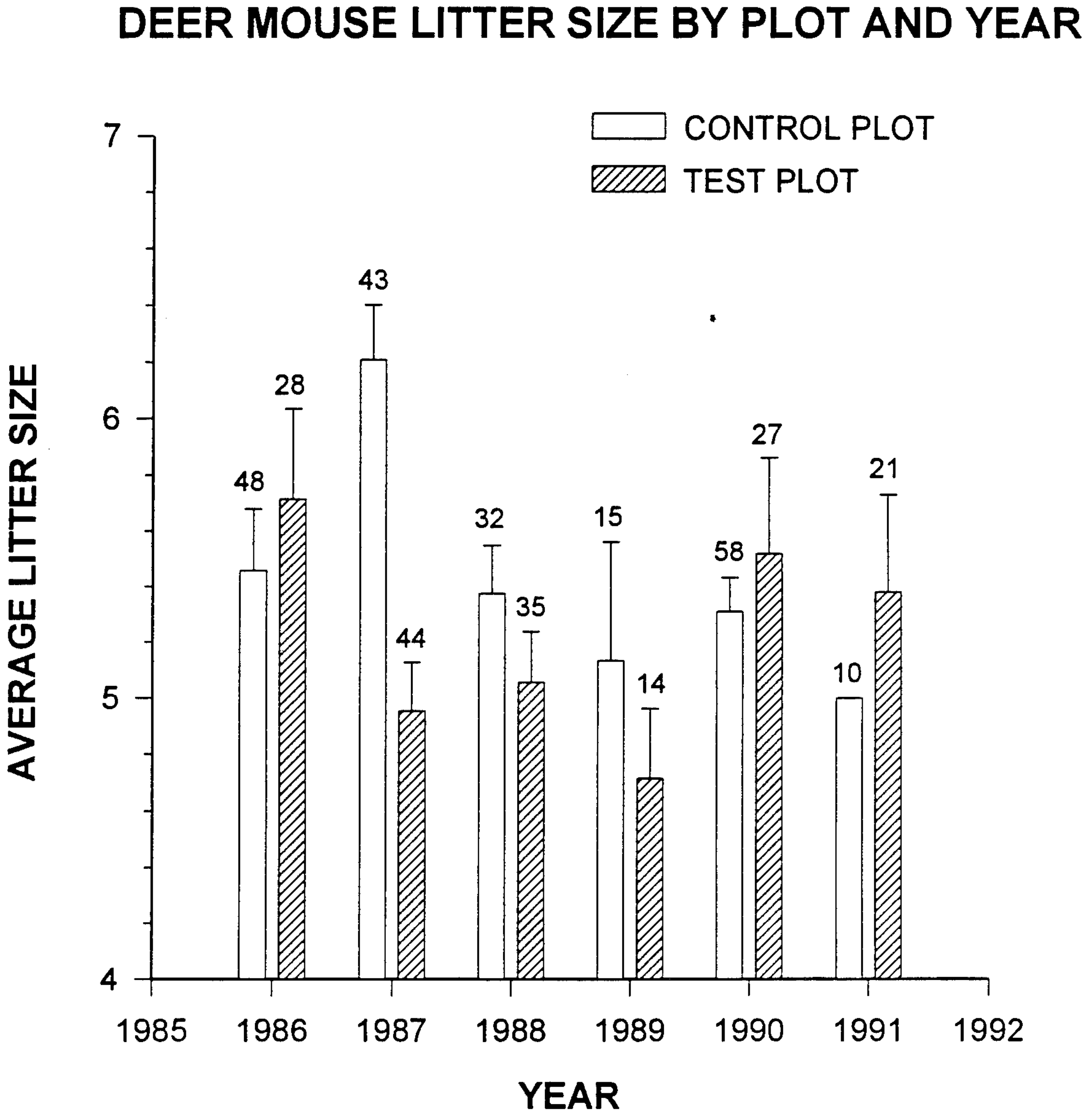


Figure 63. Deer mouse litter size (mean ±95% confidence interval) on control and test plots for each year of the study. The number of litters is given above each bar

Ages at incisor eruption were similar between test and control plots throughout the experiment (Figure 64). Age at incisor eruption was not significantly different among operation periods yet was significantly different between test and control plots (PLOT, Table 36). The plot effect was due to the trend for earlier incisor eruption on the test plot, especially in 1988 and 1989 (Figure 64). A highly significant effect due to year within operation was present but not for the interaction of operation and plot (OPER*PLOT, Table 36). The year within operation effect seems to be due to the lower means for 1988 and 1989 in combination with the higher means in 1987. A long and severe drought prevailed during 1988 and 1989, perhaps explaining this pattern.

The operation-plot interaction was not significant for the age at incisor eruption, indicating the absence of any trends associated with operation of the Communications System.

Table 36. Nested analysis of variance for age of the landmark events, eye opening and incisor eruption, in deer mice. Data are untransformed

Nested ANOVA for deer mouse age at eye opening

SOURCE	DF	SS	MS	F	P
OPERATION	2	62.9399	31.4700	3.83	0.1492
PLOT	1	144.5471	144.5471	52.92	0.0001[a]
YEAR(OPER)	3	24.6373	8.2124	3.01	0.0303[a]
OPER*PLOT	2	41.4657	20.7329	7.59	0.0006[a]
ERROR	366	999.7493	2.7316		

Nested ANOVA for deer mouse age at incisor eruption

SOURCE	DF	SS	MS	F	P
OPERATION	2	2.8471	1.4235	0.06	0.9398
PLOT	1	17.9033	17.9033	10.90	0.0011[a]
YEAR(OPER)	3	67.4098	22.4699	13.67	0.0001[a]
OPER*PLOT	2	2.6971	1.3486	0.82	0.4409
ERROR	375	616.1961	1.6432		

[a] Significant at 0.05 or less

Statistical Sufficiency. The power of the test and detectable differences were estimated for the operation and plot effects of the analysis of variance for the deer mouse growth constant, age at eye opening and age at incisor eruption (Figure 65). Actual detectable differences due to an

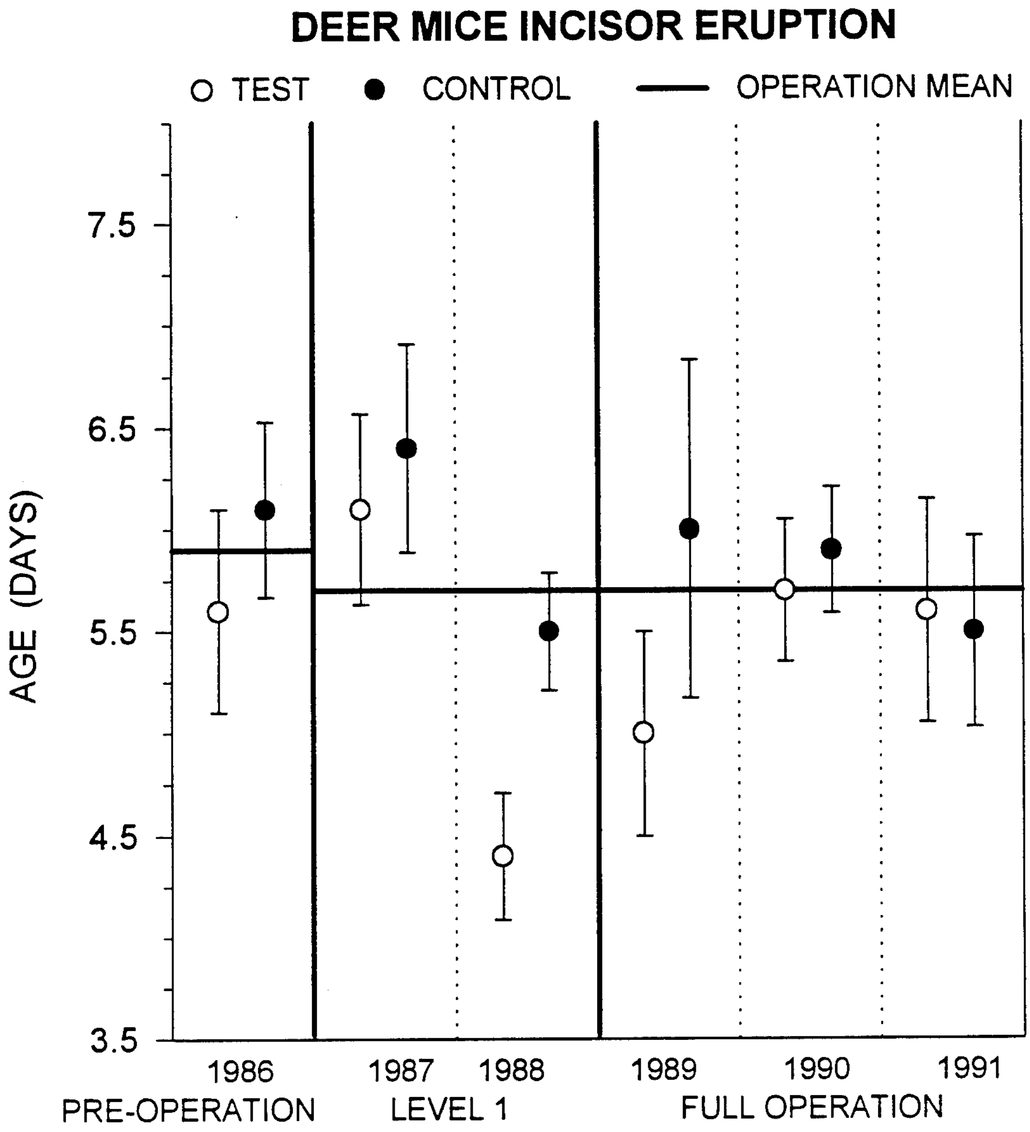


Figure 64. Age at incisor eruption (days, mean ±95% confidence interval) of young deer mice observed on test and control sites for 1986 through 1991

operation effect were about 14% for incisor eruption, about 8% for body mass growth constant and about 6% for age at eye opening. The power of these tests was between 50% and 55% for body mass growth constant and age at eye opening and less than 30% for age at incisor eruption.

With power set at 70%, a difference of up to 28% in age at incisor eruption means would be necessary to detect an operation effect with confidence. Means for age at eye opening and body mass growth constant would only have to differ by about 7% and 12%, respectively, to detect an operation effect for these variables.

Actual detectable differences in means due to a plot effect ranged from 4 to 7.5%, for age at incisor eruption, age at eye opening and body mass growth constant. The power of these tests was high, being above our established 70% level for each variable. Therefore, we were able to detect very small differences in plot means for these variables with considerable power.

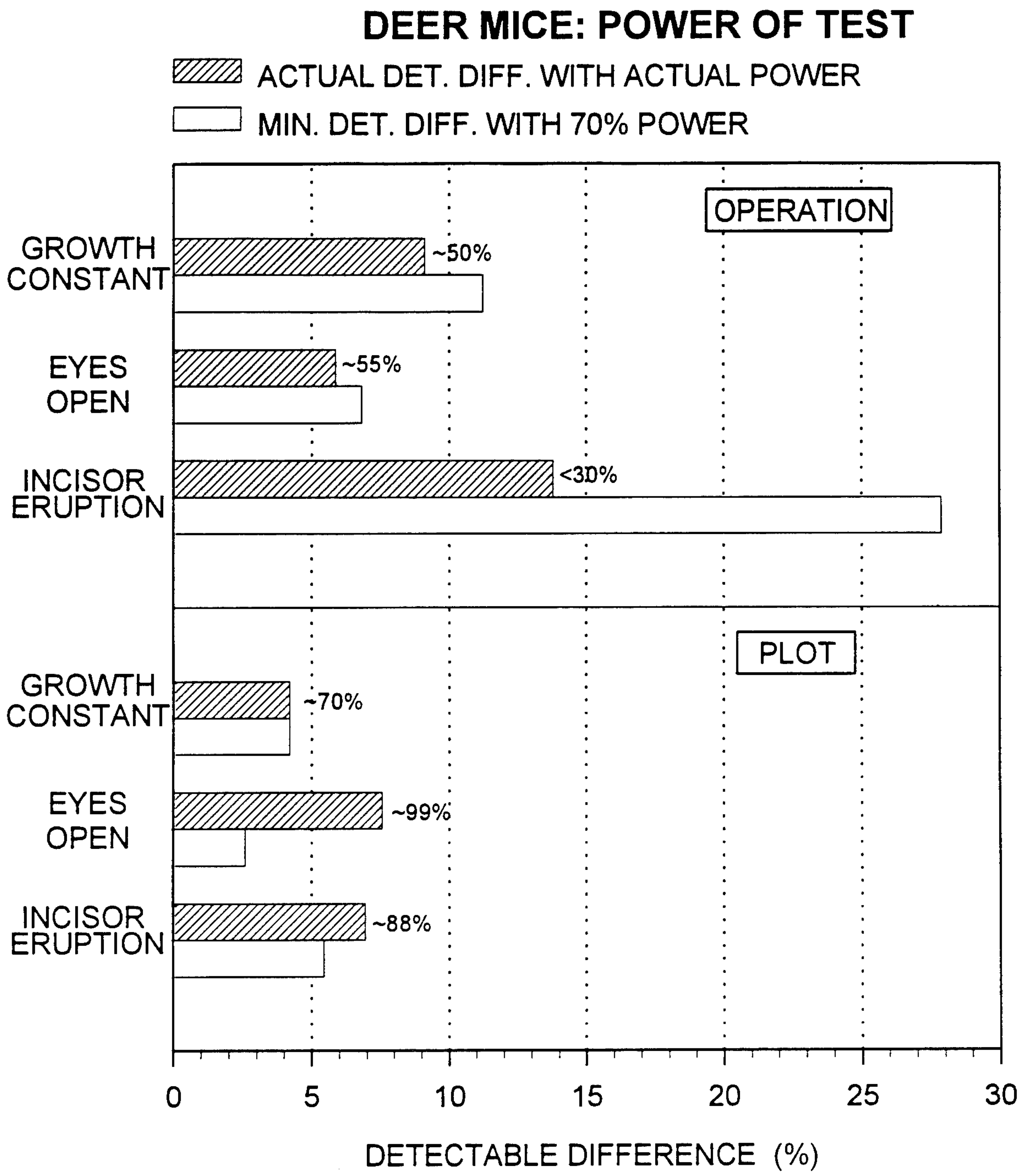


Figure 65. Detectable differences of deer mouse growth variables for operation and plot effects

HOMING STUDIES - TREE SWALLOWS

I. Purpose

The purpose of these studies was to measure the homing success of tree swallows at test and control sites and to test for possible effects of the ELF Communications System on such success. Variables measured were the proportions of swallows that successfully returned home after displacement from their nest, and the time required for each bird to return home. Birds returning to their nest box within a set time period following release (usually 300 min) were considered successful.

II. Methods

Adult birds were captured at the nest box when they arrived to feed the young (6-13 days post-hatch) using a passive nest box trapping device (Magnusson 1984) or, earlier in the study, a "clothes pin rig" (Cohen and Hayes 1984). Captures took place between 0800 and 1100 to allow adequate feeding of the young in the nest prior to capture. Following capture, each bird was sexed (using the presence of a cloacal protuberance for males and brood patch for females) and aged using plumage characteristics (Hussell 1983a). Birds were banded using a standard U.S. Fish and Wildlife band and were color marked on the breast using "magic markers" to provide rapid and positive identification while in flight. Birds were placed in wire cages which were covered with black cloths, and then driven to the release sites. Only one of the two parents from each nest was displaced on any given day, and adults were only homed once. Upon release, the time, vanishing direction, and weather conditions were noted. Observers located near the nest boxes recorded the time at which the birds returned. Birds at each release site were released singly, with each released when its predecessor had disappeared from sight (approximately three minutes).

In our first studies of swallow homing in 1984 and 1985, we released birds at release points located at all four cardinal compass directions (east, west, north, south) from the nesting areas at test and control sites. The results revealed no differences in homing success from one compass direction to another. Furthermore, because tree swallows probably home without regard to habitats they fly over, and they are not likely to be exposed to any systematically different hazards (predators, etc.) in homing from one direction as opposed to another, we felt justified in changing our research plan after 1985 to displace birds in just one compass direction. This protocol was more efficient in terms of personnel effort than the use of four displacement directions and thus facilitated the achievement of adequate sample sizes.

The release points used for 1986-1990 were located in open areas at a distance of 30 km from the nest sites and at a compass direction 20 degrees NE of the nest sites. The distance was chosen because it was beyond the distance corresponding to a drop of two orders of magnitude of potential electromagnetic fields given off by the Communications System. The direction of the release points in relation to the nest sites was chosen so that birds from the test plots, in attempting to return to the nest site in a straight line, would cross both east-west legs of the antenna configuration, areas that would supposedly be maximally influenced by Communications System electromagnetic fields. Due to reviewer comments on the results from 1986-1990 this protocol was altered during 1991 and years following. See the results section below for further details.

III. Results

ELF Exposure for Tree Swallow Homing Research Task. During our tree swallow homing studies, only the northern east-west antenna element was on at very low strength for a short period of time during 1986. The entire Communications System was on at low strength and for relatively few hours during 1987 and 1988, but was on at full strength from 1989 to 1993 (Figure 66 and Table 39). No field strength and hours of operation data are presented for 1992 because a severe weather system killed nearly all nestlings, which caused mass nest abandonment by adults prevented us from conducting any homing studies.

Results for 1986-1990. Results from the first five years (1986-1990) of the tree swallow homing study (Table 37) showed that, with data pooled over years, birds from the test plots were

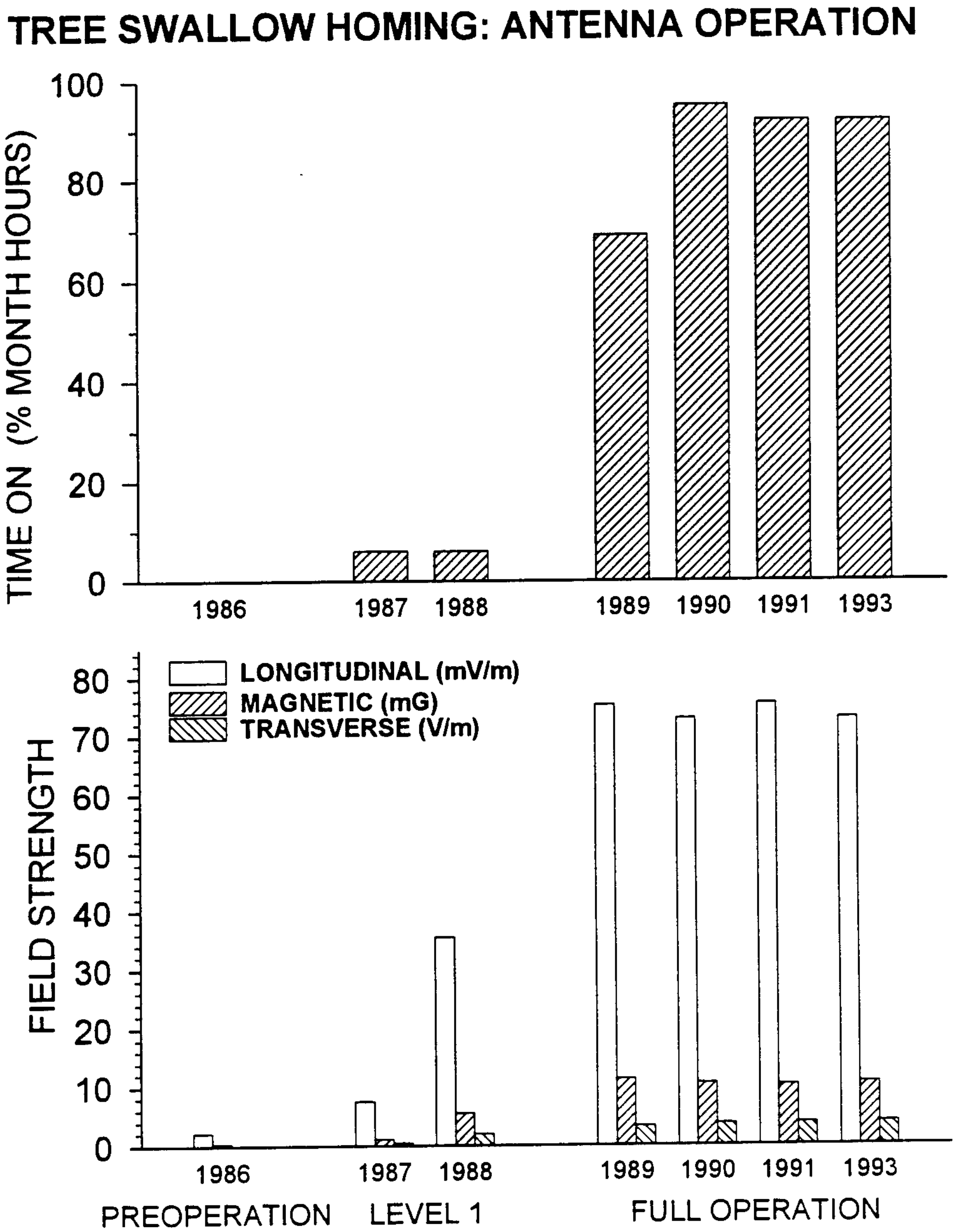


Figure 66. Antenna operational hours (% month-hours) and field strengths during tree swallow homing studies

Table 37. Likelihood of tree swallows to return following displacement during all years of the homing study. Test and control plots were compared using a χ^2 test

Year	Plot	Return	Not Return	% Return	χ^2	P
1993	Test	17	3	85.0	<0.001	>0.900
	Control	17	3	85.0		
1991	Test	34	1	97.1	13.789	<0.001[a]
	Control	24	15	61.5		
1990	Test	41	1	97.6	8.004	0.005[a]
	Control	30	9	76.9		
1989	Test	14	0	100.0	0.905	0.341
	Control	15	1	93.8		
1988	Test	37	4	90.2	0.267	0.605
	Control	39	6	86.7		
1987	Test	36	1	97.3	12.258	<0.001[a]
	Control	25	13	65.8		
1986	Test	26	3	89.7	1.615	0.204
	Control	24	7	77.4		

[a] Significant at 0.05 or less

more likely to return than control birds (94.5% mean return for test birds, 78.7% mean return for control birds). In addition, test-plot birds returned significantly more rapidly in every year (Figure 67).

In 1990 we attempted to understand these differences, without altering our original design, by investigating properties possibly unique to the Panola Plains control site which could be contributing to the observed differences. We compared the likelihood to return and the return speeds for birds displaced from Panola Plains (our normal control birds) to a sample of birds from Tachycineta Meadows control (n = 13), a site not previously used for homing. Birds from both plots were displaced and released from the normal Panola Plains release site, which effectively controlled for any release site characteristics. Likelihood to return was shown to be independent of plot (G-test, G = 2.276. P > 0.1) even though 76.9% returned to Panola Plains while only 53.8% returned to Tachycineta Meadows. The distances travelled by the returning birds were slightly

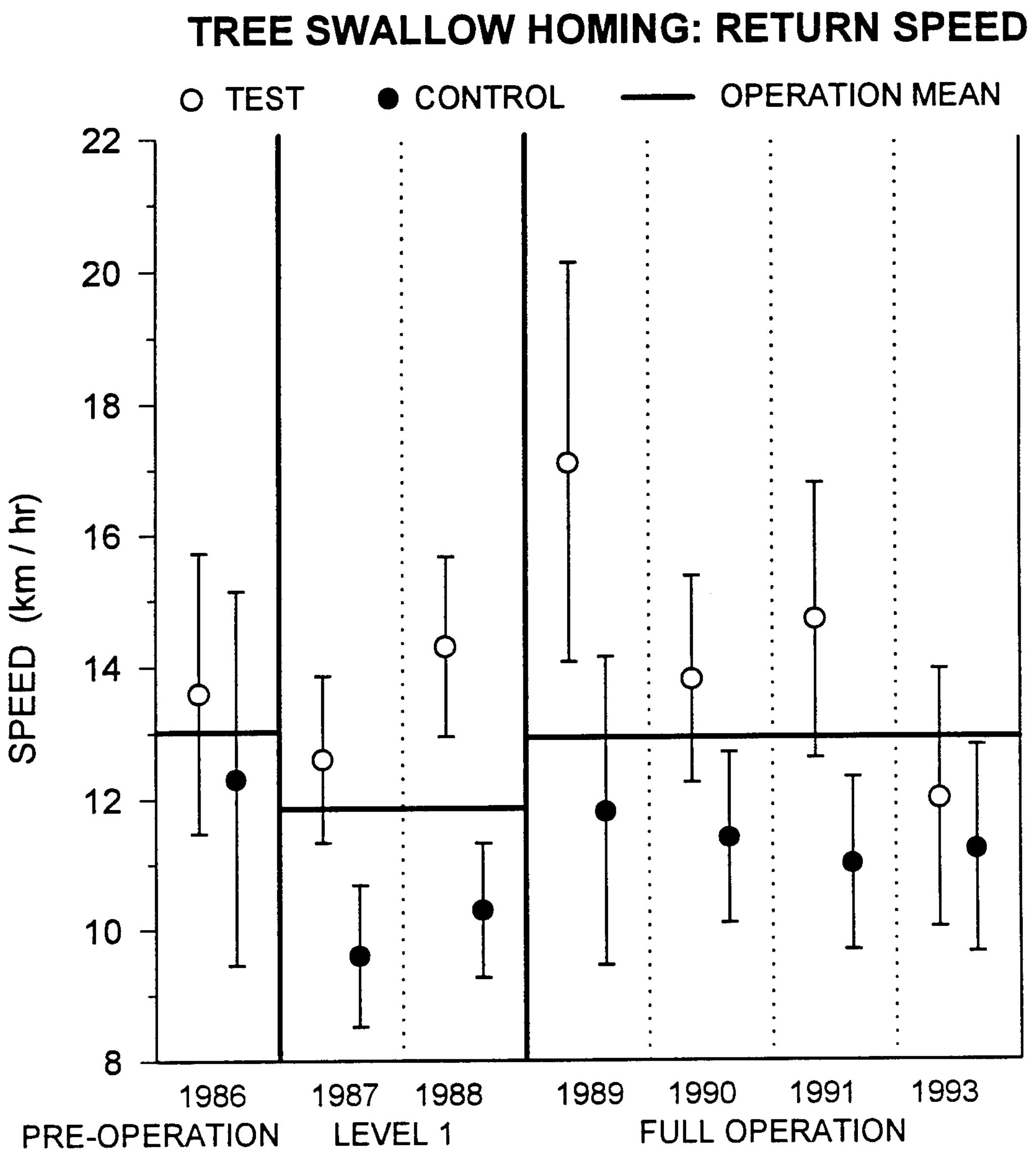


Figure 67. Return speeds (km/hr) assuming a linear path of tree swallows homed to test and control sites for 1986 through 1991 and 1993

shorter to Tachycineta Meadows (27 km) compared to Panola Plains (30 km), so return speed in km/hr was used for comparison rather than minutes to return. Speeds were shown to be faster for birds returning to Panola Plains (11.4 km/hr) than to Tachycineta Meadows (8.6 km/hr, t-test, t = 2.037, P = 0.049). These results suggested differences in plot characteristics between Panola Plains and Tachycineta Meadows rather than a release site effect. However, the number of birds displaced from Tachycineta Meadows was too small to make this analysis conclusive. Sample size problems aside, these results did not help explain the differences we had observed between established test and control plots over the previous five years.

Results From 1991 and 1993. Due to reviewers' comments on the 1990 and previous year's results, we changed protocols for the tree swallow homing study during 1991. One of the major criticisms in the past had been the fact that our observed differences may have been due to release point differences rather than differences inherent to the test and control plots. In order to test this hypothesis, the reviewers suggested that samples of birds from both test and control should be displaced to other plot's release point as well at their normal release point. For example, samples of control birds from Panola Plains would be released simultaneously at the normal control release site as well as the test release site.

There were several factors which prevented us from using this approach. First, the distances between nest and release point would differ greatly in the different release points for birds from Panola control plot. The normal displacement distance was 30 km; test birds released at the control release point would be displaced 27 km, and control birds released at the test release point would be displaced 56 km. Secondly, test birds displaced to the control release site would be taken out of the area of electromagnetic influence produced by the antenna, whereas control birds displaced to the test release site would be taken into this area of influence. This proposed design would have led to many confounding factors, and adequate sample sizes needed to account for these factors would have been impossible to attain.

As a second choice, the reviewer suggested using a common release point for birds displaced from both test and control plots. This was the approach we took. If test birds still showed a greater likelihood to return and also returned faster, then we could conclude that the differences between test and control birds were not attributable to the release site. When we located a common release point on the map with equal distances to each plot, the site turned out to be within three kilometers of the original control release site. Because of this, it was decided to continue using the same normal control release site as the common release point even though return distances were 30 km to the control plot but only 27 to the test (see Figure 1). Use of the normal control release point would allow us to continue to compare at least our control data from year to year in an unaltered fashion. Due to these differences in distance, km/hr was the variable measured rather than minutes to return, and test birds were given only 270 minutes to return to be scored as a positive return compared to 300 minutes for control birds.

A total of 74 birds was displaced in 1991 (35 test, 39 control). Whereas 97.1% returned on the test plot, only 61.5% returned on the control plot (Table 37). These marked differences in likelihood to return are significant ($\chi^2 = 13.789$, $P < 0.001$) and are similar to results from 1990 and 1987. No significant differences in likelihood to return were found during 1989, 1988, or 1986.

Mean return speed was also shown to be different for the two plots, return speeds for test birds (14.7 km/hr) being significantly faster than control birds (11.0 km/hr, t-test, $t = -3.03$, $P = 0.0038$; Figure 67).

Homing studies were not conducted in 1992 due to severe weather. In 1993, the same research design as in 1991 was used. A total of 40 adult tree swallows was used in the homing experiment during 1993 (20 test, 20 control). Due to unsettled weather patterns during the time frame when homing was possible, there were only two days when birds could be successfully displaced (June 22 and 23). Likelihood to return was the same for test and control plots (17 of 20 returning on both plots, 85%), and flight speeds of those returning did not differ (t-test, $t = 0.652$, P

= 0.519). Thus, the common release site yielded mixed results, with the probability and speed of return greater for test than control plot birds in 1991 but equal in 1993.

Overall Review of Data. Using heterogeneity χ^2 testing for all years of the study without regard to operational status we find that all years are considered homogeneous ($\chi^2 = 9.432$, df = 6, $P > 0.1$). Of the seven years of the study, six years showed higher percentages of displaced birds returning to the test plots when compared to the control, and three of these six years show significant lack of independence with regard to plot (Table 37).

Analyzing the likelihood to home data using the contingency table approach, we first tested for homogeneity of the yearly 2 X 2 tables within operational status, with the exception of the preoperational time period which only had one year (1986). During the level 1 antenna testing phase (1987 and 1988), the two years were shown to be heterogeneous ($\chi^2 = 3.914$, df = 1, $P < 0.05$) and thus could not be pooled. While the antenna was fully operational (1989, 1990, 1991, 1993), years were shown to be homogeneous ($\chi^2 = 4.630$, df = 3, $P > 0.1$), even though 1991 and 1993 were a completely different design from the other years, and thus could be pooled.

Even though yearly data over the entire study were shown to be homogeneous, the further heterogeneity χ^2 testing just described showed a lack of homogeneity within categories of operational status. Because a full multidimensional model with operation level as a factor could not be used, it appeared as though assessing trends from the yearly χ^2 comparisons was the most reasonable approach.

We analyzed data on return flight speeds from all years of the study (Figure 67, total n = 377, 1985-1993, with no data from 1992 as noted earlier) in a nested analysis of variance to assess the potential effects due to antenna operation (OPERATION) with levels of pre-operation: 1986, level 1 testing: 1987 and 1988, and fully operational: 1989 through 1993; plot (PLOT) with test and control plots; year nested within the operation effect [YEAR(OPER)]; and the operation-by-plot interaction (OPER*PLOT). Due to the nested design, the error term used to compute the

OPERATION effect F value was the mean square value for YEAR(OPER). Prior to running this analysis, the data were tested for normality using the methods of D'Agostino *et al.* (1990) and for variance heterogeneity using Bartlett's test (Sokal and Rohlf 1981). A transformation to the 0.02 power resulted in normality, and with this transformation variances were homogeneous at all levels of the analysis of variance model (all P > 0.18). Box plots and stem and leaf plots in SYSTAT showed one extreme outlier (Wilkinson 1990) which was removed from the data set. Results of the analysis of variance (Table 38) show a significant effect due to treatment plot (F = 28.848, P < 0.001) which is due to return speeds being faster on the test plot during all years of the study (Figure 67). Test plot birds pooled over years averaged 13.77 km/hr while control birds averaged 10.97 km/hr (t = 6.291, P < 0.001). No significant effects were detected due to antenna operation, year within operation or the interaction of operation and plot.

Table 38. Nested analysis of variance for Tree Swallow return speeds (km/hr). Data were transformed by raising to the 0.02 power and one outlier was removed

SOURCE	DF	SS	MS	F	P
OPERATION	2	0.000246	0.000123	1.225	0.385
PLOT	1	0.001347	0.001347	28.848	<0.001
YEAR(OPER)	4	0.000402	0.000100	2.151	0.074
OPER*PLOT	2	0.000143	0.000071	1.530	0.218
ERROR	366	0.017090	0.000047		

When all years of the tree swallow homing study are taken together, the results have been consistent and straightforward. Birds released from the test sites showed a greater likelihood to return than control birds, and flight speeds of returning birds were faster on the test sites. This was true at all levels of antenna operation. We can conclude that although there were distinct plot related differences in homing performance, the operational status of the antenna had no effect on the results.

Most of our study elements dealing with individuals (growth of young, metabolic rates, etc.) can be considered in light of long-term antenna exposure. For example, development from fertilization to fledging in tree swallows takes approximately 40 days, and the potential impact of ELF electromagnetic fields could occur at any point in this time frame. There could also be a possible cumulative effect. For tree swallows displaced from their nest for the homing experiment, there are two possible impacts of ELF electromagnetic fields, namely long- and short-term exposure. We have investigated the potential long-term effect using the analyses just described and found no evidence of an effect. For the analysis of potential effects of short-term exposure, we focused on the antenna operational parameters during times when the displaced birds were actually in the air following release. Due to the highly variable, nearly hourly, nature of antenna operation, it is difficult to build analysis models which incorporate all levels of operation.

Based on antenna parameters prevailing during actual homing flights, we partitioned the sample size at the test plots into various categories of antenna operation (Table 39) and then compared these samples in various combinations in an attempt to answer the following questions:

1) During 1986, did low level 6 ampere testing of either east-west antenna element affect likelihood to home or homing flight speeds of test-plot birds?

2) During 1987 and 1988, did rotational cycling between the north-south and east-west antenna affect likelihood to return and homing flight speeds of test plot birds?

3) During 1989, 1990 and 1993, did full power antenna operation affect likelihood to home and homing flight speeds?

When we compared the two groups of test-plot birds during 1986 (question 1, above), we found no differences in likelihood to return ($\chi^2 = 0.299$, $P = 0.584$) or return flight speeds ($t = 0.216$, $P = 0.831$). From this we can conclude that 6 ampere testing did not appear to be affecting homing abilities in these test-plot birds.

When we made comparisons within the 1987 and 1988 test plot samples (question 2, above) we found no differences in likelihood to return during either year (χ^2 tests, both $P > 0.23$). When we compared returning birds within the test plot sample during 1987, we found that the birds that

Table 39. Status of antenna operation and corresponding sample size during the time when individual birds were displaced during the Tree Swallow homing study

Year	Antenna Status	Sample Size		
		Test *n*	Total Test *n*	Control *n*
1986	Off	14		
	EW1 @ 6 amps[A]	15	29	31
1987	Off	10		
	EW and NS @ 15 amps[B]	27	37	38
1988	Off	10		
	EW and NS @ 15 amps	31	41	45
1989	Off	6		
	EW and NS @ 150 amps	7		
	NS only @ 150 amps for 0.05hrs[C]	1	14	16
1990	EW and NS @ 150 amps	30		
	Partial EW and NS @ 150 amps[D]	12	42	39
1991	Off	1		
	Partial NS only @ 150 amps[D, E]	4		
	NS only @ 150 amps[E]	30	35	39
1993	Off	4		
	Partial EW and NS @ 150 amps[D]	6		
	EW and NS @ 150 amps	10	20	20

[A] Only one leg of EW antenna operational; uncoupled from EW2.

[B] Both EW legs of antenna now coupled (EW1 and EW2) and remain coupled for rest of study. Rotational cycling: EW/NS/OFF @ 5 minute intervals.

[C] Only on during three minutes of this individual's flight time.

[D] Only on during part of homing flight—percent of time varies with individual.

[E] Only NS leg of antenna on; EW off.

homed during times when the antenna was on showed significantly faster flight speeds when compared to those birds displaced when the antenna was off ($t = -2.446$, $P = 0.020$, see Table 40). Mean flight speeds of returning birds during 1988 when the antenna was on were also slightly higher, but not significantly different, from those of birds homed when the antenna was off ($t = -0.858$, $P = 0.397$). An analysis of variance model for 1987 and 1988 taken together (Table 40), reveals a significant effect due to antenna operation as well as a significant year effect. Thus it appears that the rotational cycling of the antenna during 1987 and 1988 was having an effect on the flight speeds of returning birds on test plots. Birds displaced when the antenna was on returned

Table 40. (A) Mean flight speeds (km/hr) of returning test plot birds during 1987 and 1988 comparing birds displaced when the antenna was off to those displaced when the antenna was on. (B) Analysis of variance of these data

(A)

Year	Antenna	*n*	km/hr	S.E.	t-test
1987	On	26	13.54	0.719	t = -2.446
	Off	10	10.35	0.950	P = 0.020[a]
1988	On	27	14.62	0.804	t = -0.858
	Off	10	13.32	1.219	P = 0.397

(B) Analysis of variance of test plot birds returning when the antenna was on compared to when it was off

Source	df	SS	MS	F	P
Antenna	1	73.149	73.149	5.022	0.028[a]
Year	1	59.652	59.652	4.096	0.047[a]
Antenna*Year	1	12.912	12.912	0.887	0.350
Error	69	1004.943	14.564		

[a] Significant at 0.05 or less

more rapidly than those birds displaced when the antenna was off.

There are several hypotheses which may be proposed to explain this observed result. The electromagnetic fields given off by the antenna may provide a beacon of sorts that the birds can home on. However, this seems unreasonable given the nature of antenna testing at the time, which involved five-minute interval cycling between the east-west antenna, the north-south antenna, and then both north-south and east-west antenna off. This cycling would change the overall intensity of the electromagnetic fields considerably at any given point in the flight path and would seemingly provide mixed signals rather than a constant beacon. Another possible hypothesis is that weather patterns on the days of homing were somehow responsible for the observed results. The data from both 1987 and 1988 when the antenna was off all come from only one day during each year. Patterns of wind, high and low pressure cells, cloud cover, and other weather variables were uncontrollable factors in our homing studies and could have been unusual on the days the antenna was off. Although we made every effort to conduct the homing displacements during times of consistent weather, the studies were conducted in a geographic region known for its rapid weather changes. However, a careful perusal of our field notes from these days did not disclose any unusual weather conditions.

Table 41. Likelihood to return for displaced birds during the 1989, 1990, and 1993 tree swallow homing study. All test birds were displaced when the antenna was operating at full power

Year	Plot	Return	Not Return	% Return	χ^2	P
1993	Test	9	1	90.0	0.144	0.704
	Control	17	3	85.0		
1990	Test	29	1	96.7	5.334	0.021
	Control	30	9	76.9		
1989	Test	7	0	100.0	0.457	0.499
	Control	15	1	93.8		

Table 42. (A) Mean flight speeds (km/hr) of test (antenna on) and control plot birds during the 1989, 1990 and 1993. Sample n is of birds that returned. (B) Analysis of variance for these data

(A)

Year	Treatment	*n*	km/hr	S.E.	t-test
1989	Test	7	18.80	1.419	t = -3.700
	Control	15	11.82	1.101	P = 0.001[a]
1990	Test	29	13.11	0.939	t = -1.486
	Control	30	11.43	0.639	P = 0.143
1993	Test	9	11.28	1.153	t = -0.046
	Control	17	11.22	0.745	P = 0.963

(B) Analysis of variance of mean flight speeds of test and control birds returning when the antenna was on.

Source	df	SS	MS	F	P
Treatment	1	169.748	169.748	10.346	0.002[a]
Year	2	189.567	94.784	5.777	0.004[a]
Treatment*Year	2	139.534	69.767	4.252	0.017[a]
Error	101	1657.163	16.408		

[a] Significant at 0.05 or less

The third question we asked concerned homing during full-power antenna operation (question 3, above) and involved a more straightforward test vs. control analysis. For comparison to the controls, we used only those test birds that were homed during the time of full-power operation on both the EW and NS legs of the antenna. Results showed a significant difference in likelihood to return between test and control plots during 1990 (Table 41, $\chi^2 = 5.334$, $P = 0.021$). Whereas 96.7% of displaced birds returned to the test plot, only 76.9% returned to the control. No differences were detected in 1989 or 1993. When flight speeds of returning birds are considered (Table 42), test birds returned faster than controls during 1989, but not in 1990 or 1993. Analysis of variance of these data revealed a significant treatment, year and treatment-by-year interaction effect. The significant treatment effect is due to the higher return rates for tree swallows from test plots in 1989 and 1990. These higher means also seem to have generated the significant year effect in the ANOVA model. The significant interaction effect of treatment and year is due to the convergence of the high average return rates in test plot birds in 1989 to the same level of the control plot birds by 1993 (Figure 68). This could be interpreted as an effect of the Communications System. If one postulated that the pre-existing higher return rates of test plot birds prior to full strength operation of the antenna were diminished to the level of the controls by the high electromagnetic fields during full operation, then this would be evidence for an effect of the Communications System. However, this conclusion must be tempered with the fact that the means declined over a period of four years. This is not what one would expect to see if the effect of the Communications System was to impact the minute-by-minute decisions a tree swallow must make in flight during homing. For the effect to have acted in the short-term, the decrease in performance should have been strongly observed in 1989 and consistently thereafter. It is possible that these data result from long-term exposure to ELF electromagnetic fields, and in fact the data fit this hypothesis better than a short-term effect hypothesis. However, only a few study birds were used in two consecutive years of homing and none in three or four years. Our data on survival of adults also shows that the average life expectancy is only about 2-3 years (see earlier section on mortality). The long-term effect implicated by the treatment-by-year interaction in our data could possibly be explained by an impact on parents which is also transmitted to their offspring. However, the likelihood that these data represent a long-term exposure effect is diminished when one considers that other test-plot birds homed during these same years, but while the antenna was off, do not show diminished flight speeds during their return.

Overall, operation of the Communications System did appear to have an effect in the short-term on return rates and speeds of return, and it was a positive effect for test plot birds. Comparing test and control plot birds over all years, however, the effect was negative on test plot birds.

HOMING STUDIES - SMALL MAMMALS

I. Purpose

The purpose of these studies was to measure the homing success of small mammals at test and control sites and to test for possible effects of the ELF Communications System on such success. The variable measured was the proportion of individuals that successfully returned home after displacement, and the principal species studied were deer mice and chipmunks.

II. Methods

During our initial studies on mammal homing in 1985 (Beaver *et al.* 1986), we displaced chipmunks and deer mice in all four compass cardinal directions in order to investigate any directional biases in homing ability. No such biases were found even though animals displaced west and north on the control and test plots had — unlike those displaced east or south — to cross the sham corridor or actual antenna corridor, as well as somewhat different habitat types. However, our sample sizes were small for any particular displacement direction (maximum of 10 animals), and we therefore could not be certain of the robustness of our tests. Thus, in contrast to the work on swallow homing, we decided to reduce the number of displacement directions to two rather than

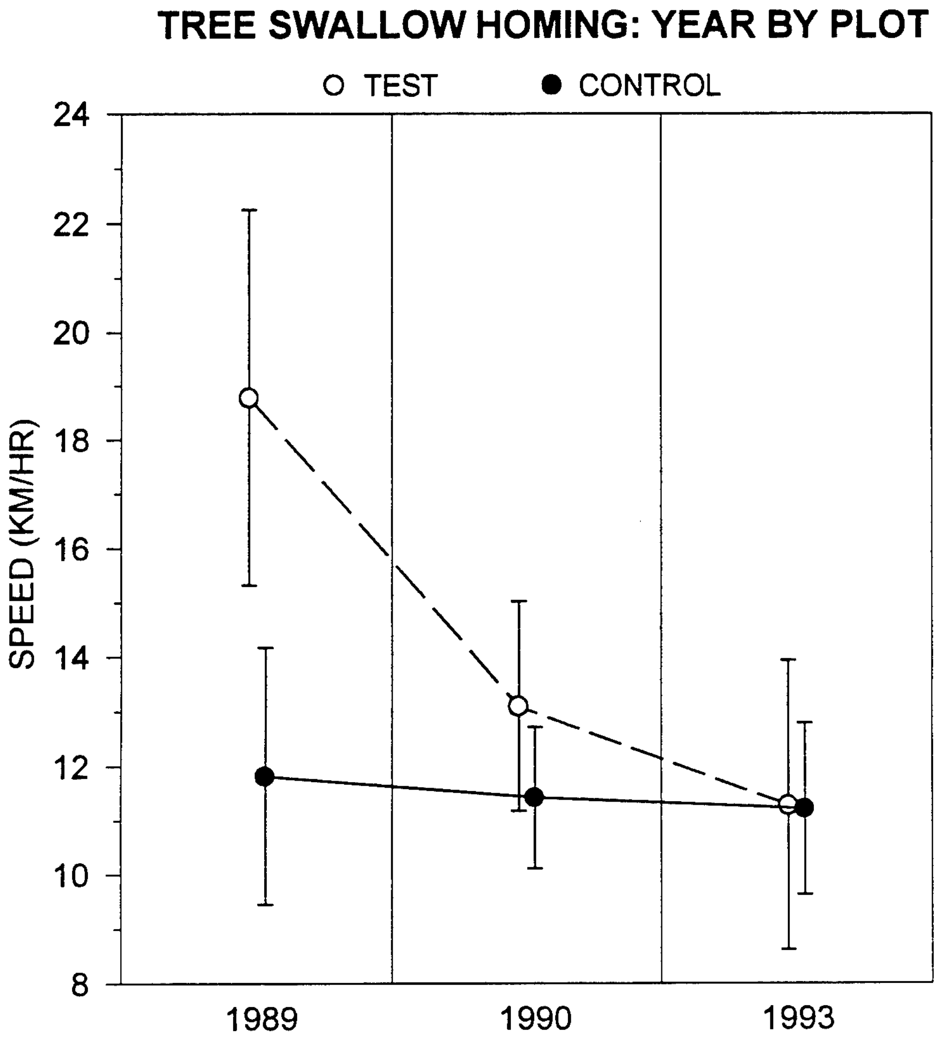


Figure 68. Interaction of mean (±95% confidence interval) return speeds for test and control plot birds displaced during full power operation of the antenna

one. Reducing the number of directions from four to two increased efficiency of sampling. By using two directions rather than only one, we maintained the diversity of habitats and corridor crossings at each site, thus helping to insure that we would be further able to examine the effects of habitat conditions as well as potential effects of ELF electromagnetic fields on homing behavior.

The small mammal homing study was conducted on two trapping grids, one at the Pirlot Road test site and the other at the Michigamme South control site. Due to the low chipmunk and deer mouse populations found in 1985 and 1986, the sizes of the trapping grids were increased in 1987. Each grid contained 100 stations spaced 15 meters apart rather than 10 meters, increasing the area covered to 1.8 ha versus 0.81 ha. One Leathers live-trap containing cotton or polyester batting for bedding material, baited with peanut butter and rolled oats or sunflower seeds, was placed at each station. The grids were situated on the east side of both the Communications System corridor (test) and the sham corridor (control). A habitat buffer between each antenna or sham right-of-way (ROW) and its respective trapping grid was increased in 1987 to 50 meters, rather than the 10 meters of 1986. This increase helped insure that both the grids and their displacement lines were located in more uniform habitat, a continuous mixed deciduous forest dominated by sugar maple (*Acer saccharum*).

Traps were checked twice daily (ca. 0800 and 1900) and re-baited as necessary. Each animal was weighed, sexed, and toe-clipped upon first capture for individual identification. Reproductive condition, station number, and capture time were also recorded. Individuals were displaced after their third capture; animals caught three times were deemed to be residents of the area where the trapping grid was established, which hopefully insured their detection by recapture on the trapping grid upon returning from displacement. Only adults were displaced; deer mice in obvious juvenile pelage or weighing less than 15 grams, and chipmunks less than 65 grams, were not displaced. Before being displaced, each animal was kept in a cage supplied with nesting material, lab chow, and water. Cages were placed in screened-in storage sheds located near each site. Displacements took place during, or just prior to, the next activity period following capture; deer mice (nocturnal) were displaced at dusk (ca. 1900), and chipmunks (diurnal) were displaced in the morning (ca. 0800). Each animal was displaced 450 m from the trap it was captured at when kept for displacement. Displacements took place to the south and west of the home grids. Trapping continued for five days after the last animal was displaced to detect late returns.

At both test and control plots, displacements to the south were through continuous forest, whereas those to the west required returning animals to cross the antenna corridor at the test site and the sham corridor at the control site. Use of the two displacement directions thus specifically allowed us to test for directional differences in return rates which might occur due to the fact that test animals returning from the west had to pass beneath the antenna line, potentially the area of greatest electromagnetic disturbance.

We experienced varying levels of trap disturbance by larger mammals during some years, primarily at the Michigamme control plot, so we actively trapped for gray squirrels, skunks, and raccoons using several sizes of Tomahawk live traps. In order to minimize the level of additional predator attraction posed by these traps, we baited these larger traps only with small amounts of the same bait used in the smaller Leathers traps. Numbers of all three of these species were captured and removed from both test and control plots.

III. Results

ELF Exposure During Small Mammal Homing Studies. There were four major levels of antenna operation (Figure 69) during the time periods when the mammal homing study was conducted: six-ampere intermittent testing (1986), 15-ampere testing (Level 1,1987), 75-ampere testing (Level 2, 1988), and fully operational (1989-1993). All years of the mammal homing study were characterized by at least a low level of antenna operation, so none of the years could be considered truly preoperational (Figure 69).

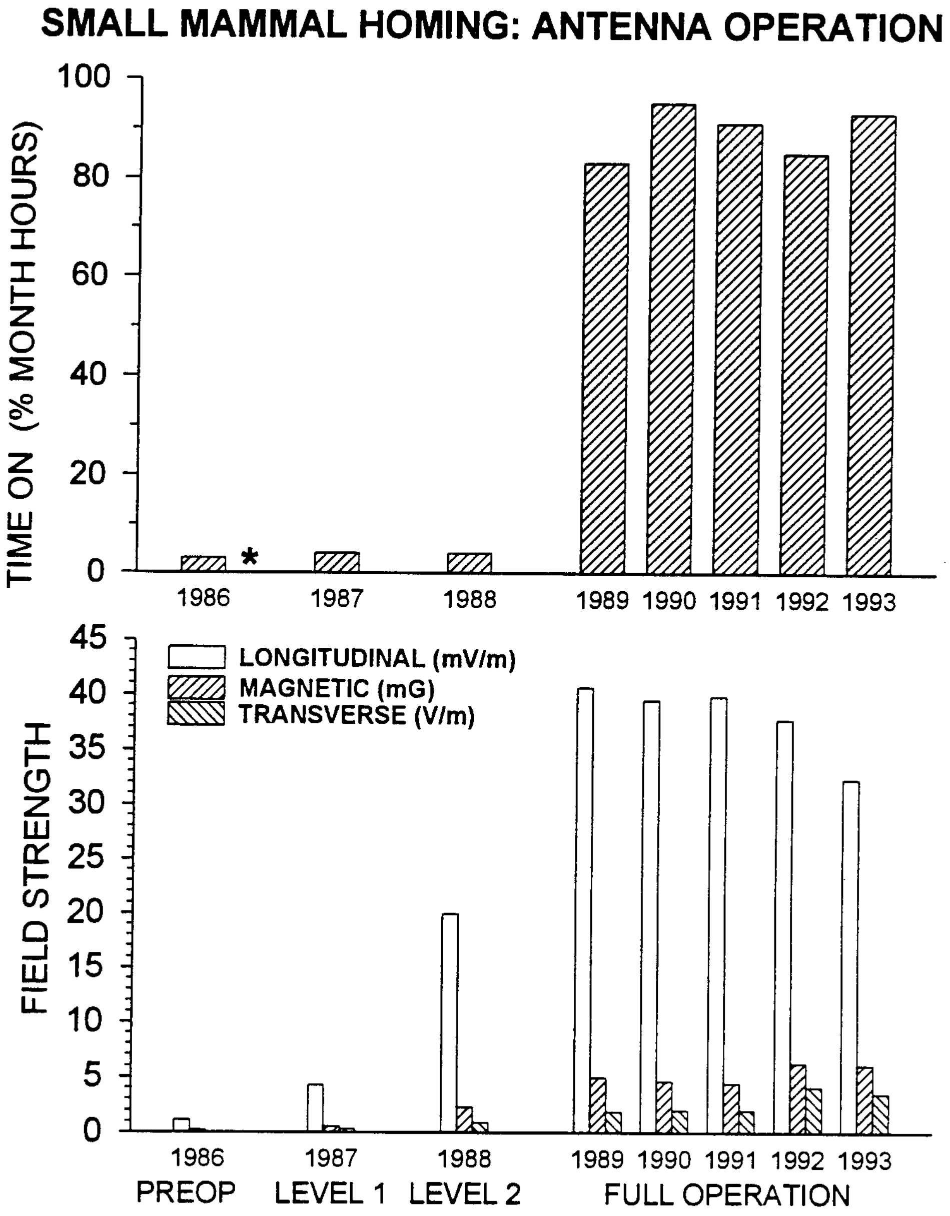


Figure 69. Antenna operation hours (% month-hours) and field strengths during small mammal homing studies. *= intermittent operation, 3% of time at 4 amperes and 1% of time at 6 amperes

Data on Homing. Trapping began on 7 July and ended on 27 July for the 1993 field season. A total of 30 chipmunks (20 test, 10 control) and 39 deer mice (21 test, 18 control) were displaced during 1993 (Table 43 and Table 44). No difference in likelihood to return was detected between the two displacement directions for chipmunks at either treatment plot, so data from both displacement directions were pooled.

Table 43. Likelihood of chipmunks to return following displacement during all years of the homing study. Test and control plots were compared using a χ^2 test

Year	Plot	Return	Not Return	% Return	χ^2	P
1993	Test	11	9	55.0	0.600	0.439
	Control	4	6	40.0		
1992	Test	19	8	70.4	1.667	0.197
	Control	1	2	33.3		
1991	Test	7	6	53.8	0.151	0.697
	Control	5	3	62.5		
1990	Test	11	12	47.8	2.530	0.112
	Control	15	6	71.4		
1989	Test	15	8	65.2	0.321	0.571
	Control	9	7	56.3		
1988	Test	5	12	29.4	0.200	0.655
	Control	2	3	40.0		
1987	Test	4	8	33.3	0.356	0.551
	Control	2	2	50.0		
1986	Test	13	6	68.4	3.283	0.070
	Control	20	2	90.9		

For deer mice however, differences in likelihood to return were detected between the west and south displacement directions at the Michigamme control plot ($\chi^2 = 8.654$, $P = 0.003$). Whereas 100% (10 of 10) of the deer mice returned from the south displacements, only 37.5% (3 of 8) returned from the west displacements. This was the first year where there was any directional difference detected for either species at either plot, so this may simply be a random occurrence. However, the manner in which animals were taken to the control plot's west displacement release site during the course of the experiment had to be altered for the 1993 field season. We endeavored

Table 44. Likelihood of deer mice to return following displacement during all years of the homing study. Test and control plots were compared using a χ^2 test

Year	Plot	Return	Not Return	% Return	χ^2	P
1993	Test	18	3	85.7	1.082	0.298
	Control	13	5	72.2		
1992	Test	9	3	75.0	0.157	0.692
	Control	9	2	81.8		
1991	Test	28	10	73.7	1.462	0.227
	Control	11	8	57.9		
1990	Test	20	23	46.5	10.913	0.001[a]
	Control	29	6	82.9		
1989	Test	13	8	61.9	4.859	0.028[a]
	Control	3	10	23.1		
1988	Test	17	24	41.5	2.181	0.140
	Control	9	5	64.3		
1987	Test	16	7	69.9	0.025	0.874
	Control	6	3	66.7		
1986	Test	5	1	83.3	2.250	0.134
	Control	1	2	33.3		

[a] Significant at 0.05 or less

in the past to approach all displacement release sites by specifically avoiding a direct line route from the trapping grid to the release site. The reasoning was to avoid leaving a well-marked scent trail which could potentially be followed by animals back to the trapping grid. We are unsure as to what cues either species may use in attempting to return home, so this seemed to be a reasonable approach. Due to the blocking of a road used to help reach the west displacement site at the Michigamme control plot, during 1993 we simply walked with the caged animals to the west release site from the sham corridor. This was deliberately not a straight-line route, but started approximately 50 meters north of the northwest corner of the trapping grid. Whether or not this change in protocol was the factor which contributed to the difference between the two directions for deer mice observed in 1993 is not certain. Chipmunks were subjected to the same change, yet showed no difference in likelihood to home from either displacement direction. Chipmunks, however, may not use the same cues to facilitate returning to home. Because of the directional differences shown for deer mice at the control plot, analyses for test/control comparisons were conducted using two data sets, one where the deer mice were pooled for 1993 at the Michigamme control, and another where 1993 deer mice were excluded.

For chipmunks (Table 43) during 1993 there were no differences in likelihood to return shown between test and control plots ($\chi^2 = 0.600$, $P = 0.439$). This is the same result obtained during all years of the study and heterogeneity χ^2 testing showed that all years of the study were homogeneous ($\chi^2 = 6.791$, df = 7, $P > 0.25$). There are difficulties with the chipmunk data set due to low sample sizes at the control plot during 1992, 1988 and 1987. With these years of low sample size excluded, the remaining years are still homogeneous ($\chi^2 = 4.783$, df = 4, $P > 0.25$).

Considering only those years of full antenna operation and adequate sample sizes (1989-1991 and 1993), heterogeneity χ^2 testing shows the years to be homogeneous ($\chi^2 = 3.356$, df = 3, $P > 0.25$). Further, a multidimensional contingency table approach results in failure to reject the initial hypothesis of mutual independence ($\chi^2 = 6.14$, df = 10, $P = 0.803$) which indicates that the factors of treatment plot (test vs. control) and year are not influencing likelihood to home in chipmunks.

Sample sizes for the chipmunk study were low for some years and plot locations due to inherently variable population sizes, and because of these problems the conclusions from the study must be qualified. Even so, it does not appear that the operation of the ELF Communications System has had any effect on homing abilities in chipmunks.

For deer mice, first including the 1993 data and pooling over displacement directions at the Michigamme control site, no differences in likelihood to home were detected in 1993 between test and control plots (Table 44, $\chi^2 = 1.082$, $P = 0.298$). Over the course of the study there were only two years where a significant lack of independence was detected between test and control plots for deer mice. During 1989 a higher proportion of displaced individuals returned to the test plot, whereas during 1990 a higher proportion returned to the control plot.

Heterogeneity χ^2 testing shows that years cannot be pooled within the fully operational time period for deer mice ($\chi^2 = 18.313$, df = 4, $P < 0.005$). This result precludes the running of a multidimensional contingency table model which would include a level for operation. Considering only those years of full antenna operation, a multidimensional contingency table approach results in the rejection of the initial hypothesis of mutual independence ($\chi^2 = 31.440$, df = 12, $P = 0.002$). Thus, we formulated and tested three hypotheses of partial independence:

1. Return rate is independent of treatment plot and year
2. Treatment plot is independent of year and return rate
3. Year is independent of return rate and treatment plot.

All three of these null hypotheses were rejected (all $P < 0.01$) which indicates that during the time of full antenna operation the likelihood of displaced deer mice to return is influenced by both year and treatment plot. This conclusion seems reasonably to reflect the data presented in Table 44. During 1989 a significantly higher proportion of displaced individuals returned to the test plot, whereas during 1990 a higher proportion returned to the control plot.

With the 1993 deer mice data excluded due to directional pooling problems at the Michigamme control plot, the results remain unchanged. There is lack of homogeneity within the yearly samples at the time when the antenna was fully operational and all tests of mutual and partial independence are rejected. The conclusions remain the same.

As was the case with chipmunks, lack of adequate sample sizes in some plot/year combinations makes interpretation more difficult, yet there is no indication that the ELF Communications System has had any effect on homing abilities in deer mice.

We have not attempted to examine the homing behavior of small mammals according to a day-by-day schedule of antenna operations as we did with the tree swallows. Homing of small mammals takes a longer time, and animals were homed as they became available in our trapping activities. We never had a sample of even 5-6 animals available to be homed on a single date. We therefore could not make comparisons of antenna on-off days with sufficient numbers of animals for statistical tests.

DEVELOPMENTAL STUDIES

I. Purpose

The purpose of these studies was to characterize aspects of normal embryological development in tree swallows and to investigate potential effects of the Communications System on development within the egg. Specifically, early embryological development of tree swallows has been characterized; developmental abnormalities in field populations of tree swallows have been described and their frequency in test and control plots determined; and the size of eggs from test and control plots has been compared.

II. Methods

Tree swallow eggs were collected during late May and early June. Active nests were checked daily and eggs numbered sequentially as they were laid. Routinely, three or four days after the appearance of the last egg, the entire clutch was removed from the nest and coded so that the rest of the analysis could be performed as a blind study.

Each year eggs were routinely collected from 30 nests of which half were located on control plots, half on test plots. As will be discussed subsequently, in 1993, very little development occurred in any egg in eight nests (numbers 16 through 23), probably as a result of two extremely cold days at a critical time in the laying period. Development was too retarded in these nests to allow an assessment of embryogenesis using the criteria which we have established. Accordingly, eggs were collected from an additional 5 nests to provide a total of 180 eggs; of these, 140 were utilized in the study of embryogenesis. All were utilized for size determinations.

Egg sizes were determined using both weight and volume measurements. Each year eggs were weighed on either a Pesola balance to 0.1 g (1985-1988) or a Sybron Digimetric balance to 0.01 g (1989-93). Measurements of egg volumes were obtained by water displacement. Length and breadth were measured to 0.001 cm using vernier calipers.

All embryos were dissected off the yolk into Howard chick Ringer's solution (Johnson and Volpe 1973) under a dissecting microscope and analyzed briefly. The specimens then were fixed in either Bouin's solution or 10% formalin for light microscopy or in 2.5% glutaraldehyde in chick Ringer's solution or phosphate buffer for scanning electron microscopy.

Embryos to be studied with light microscopy were stained as whole mounts using an alcoholic carmine solution (Watterson and Shoenwolf 1984) or alcoholic eosin. Following staining, they were dehydrated through a series of graded alcohols and cleared in methyl salicylate. All embryos were then carefully observed with an Olympus stereomicroscope using transmitted light, and a photographic record of any suspected abnormality was obtained. The use of methyl salicylate as a clearing agent allows biological materials to be observed as whole mounts and stored without undue tissue hardening. Subsequently, material can be embedded in paraffin and analyzed by routine histology.

After embryos were carefully analyzed and photographed, some were embedded in paraffin, sectioned at 10 microns, and stained with hematoxylin and eosin or toluidine blue for histological examination.

Embryos fixed in glutaraldehyde were dehydrated through a graded series of alcohols, critical point dried and sputter-coated for scanning electron microscopy. They were observed and photographed using a JOEL 35C scanning electron microscope.

All embryos were staged using the chick embryo series of Hamburger and Hamilton (1951) as a reference. In 1992, in addition to the tree swallow embryos, approximately 100 chick embryos at developmental stages similar to the tree swallow embryos were fixed and treated by the above methods. These have been used as a basis of comparison for the tree swallows, whose embryology is previously undescribed.

Abnormalities were tabulated and characterized as completely as possible.

III. Results

ELF Exposure During Embryological Studies. During the collection of eggs for embryology, the antenna system was not operational in 1985-1987. Low-level operation occurred during 1988, and full operation occurred from 1989-1992 (Figure 70).

Normal Development. As we have reported previously (Beaver, Hill and Asher 1984, Beaver, Hill and Hill 1991), development in tree swallows is similar to that of the chick as described by Hamilton and Hamburger (1951). Although some species differences are apparent and will be briefly mentioned later in this section, comparisons with chick development have been very helpful in determining the "normalcy" of development.

Tree swallow eggs show an asynchrony of development with the last egg laid routinely lagging behind the rest of the clutch by several stages. We have reported this observation previously (Beaver, Hill and Asher 1984, Beaver, Hill and Hill 1991). In other parts of our study, it is often observed that the last egg hatches approximately a day later than the rest of the eggs. This developmental delay is probably a reflection of the nesting behavior of the parents. Females are frequently observed to spend time on the nest before the clutch is complete; thus, development is probably initiated in "older" eggs before the last egg is deposited. This behavior has been described previously and seems common among small, altricial passerines (Clark and Wilson 1985).

Once the clutch is complete, the amount of time that birds spend on the nest can be influenced by climatic conditions. We have previously reported failure to develop in some nests and attributed it to "parental neglect" (Beaver, Hill and Hill 1992). While it is conceivable that parental neglect might result from the influence of the antenna, in previous years we have found no evidence that this is the case. In 1993, 8 nests (nests 16 - 23) contained 100% severely retarded

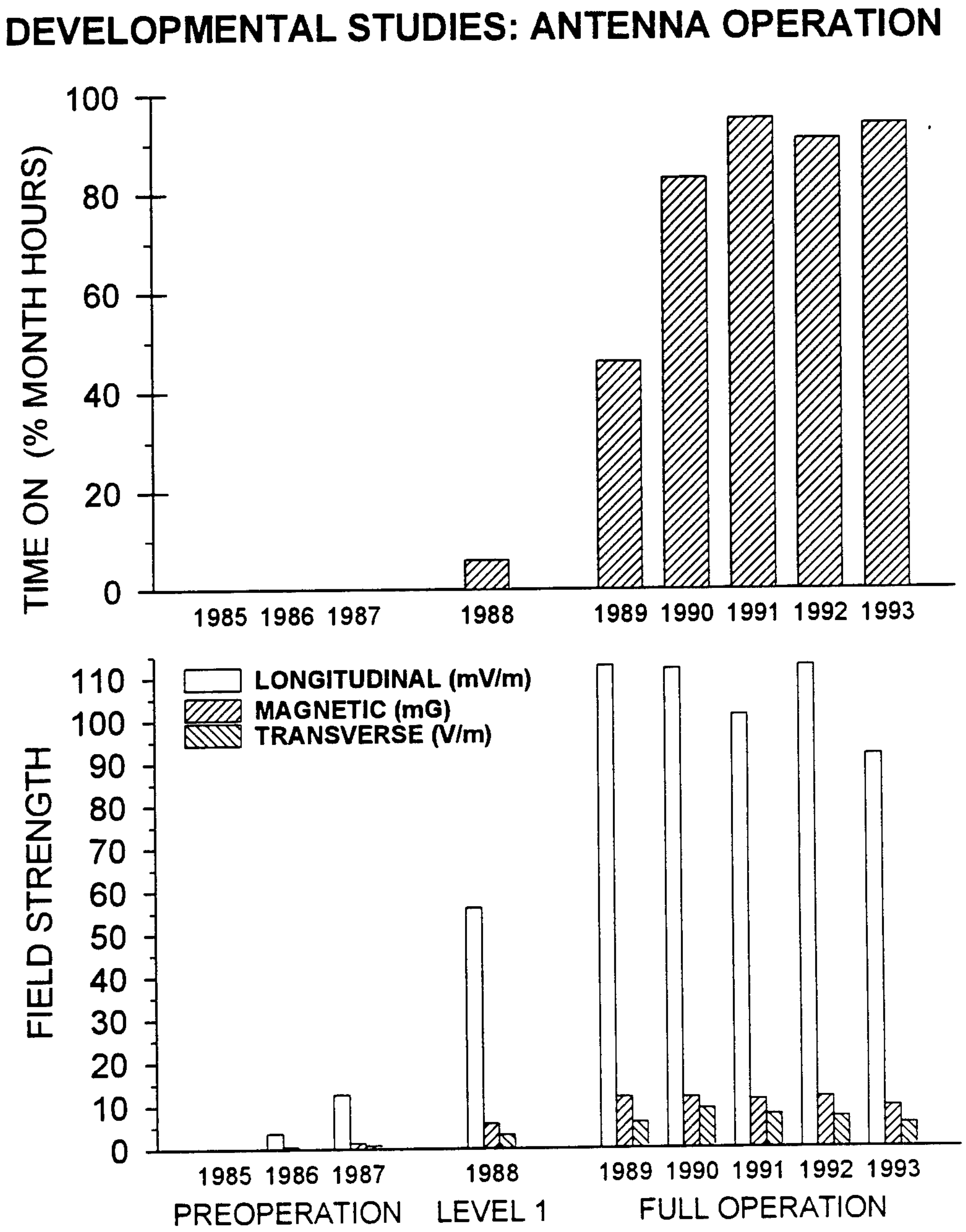


Figure 70. Hours of operation (% month-hours) and field strengths for the ELF antenna during developmental studies from 1985 through 1992

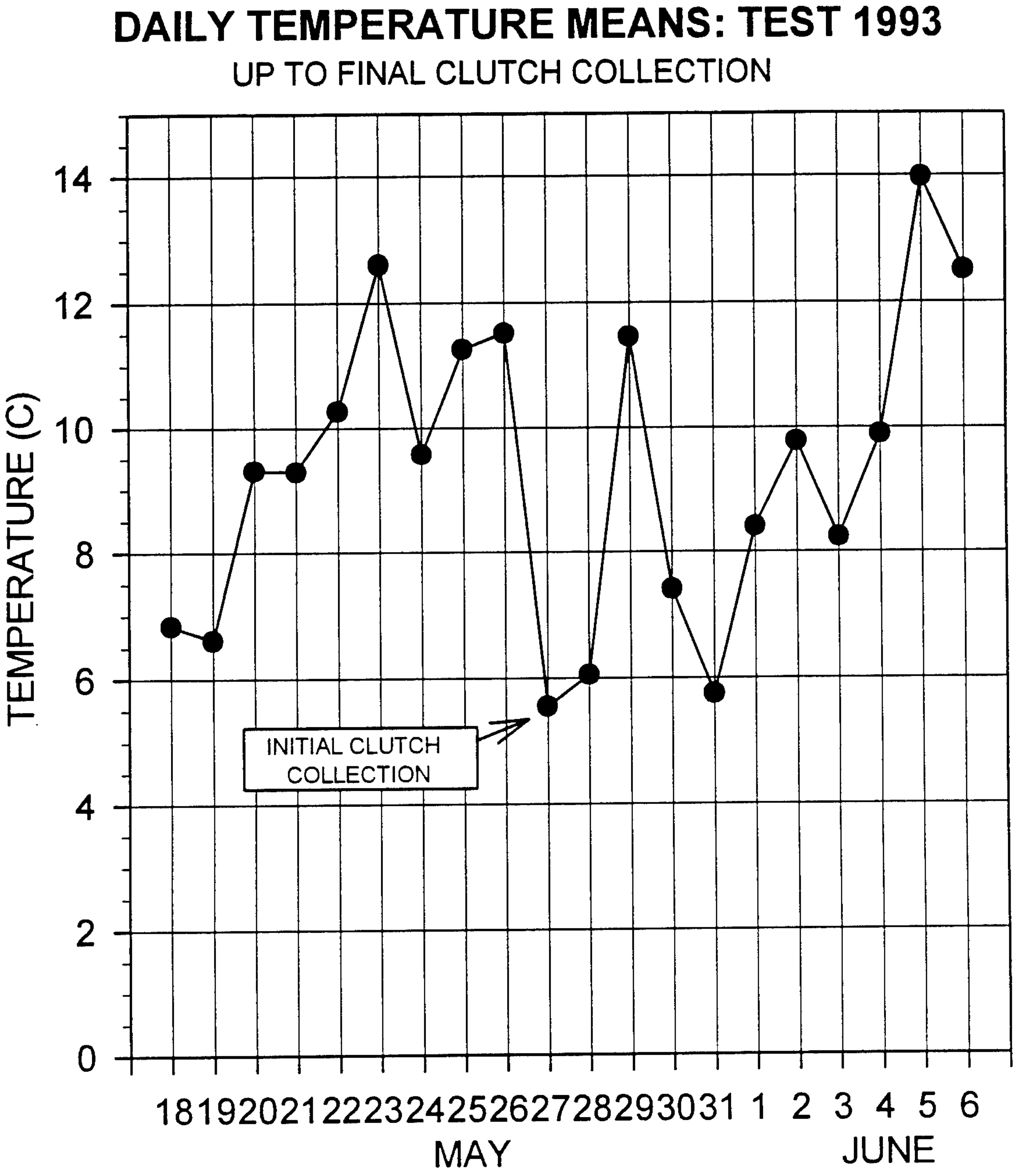


Figure 71. Mean daily air temperatures on the Pirlot Road test plot during egg laying and early incubation in 1993. Collections of some clutches occurred during cold weather on May 27 and 28

embryos. A very strong correlation is seen between a drop in atmospheric temperature and a failure to develop. Plots of the mean daily temperature show that on May 27 and 28, temperatures dropped to an average of between 5 and 6°C (Figure 71). All of our clutches which were completed on these days showed a failure to develop. Birds in the early stages of forming their clutches seem not to have been influenced by the low temperatures. We feel that the most parsimonious explanation for the failure to develop in these nests is that birds neglected the eggs because of low temperatures rather than because of an effect produced by the antenna. Eggs from these eight nests were all severely retarded. Seven of the nests were collected from test plots, one from a control plot. Development was so slight, ranging from stage 1 or 2 to 6, that it was impossible to determine whether the eggs would develop normally. Consequently, they were removed from further studies of embryogenesis.

In 1992, three delayed and potentially deserted clutches were collected from control plots. In 1991, three clutches in which development was severely delayed were collected from test plots. In 1990, two delayed nests were found on test plots. None were observed in 1989 or 1988. In the preoperation years, five neglected nests were found in 1987, three on future test plots, two on control plots. From our data, parental neglect does not seem to be linked to the functioning of the Communications System.

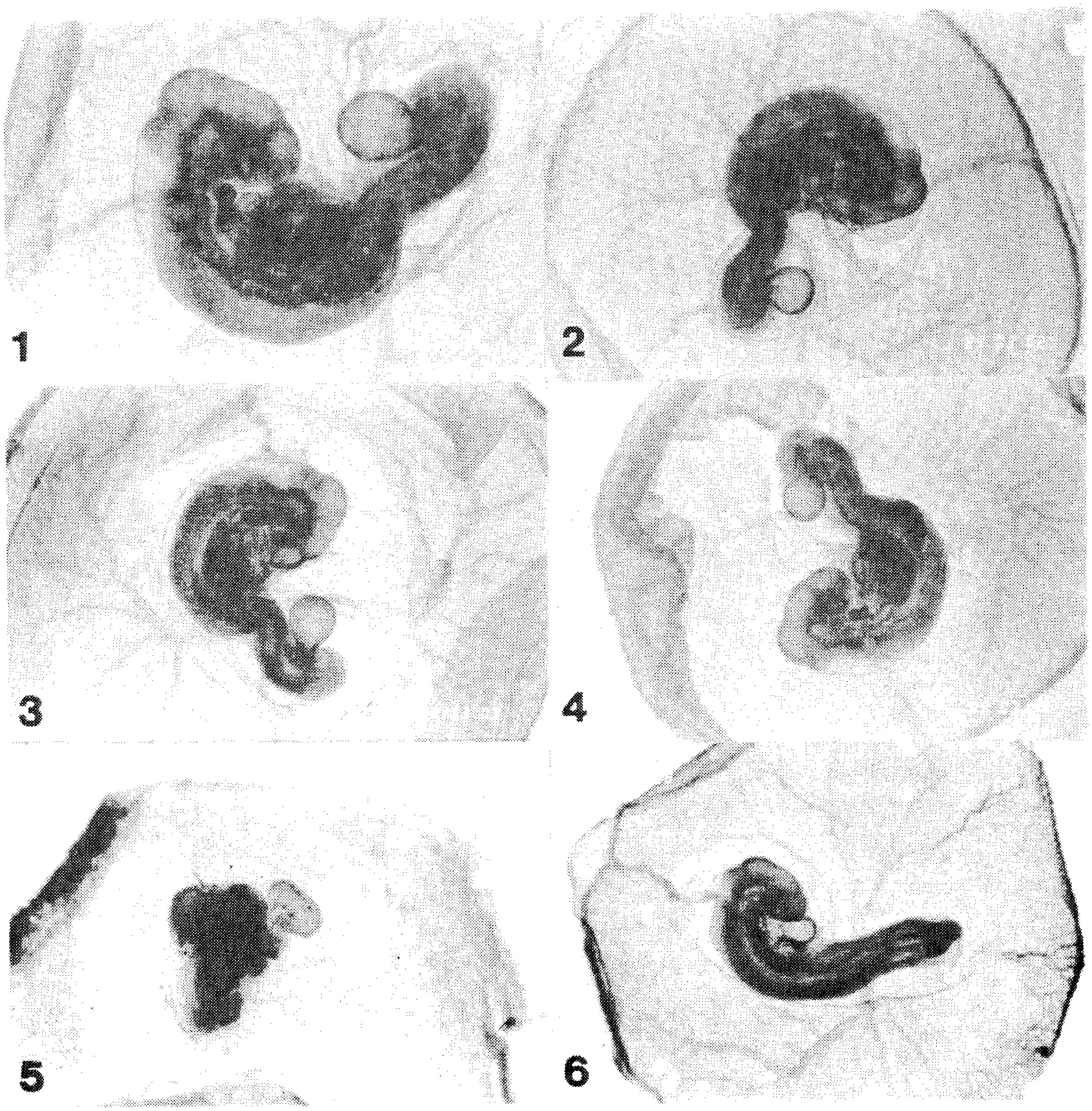
Abnormal Development. Embryos were carefully observed for any abnormalities. The status of the following was assessed in each embryo: developmental stage, brain, eye, ear and branchial arches, heart, spinal cord and somites, limb buds, extra-embryonic membranes and flexion and rotation of the embryo.

Our experimental design has differed from other investigations of ELF electromagnetic fields on embryological development (*e.g.*, the Henhouse Project, Berman *et al.* 1990) in that ours is a field study. This has meant that many factors which were controlled in other laboratories were determined in our study by events over which we had no control. For example, the onset of egg laying and the timing of initiation of incubation, the temperature and humidity at which eggs were maintained, even the strength of the electromagnetic fields at the egg surface are factors outside our control. The stage of development reached by embryos, usually expressed either according to the Hamburger-Hamilton series or as the number of muscle somites differentiated, has frequently been used as a measure of the effect of exposure to electromagnetic fields (Juutilainen *et al.* 1986; Martin 1992a). In our study, because of the asynchrony of development within clutches and because of the inability to determine precisely the onset of incubation, this is not a meaningful measure. We have used the developmental stage as part of the determination of normalcy but the stage attained has not formed part of the statistical analysis.

The most frequently occurring abnormalities involved the developing spinal column. Most frequently, the developing nerve cord and associated muscle somites appeared twisted, too curved or dented. In some, the embryo seemed unable to complete rotation. Sometimes, spinal abnormalities were accompanied by other problems such as abnormal, poorly vascularized, extra-embryonic membranes, abnormal hearts, and lack of well-defined muscle somites. In these cases where more than one abnormality occurs, it is not possible to distinguish the primary problem. In 1992, several embryos showed an abnormal brain development, most apparent in the mesencephalic region. This particular deviation was not apparent in our specimens in other years.

A common variation seen at stage 18-19 embryos involved the initiation of allantois development in the wrong direction (Figure 72 - 6). These embryos are not included in the "abnormal" group because, as explained previously (Beaver, Hill and Hill 1991), this aberration was seen only once in later staged embryos and so is probably self-correcting. Consequently it appears more parsimonious to consider it a variation rather than an abnormality.

Our histological investigation of developing tree swallow tissues is nearly completed. It is neither practical nor prudent to section all the embryos. We have attempted to section enough normal embryos at each developmental stage to provide a sound reference bank. Some embryos



*1-4. Embryos (sibs) showing a spinal abnormality. Note the "dented" appearance of the backs. 5. Highly abnormal embryo in which development was chaotic. The vesicle to the right was a malformed, but pulsing, heart. 6. Embryo, considered normal, showing initiation of allantois development in the wrong direction.

Figure 72. Deviations in tree swallow embryological development

which were detected as abnormal were sectioned and compared with the normal collection.

We are aware that some abnormalities may only be apparent at the histological level. Accordingly, as few assumptions as possible have been made concerning the status of any system. In making our observations, we have paid close attention to the areas where other investigators have reported abnormalities in chick embryos exposed to ELF electromagnetic fields (*e.g.* nervous system (Ubeda *et al.* 1992), vestibular ganglia (Leon *et al.* 1992)). No effect of the Communications System has been found.

Decisions concerning the normal or abnormal status of an embryo can be quite subjective. In some instances, it is very clear that an animal is developing abnormally and will not survive (Figure 72 - 5). In other instances, however, it is obvious that the appearance of a structure deviates from that normally seen, but whether the outcome of the deviation would have been death or impairment of the developing bird, a benign variation, or merely a different way of achieving the same end goal cannot be determined with certainty. For example, we have considered the "dented back" embryos shown in Figure 72 (images 1 - 4) to be abnormal because they are obviously quite different than most embryos of the same stage. Whether this leads to a defect of the spine or whether it would self correct as development proceeds is not known. Accordingly, we use "abnormal" to mean that an embryo varies enough from the normal state that it is readily recognizable and that normal development may be impaired. One of us (S. Hill) has screened all of the embryos a minimum of three times, before and after staining, without being aware of their test/control status. Input has been obtained from other investigators. Our status assignments have been based on these observations.

Data have been analyzed each year using χ^2 contingency tables (summarized in Table 45). No differences in the number of abnormalities were detected between test and control plots for any single year.

Table 45. Summary of numbers of normal and abnormal embryos collected between 1986 and 1993. Three levels of operation of the Communications System are included: preoperation, level one, and full operation

Operation	Year	Treatment	Normal	Abnormal	% Abnormal	
Full	1993	Test	7	61	10.3	$\chi^2=1.720$
		Control	13	59	18.1	P=0.190
	1992	Test	16	57	21.9	$\chi^2=0.004$
		Control	15	52	22.4	P=0.947
	1991	Test	8	56	12.5	$\chi^2= 0.273$
		Control	12	65	15.6	P=0.601
	1990	Test	10	57	14.9	$\chi^2=0.158$
		Control	10	69	12.7	P=0.691
	1989	Test	9	70	11.4	$\chi^2=0.081$
		Control	8	72	10.0	P=0.776
Level 1	1988	Test	6	99	5.7	$\chi^2=0.047$
		Control	5	72	6.5	P=0.827
Preoperation	1987	Test	7	88	7.4	$\chi^2=0.567$
		Control	3	64	4.5	P=0.451
	1986	Test	3	41	6.8	$\chi^2=0.579$
		Control	6	47	11.3	P=0.447

χ^2 values and probabilities are those obtained for each year when numbers of normal and abnormal embryos from test and control plots are compared.

To determine if the years were homogeneous and if years within operational status, were homogeneous, the data were examined using the technique of heterogeneity χ^2 (Zar 1984). For all years, we obtained a heterogeneity χ^2 of 2.804 (df = 7, $P > 0.9$). When homogeneity of years within operational status was tested, a heterogeneity χ^2 of 0.926 (df = 1, $P > 0.1$) was obtained for preoperation and 2.022 (df = 4, $P > 0.5$) for full operation. Level one operation was not tested because only one year of data was collected.

Because years, and years within operational status were homogeneous, data for years within operation were pooled (Table 46). We then tested to see if operational status, treatment plot and likelihood of abnormalities were mutually independent. A test of the mutual independence of operational status, treatment plot and likelihood of abnormalities ($\chi^2 = 24.05$, df = 7, P = 0.001) led to a rejection of this hypothesis and to the conclusion that some combination of factors is influencing the likelihood of abnormalities.

Three tests of partial independence were performed.

1) Operation is independent of treatment and abnormalities ($\chi^2 = 23.03$, df = 6, $P = 0.001$).

2) Treatment is independent of abnormalities and operation ($\chi^2 = 6.31$, df = 5, $P = 0.277$).

3) Abnormalities are independent of operation and treatment ($\chi^2 = 17.61$, df = 5, $P = 0.003$).

Table 46. Normal and abnormal embryos from test and control plots grouped by operational status of Communications System

Operation	Treatment	Abnormal	Normal	% Abnormal	
Full	Test	50	301	15.5	χ^2=0.214
	Control	58	317	18.1	P=0.644
Level 1	Test	6	99	5.7	χ^2=0.047
	Control	5	72	6.5	P=0.827
Preoperation	Test	10	129	7.2	χ^2=0.009
	Control	9	111	7.5	P=0.925

χ^2 values and probabilities are those obtained when numbers of normal and abnormal embryos are compared for test and control plots within each operational level.

Table 47. Total numbers of normal and abnormal embryos collected during each operational level of the Communications System

Operation	Abnormal	Normal	% Abnormal
Full	108	618	14.9
Level 1	11	171	6.0
Preoperation	19	240	7.3

$\chi^2 = 17.321$ df = 2 $P < 0.001$ χ^2 value and probability is that obtained when embryos from test and control plots are pooled and numbers of normal and abnormal embryos at different operational levels are compared.

Since the second hypothesis is not rejected, we conclude that treatment is independent of the incidence of abnormalities and operational status. This, then, allows us to test whether abnormalities are independent of operational status (Table 47). Since $\chi^2 = 17.321$ (df = 2, P <

0.001), we conclude that the incidence of abnormalities differs among operational levels. The differences are apparent, however, in both test and control plots. There is a tendency for the frequency of abnormalities to increase after the antenna system reached full operation (Table 45); however, this tendency is apparent in embryos from both test and control plots. In two of the five years of full operation, the incidence of abnormalities was higher in test plots than in control plots. In the other three years of full operation, the incidence was higher in control plots. This is not the pattern expected if level of operation were having an effect on the frequency of abnormalities. Consequently, we conclude that the differences result from differences in years and factors inherent in the plots rather than the operational status of the Communications System.

Size of Eggs. Since avian embryos develop in a closed system (the egg), the resources allocated to each offspring by the parent during oogenesis could have a marked influence on the success of the embryo. If females forage less effectively in some situations than in others, eggs may be of lower nutrient value and chick survival may be compromised. To determine whether ELF electromagnetic fields affect the amount of nutrient deposited in eggs, each egg we collected was measured in three ways. First, each egg was weighed. Second, since 1990, volume was obtained using water displacement. Third, length and breadth of each egg were determined using vernier calipers.

The D'Agostino *et al.* (1990) test indicated that data for all years on weight and volume were normally distributed. Outliers detected by SYSTAT box plots and by stem leaf plots were removed from the data set prior to analysis.

Weights of eggs from test and control plots have been compared for three years before the antenna was operational, one year at low level operation, and five years of full operation using nested analysis of variance to assess effects due to OPERATION, PLOT (test vs. control treatment), YEAR (nested within operation), and OPERATION*PLOT INTERACTION. Basic statistics and analysis of variance results are shown in Figure 73 and Table 48. As noted previously (Beaver, Hill

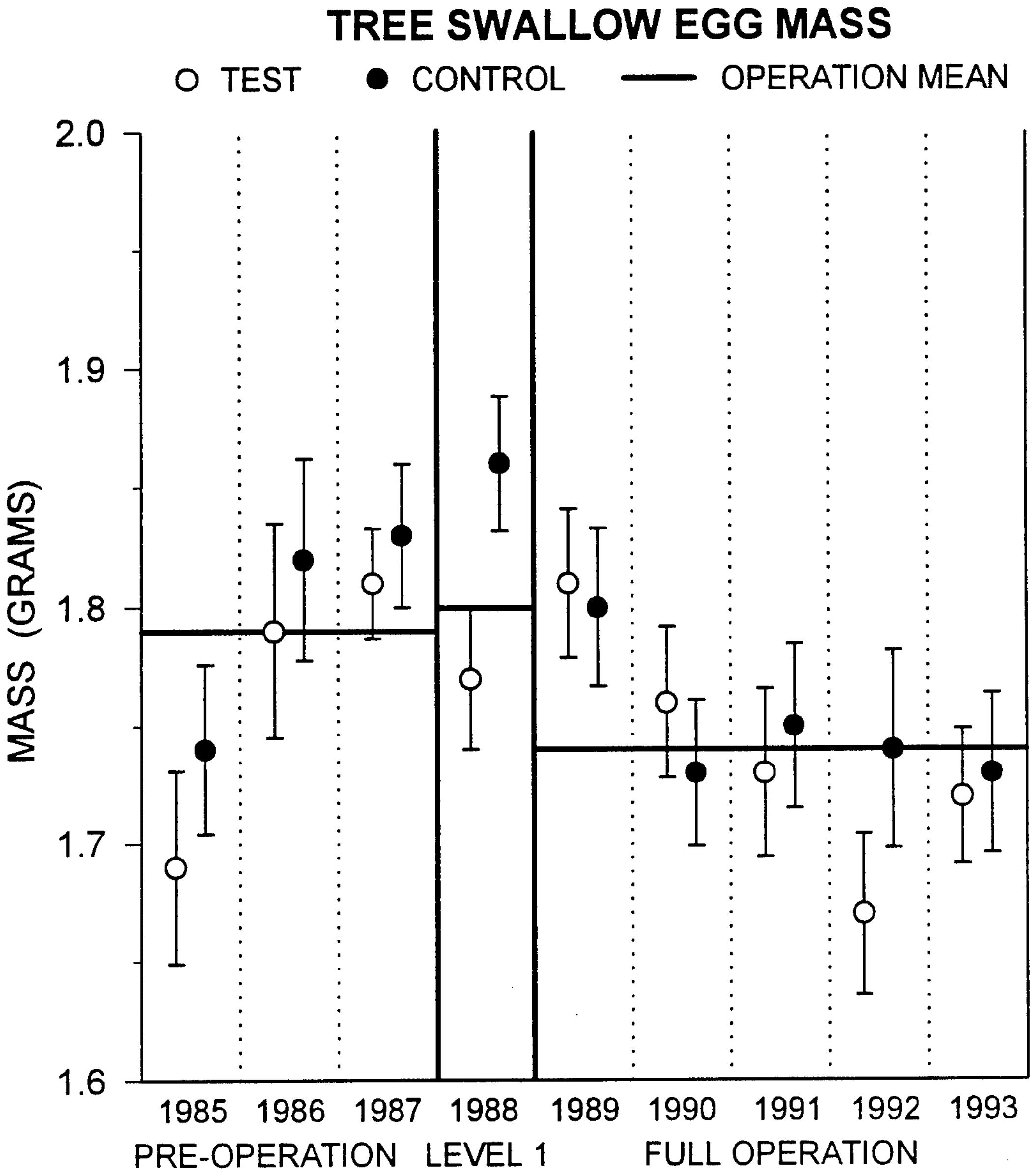


Figure 73. Mean tree swallow egg mass (grams ±95% confidence interval) observed on test and control sites for 1985 through 1993

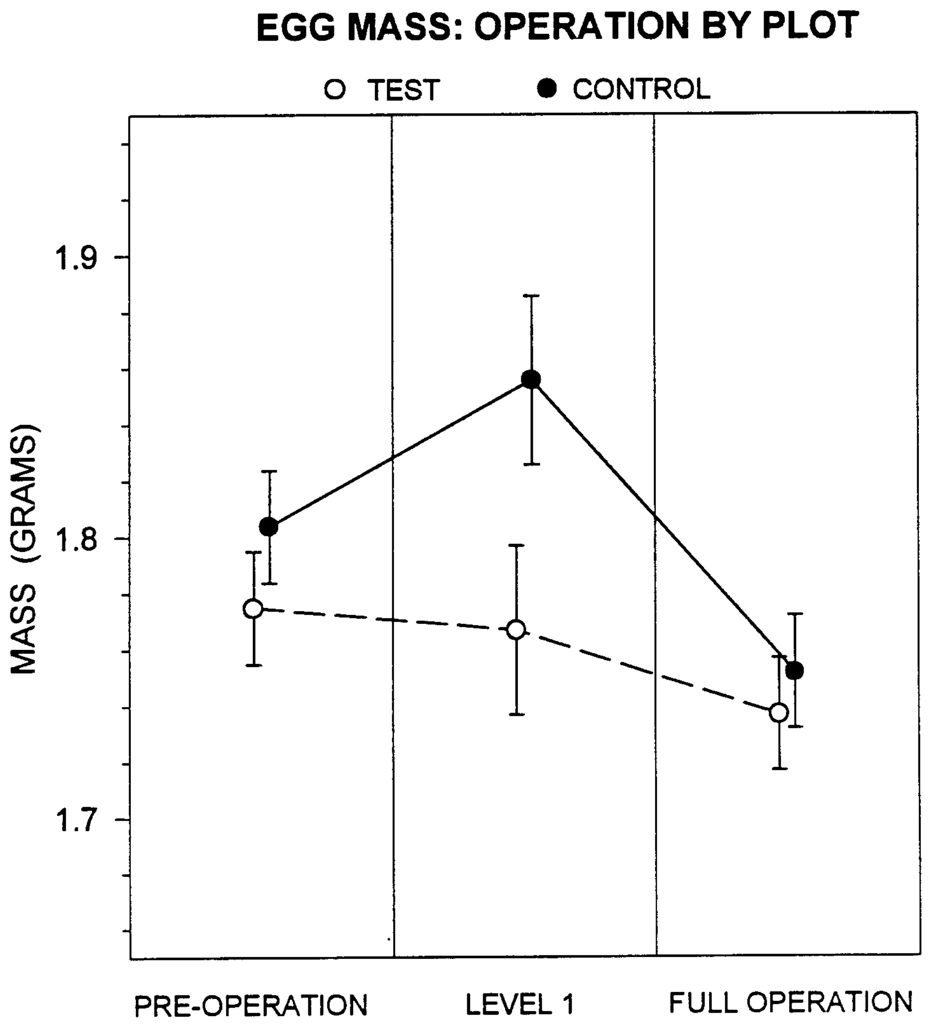


Figure 74. Mean egg mass (grams ±95% confidence interval) for tree swallows showing operation and plot interaction effect

Table 48. ANOVA of egg weight by plot, year, operation and nest of origin, 1985 to 1993

Source	SS	DF	Mean-Square	F-ratio	P
OPERATION	0.779	2	0.390	1.514	0.294
PLOT	0.440	1	0.440	20.917	< 0.001
YEAR(OPER)	1.544	6	0.257	12.227	< 0.001
OPER*PLOT	0.191	2	0.095	4.536	0.011
ERROR	27.836	1323	0.021		

and Hill 1991), year effects and plot effects are apparent in the data. Eggs were quite routinely larger on control plots than test plots in all years ($F = 20.917$, $P < 0.001$), independent of the operational status of the antenna. The year within operation effect was due to a series of years with higher mean egg mass beginning in 1986 and continuing through 1989. We see no significant effect due to operation ($F = 1.514$, $P = 0.294$). We interpret these effects as related to year (probably weather) factors and differences of unknown origin between plots. Since the effects were not coincident with the levels of operation of the Communications System, we do not interpret them as an effect of the antenna.

The significant interaction of operation period and plot ($F = 4.536$, $P < 0.01$) indicates the possible effect of the Communications System on egg mass. However, the means show a pattern of divergence only during the single year of level 1 operation. In this year, the control mean was higher than the test mean. The means were similar in the preoperation and fully operational periods (Figure 74). There is a trend for means on both test and control plots to decline from preoperation levels to full operation, but the means on the test plots are basically constant over all levels of operation (Figure 74). Small differences are apparent between test and control plot means during the preoperational period. The difference increased during the one year of level 1 operation, when the means were significantly different. At full operation, differences between means are similar to those seen during preoperation. During the five years of full operation, egg mass means were slightly higher on test plots for two years and on control plots for three years. For only one of the years, 1992, was the difference significant. This pattern is not that to be expected if the increased electromagnetic fields during full operation of the Communications System were postulated to have the greatest effect on egg mass. The convergence of the control mean to the level of the test plot is also not an expected result, nor is the nearly stable level of the means on the test plot through all periods of operation. The conclusion must be that the interaction effect, while significant, does not indicate a convincing, effect of the Communications System on tree swallow egg mass, but is likely a reflection of the plot differences apparent from the outset.

Because the mass of eggs is affected by both evaporative water loss and metabolic water production during development, we have considered it prudent to measure volume to obtain an independent measure of egg size. Prior to the development of an effective measuring device to determine volume in 1989, the length and breadth of eggs were determined. Since 1990, volume measurements have been obtained in addition to length and breadth (Figure 75). Measurement of egg volume is based on water displacement and, because it involves reading a meniscus, is the most subjective of our three egg measurements. For this reason, all volume measurements have been performed by the same investigator. The technique was refined to provide greater accuracy in 1991.

A comparison of measured egg volumes by analysis of variance for the two years measures were made indicates that there is no difference between test and control plots (F = 0.64; df = 1, 151 (1992), F = 0.56; df = 1, 177 (1993)).

To allow us to determine egg volume for all years, we have used volume measurements to calculate a constant, K, which relates length and breadth to egg volume according to the formula $V_{egg} = K_v B^2 L$ (Hoyt, 1979). K values were determined for eggs from alternating clutches of eggs collected in 1991 (n = 70) and 1992 (n= 80) and for all eggs collected in 1993 (n = 178). Means were calculated for K values for the three years (1991: mean = 0.4943, S.D. = 0.0129; 1992:

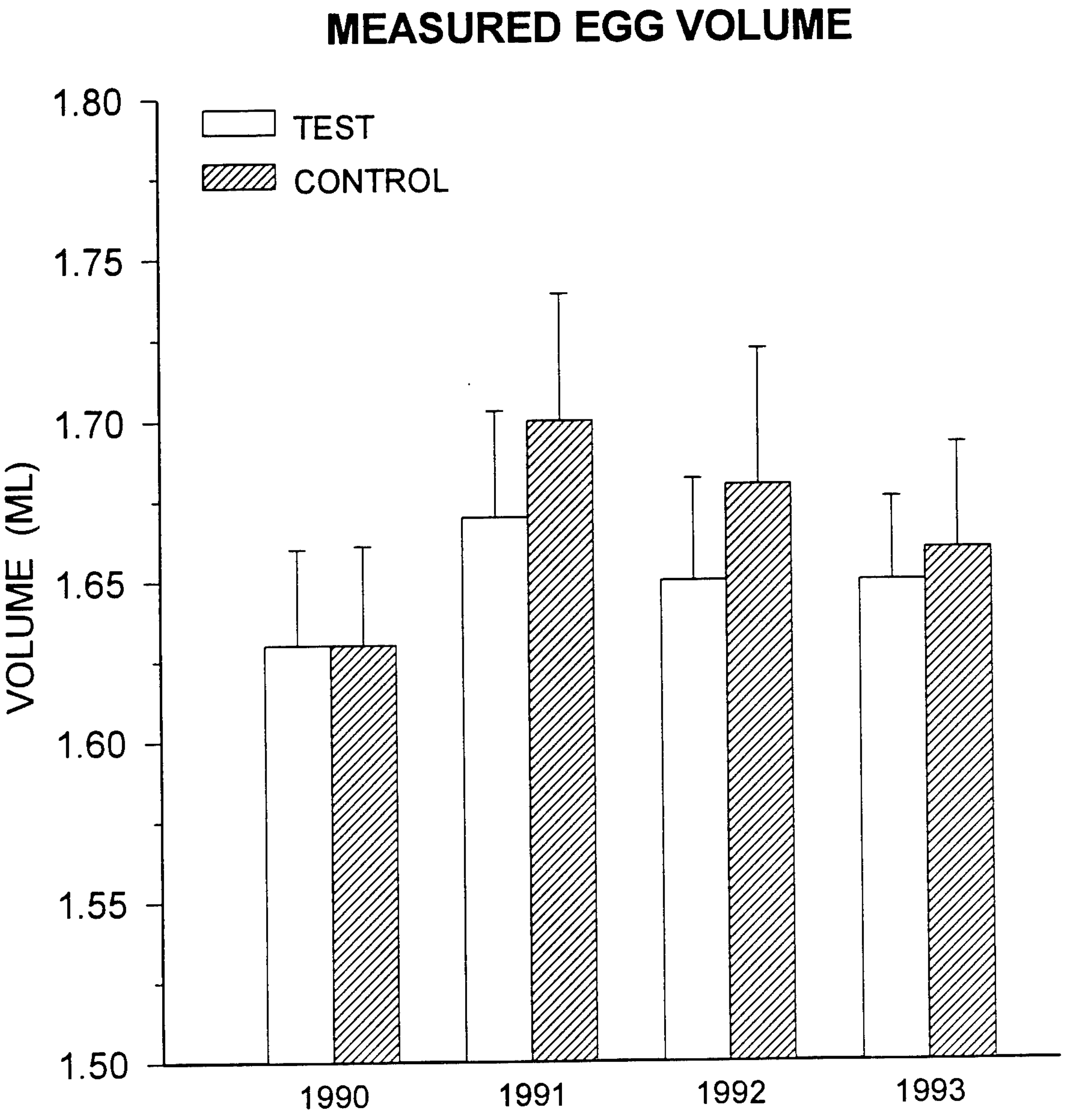


Figure 75. Tree swallow measured egg volumes (mean ml ± 95% confidence interval) observed on test and control sites for 1990 through 1993

mean = 0.4972, S.D. = 0.0126; 1993: mean = 0.4960, S.D. = 0.0131). These calculations support a value of 0.495 for K.

The predictive value of K was tested by calculating the value of the remaining half of the eggs collected in 1991 and 1992 using measured lengths and breadths in the formula $V_{egg} = 0.495 B^2L$. A comparison of the volumes of these eggs obtained by direct measurement and by calculation using length and breadth measurements (an independent sample since they were not used in the determination of K) by a paired Student's t-test showed no difference in volumes obtained by the two methods (Table 49). The determination of K involved 328 eggs; the test of its predictive value involved two independent samples of 68 and 73 eggs.

Based on these results, we have used K = 0.495 to calculate egg volumes from 1985 - 1993. Calculated volume means are shown in Figure 76. Calculated egg volumes from test and control plots have been compared by analysis of variance for all years (Table 50). As with egg weight, plot and year effects are apparent in the data. No effect of operation was seen, however. Means were usually higher on control plots than on test plots, regardless of the operational status of the Communications System.

Table 49. Results of Student's paired t-tests on measured and calculated egg volumes

Year	t	Degrees of Freedom	Standard Deviation	$\bar{D}$
1991	0.30	67	0.04	0.00162
1992	0.28	72	0.05	0.00164

$\bar{D}$ = mean difference between paired observations

The significant interaction of operation and plot for egg volumes indicates the possible effect of the Communications System. Comparison of the means for operation and plot (Figure 77) indicates a pattern that is similar to that for egg mass discussed earlier. For egg volume, the test-plot mean declined during level 1 operation, so that the means were significantly different in that

Table 50. Analysis of variance of calculated egg volumes by OPERATION, PLOT and YEAR for 1985 through 1993

Source	SS	DF	Mean-Square	F-ratio	P
OPERATION	0.2344	2	0.1172	0.726	0.522
PLOT	0.5014	1	0.5014	27.4862	<0.0001
YEAR(OPER)	0.9682	6	0.1614	8.8459	<0.0001
OPER*PLOT	0.2826	2	0.1413	7.7462	0.0005
ERROR	24.8269	1361	0.0182		

year, and then increased during full operation. The mean for the control plot increased slightly during level 1 operation, contributing to the divergence of the test-plot mean, and then converged to the test-plot mean in full operation. As with egg mass, volume means were slightly higher on test plots for two years and on control plots for three years while the Communications System was at full operation. Again, this pattern is not what one would expect to see if egg volume were responding to increasing levels of electromagnetic fields in level 1 and full operation periods. We therefore conclude that the result does not convincingly support an effect of the Communications System.

As we have indicated earlier, egg masses are affected by both evaporative and metabolic water dynamics. Consequently, we have considered the possibility that some variation in egg mass might result from the amount of time that adults spend on the nest, relative humidity and treatment conditions by investigators prior to weighing. A comparison of Figure 73 and Figure 76 indicates that such effects are minimal since graphs of mean volumes and masses from 1985 - 1993 parallel each other very closely.

Statistical Sufficiency of Egg Mass. The actual detectable differences in egg mass were about 2% for either an operation or plot effect (Figure 78). The power of the test at these differences was less than 30% for operation, but about 99% for plot. With power set at 70%,

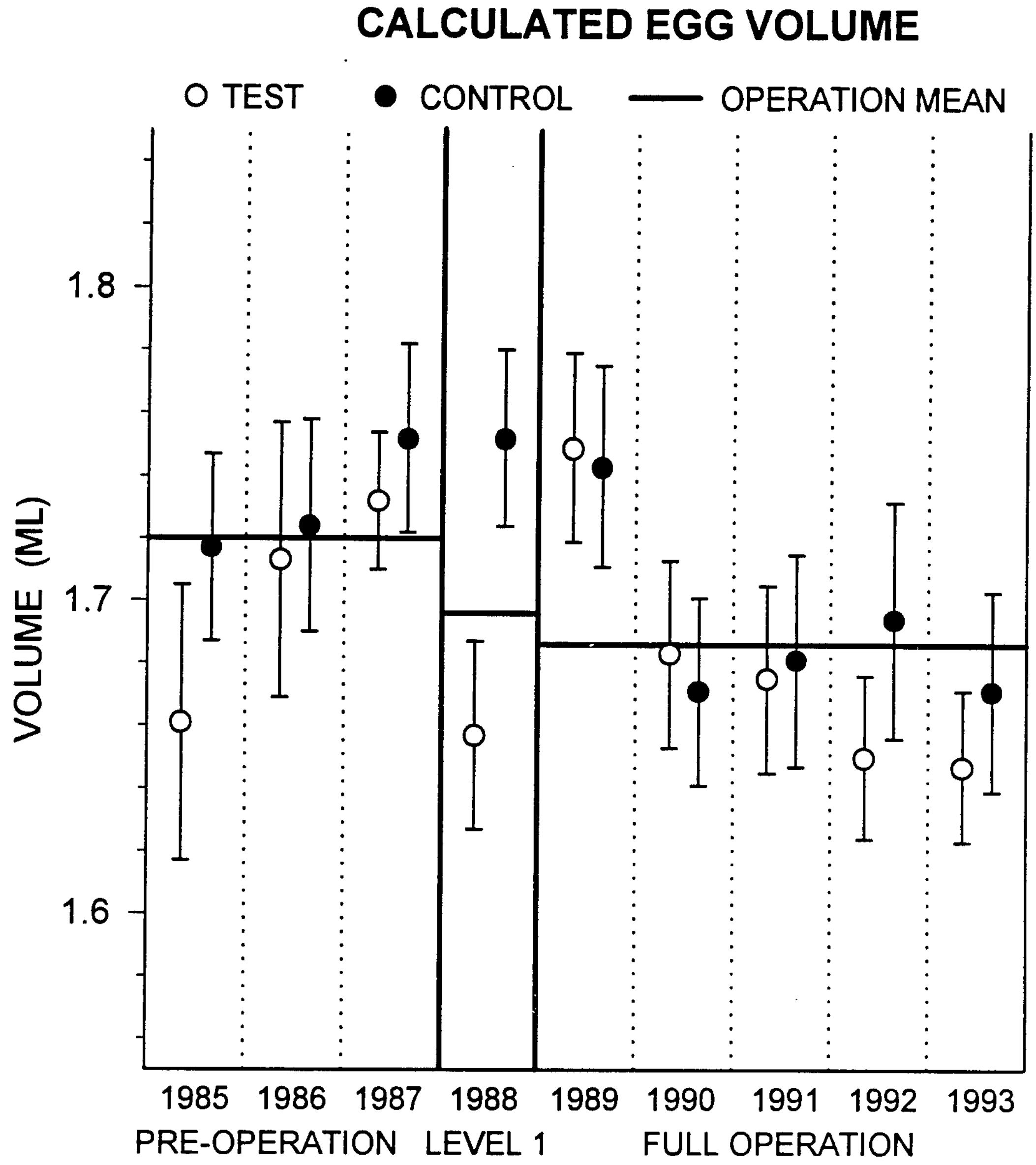


Figure 76. Mean calculated volumes (ml ±95% confidence interval) for tree swallow eggs for 1985 through 1993

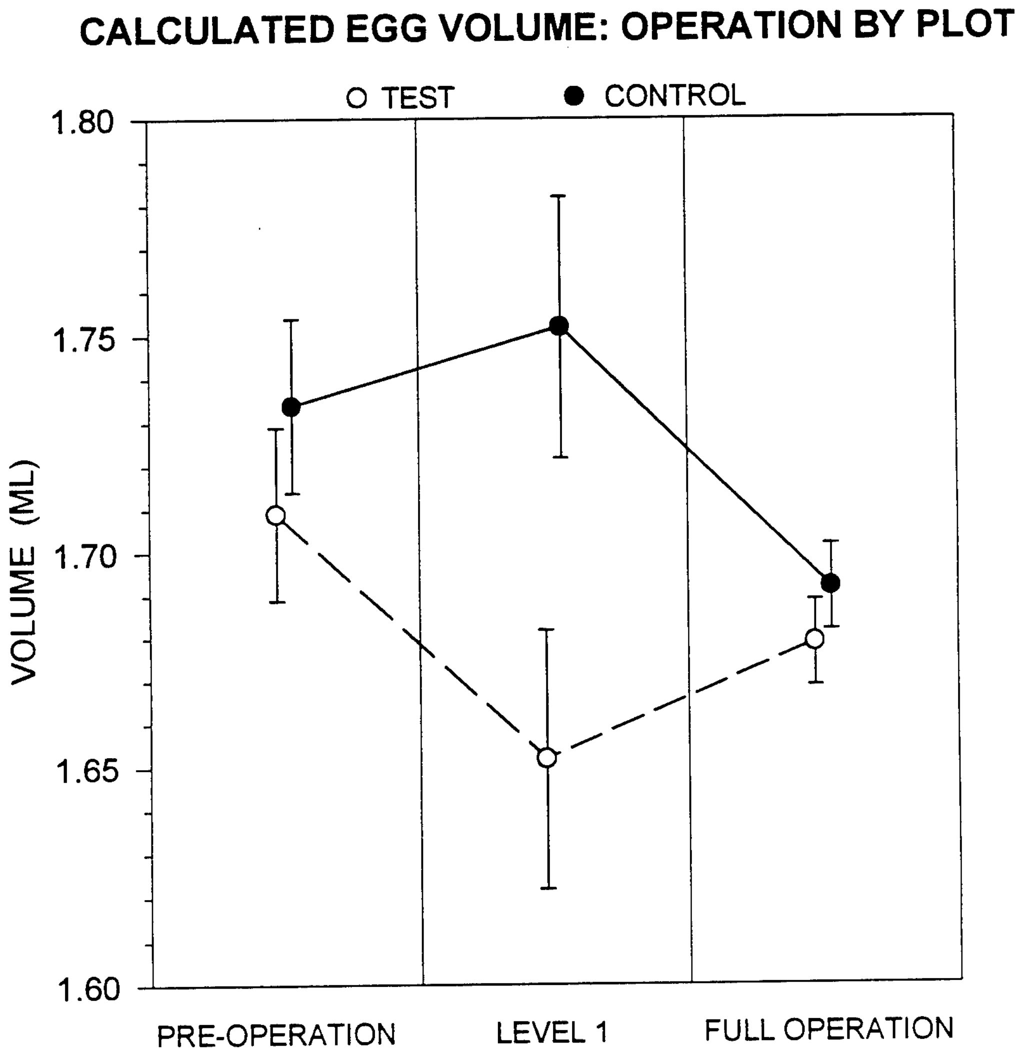


Figure 77. Mean calculated egg volume (ml ±95% confidence interval) for tree swallow eggs showing operation and plot interaction

detectable differences increase for operation effects to about 5.3%, and decrease to about 1.2% for plot effect. Thus, with our current sample sizes, we could have detected very small changes in egg mass for an operation effect, had one occurred. We were able to detect very small differences in plot means with our current data, but as noted above, these differences were not attributable to operation of the Communications System.

Comparisons With Other Species. The development of the domestic chick is the standard against which most other avian species are measured. Early tree swallow development is very similar to that of the chick although some differences are seen. In 1992, about 100 chick embryos were collected to facilitate the comparison. Differences between the two species include the constriction of the eye stalk during eye formation, the size of the cerebral hemispheres, the shape of the developing head, the timing of pigmentation of the retina, the relative size of wing buds compared to leg buds, and later, the development of feather tracts.

Adverse effects of ELF electromagnetic fields on development, specifically that of chick eggs exposed experimentally to ELF fields in incubators, have been reported (Juutilainen *et al.* 1987; Leon *et al.* 1992; Litovitz *et al.* 1992, 1994; Martin 1988, 1992a; Ubeda *et al.* 1992). Simultaneously, failures to detect significant effects continue to accumulate (Maffeo *et al.* 1988, Martin 1992b, Siskin 1986). Differences between laboratories have emerged despite extensive attempts to maintain uniform experimental conditions (Berman *et al.* 1990).

We have suggested that it is possible that chicks and tree swallows have different susceptibilities to ELF fields; however, it seems more likely that the observed differences result from our different experimental designs (Hill, S.D. *et al.* 1993). Field strengths and wave forms in the egg/embryo microhabitat probably differ. Because ours is a field study, we are not able to collect these measurements at the egg surface. Moreover, since our experiments are conducted in the field, tree swallow embryos may be partially shielded, at least from electrical fields, by the body of the incubating parent.

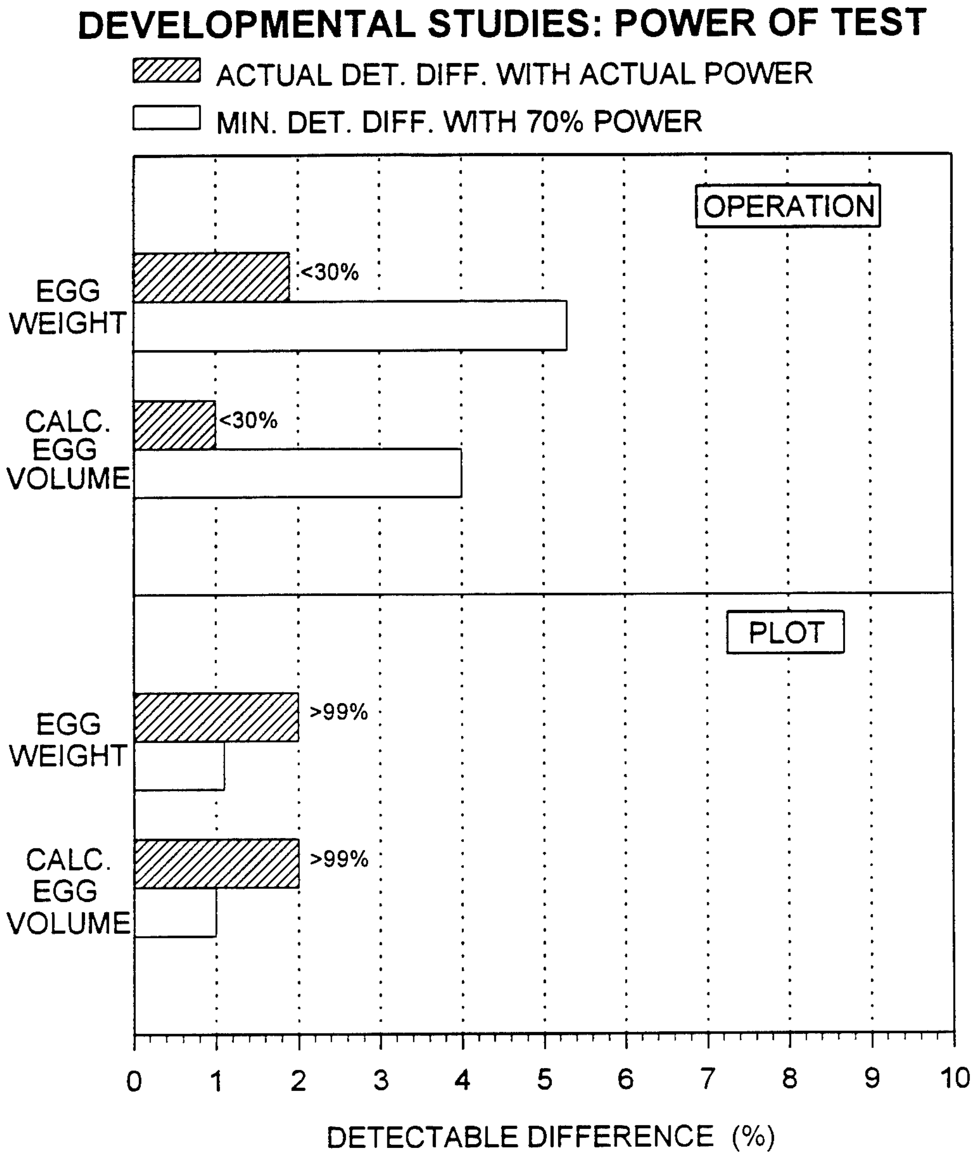


Figure 78. Minimum detectable differences and power for tests of egg mass and volume for operation and plot effects

We have found no differences in the level of abnormalities found in embryos or in the weights or volumes of eggs collected from test or control plots. The results of the effects of ELF electromagnetic fields on the embryological development of free-living tree swallows were presented at the First International Congress for Electricity and Magnetism held in June, 1992, at Lake Buena Vista,Florida. This paper has since been published (Hill, Beaver, Lederle and Herman, 1993).

STUDIES OF MAXIMUM AEROBIC METABOLISM

I. Purpose

The purpose of these studies was to measure the peak aerobic metabolic rates of animals during winter at test and control sites and to test for possible effects of the ELF Communications System on peak metabolism. The principal species studied were chickadees and deer mice.

II. Methods

Collection and Care of Birds. To attract chickadees for study, feeding stations were established in December about 50 m from the antenna or sham corridor and kept stocked throughout the winter with sunflower seeds. Chickadees were mist netted as needed from these stations during January, February, and March. Upon capture, birds were weighed to the nearest 0.1 g using a Pesola spring scale and marked with a colored plastic leg band for individual identification. When released from captivity, they were banded using a standard U.S. Fish and Wildlife Service band for permanent marking. Birds were housed singly in wire mesh cages (30 x 20 x 25 cm, except for a few that were housed in sets of 2-3 per cage in 1985-1986). Shelled sunflower seeds and snow or water were available ad libitum. In addition, each morning and late afternoon, waxworms were provided in excess. Each cage was provided with a wooden nest box (9 x 9 x 9 cm) supplied with wood shavings. The cages were kept in a screened outdoor holding facility, which provided natural lighting and temperature conditions.

Collection and Care of Mammals. Trap shelters were established in late November, prior to any substantial snowfall. The shelters were located along wandering lines situated approximately 25-150 m from the antenna or sham corridor. The habitat was northern hardwoods dominated by maple, basswood, and elm, typical of the area. Each shelter was a plastic waste container placed upside-down on top of the ground layer, with a covered top opening which provided the researcher access to the ground layer once snow was present. Mice entered the shelters through the interface between the ground layer and the wall of the shelter. One Leathers live trap was placed in the bottom of each shelter and baited with rolled oats, peanut butter, and sunflower seeds. Polyester batting was provided in the trap for nesting material. Traps were pre-baited and left open one month prior to actual trapping to insure that small mammals would include the stations in their subnivean runways. Researcher travel on the sites was by snowshoe along a consistent trail to minimize disturbance of the subnivean air spaces which are critical to small mammal movements.

Trapping was begun at the start of January and continued intermittently, according to need for animals, through March. Upon capture, individuals were toe-clipped for identification, sexed and weighed to the nearest 0.1 g with a Pesola spring scale. Once at the lab, animals were housed singly in standard plastic lab cages (28 x 18 x 12 cm) with wire lids and provided with wood shavings, polyester batting, and a diet of sunflower seeds, lab chow, and apple and snow for moisture. Cages were housed in an open outdoor facility which provided natural lighting and temperature conditions.

Laboratory Methods. To elicit a peak rate of oxygen consumption, we used a refined version of the helium-oxygen (helox) method first introduced to the study of small-animal physiology by Rosenmann and Morrison (1974). Placing an animal in a helium-oxygen atmosphere at a given ambient temperature greatly increases the individual's rate of heat loss by comparison to the rate in air (mostly nitrogen-oxygen), due to the relatively much higher thermal conductivity of helox. Thus, the animal must produce heat more rapidly in helox than air if it is to maintain a stable body temperature.

Whether the rate of oxygen consumption measured in helox is in fact a true peak metabolic rate depends partly upon the ambient temperature. Identifying the true peak for an individual therefore entails studying the animal at a series of ambient temperatures. Specifically, study at a minimum of three ambient temperatures is required for a definitive determination: there should be a measurement at the temperature that elicits the peak, and also there should be measurements at temperatures higher and lower, demonstrating that the rate of oxygen consumption in helox falls off if the temperature is either raised or lowered from that eliciting the peak. Of course, the temperatures of interest are unknown at the onset of work on an individual. Thus, in principle, many measurements would have to be made on an individual before its peak would be definitively identified. In practice, experience often permitted us to know in advance the temperature at which the peak would occur. Therefore, we often needed to test an animal at just three temperatures to establish its peak definitively. The spacing we used between temperatures was 5°C. Thus, if we tested an animal in helox at three ambient temperatures that were 5°C apart (*e.g.*, -10, -5, and 0°C) and if the highest measured rate of oxygen consumption occurred at the middle temperature, we concluded that we identified the animal's peak rate definitively.

Tests were not carried out on the day of capture to reduce any effect of capture stress. To further avoid adverse effects of stress, animals were tested only once on any given day.

Prior to a test an animal was weighed to the nearest 0.1 g on an Ohaus triple-beam balance, and its body temperature (T_b) was measured by inserting a copper-constantan thermocouple probe 2-3 cm colonically. Then the animal was placed into a metabolic chamber. Chambers were constructed from new one-half gallon paint cans, with inflow and outflow ports in the lid. The inside surfaces were painted with 3M ECP-2200, for an emissivity of nearly 1.0. A 0.5-inch-mesh hardware cloth floor covered with Dip-It plastic coating was used to elevate the animal above the bottom of the can, thus helping to insure proper airflow around the animal and permitting urine and feces to drop away so as not to wet the animal. The outflow port of each chamber housed a 36-gauge copper-constantan thermocouple to monitor chamber temperature, which was maintained by immersion of the can in a Forma Scientific 2325 water bath using ethanol as antifreeze. All temperature probes were connected to a Leeds and Northrup 250 Series Multipoint recorder which could be read to the nearest 0.1°C.

Measurements were carried out during daylight hours. Food was provided during measurements. Specifically, apple was provided for the mammals, and shelled sunflower seeds and a waxworm were provided for the chickadees. The metabolism chambers for the birds were equipped with a small light that provided dim illumination; without this light, the chickadees (which are diurnal feeders) would not eat. Our decision to provide food during tests was based on extensive preliminary experimentation and was predicated on the following considerations: (1) Animals in nature are able to feed during the day; the birds are diurnal foragers, and the mammals can feed from caches. (2) In the mice, the variance in results is lower when food is provided than when it is denied. (3) In the birds, there is evidence that fasting during these types of experiments increases the probability of death.

Oxygen consumption was measured using an open-flow system. Briefly, gas (air or helox) was pumped through the metabolic chamber at a measured flow rate, and the reduction in its oxygen content was measured. From these data, the rate of oxygen use of the animal was calculated. The oxygen content of gases was measured with an Applied Electrochemistry S3A oxygen analyzer and recorded on a Houston Superscribe potentiometric recorder. Gas flow rates were measured with Brooks 1110 rotameters. The rate of oxygen consumption was calculated according to the formulas in Hill (1972a, method B), taking cognizance of the mathematical relationship between gas composition and the output of the S3A analyzer. We empirically verified that the S3A analyzer measured oxygen levels in helox with the same accuracy as in air.

Animals were provided with air during an initial adjustment period (0.7-1.5 hr) and then switched to helox. Flow rates were 600 ml/min in air and 900 ml/min in helox. The adjustment period in air was terminated once the metabolic rate remained approximately stable for 15 to 20 minutes. Upon switching to helox, a rapid transition to the new gas was made by purging the metabolic chamber at a rate of 5 liters/min for two minutes. Then the rate of flow was reduced to the 900 ml/min already mentioned. The maximal rate of oxygen consumption under the test conditions was generally achieved within 15-20 minutes after the switch to helox, and animals were rarely exposed to helox for more than 25 minutes. Following the measurement in helox, an animal was quickly removed from the metabolic chamber, and a final T_b and weight were recorded.

All thermocouples were calibrated against thermometers whose calibration is traceable to the National Bureau of Standards. Flowmeters have been calibrated against a Brooks Volumeter also having a NBS-traceable calibration.

Adjustments for 60-Hz Fields. After work on this research element had started, IITRI engineers expressed increasing concern about 60-Hz fields prevailing at our field laboratory. During the first years of the project, captured mice and birds that were undergoing study were maintained outdoors in the backyard of our rented house at 801 Crystal Avenue, Crystal Falls; this was an in-town location positioned within the electric power grid typical of a small town. Metabolic measures were carried out inside the house, using electrical equipment that itself generated 60-Hz fields. Animals captured on test and control plots were housed side-by-side and studied using a single set of equipment. Thus, there was no direct confounding of the experiments by 60-Hz fields at the laboratory; whatever the fields were, they were experienced identically by the test and control animals. IITRI engineers were concerned, however, that in theory there might be indirect confounding effects. The concern was that high 60-Hz fields in and around the laboratory might differentially affect animals that had previously been exposed to different antenna-generated, 76-Hz fields. We hasten to add that no evidence exists for such interactive effects. However, it was deemed prudent, as the concern became better articulated, to protect all animals from exposure to high 60-Hz fields in and around the laboratory. Accordingly, an outdoor holding facility was constructed out of town at the Panola Plains control plot, and starting with the 1988 field season, all captured animals undergoing study were held in that facility between measures in the laboratory. Starting with the 1990 field season, shielding and other adjustments were made in the laboratory to reduce 60-Hz exposures during metabolic measurements (see Tables 5 and 6).

III. Results

Field Strengths. Figure 79 summarizes operational parameters for the Communications System antenna during the seven years in which metabolic data were gathered on animals from both the 1T1 test plot (Pirlot) and 1C1 control plot (Michigamme). Note that the metabolic studies were carried out in winter: a different time of year from all other work elements in this research. This explains why operational parameters given for particular years in this section of the research sometimes differ from those given for the same years in other sections.

The Communications System antenna was not operational during January-March of 1985, 1986, and 1987. Those were thus the **preoperational** years for this work element. During the winter of 1986 and earlier, the antenna had never been activated. A 4 A current was passed through the north-south antenna for 2% of the time during July-October of 1986, but then the antenna was not activated again until April of 1987. Whereas some of the animals captured on test plots during the winter of 1987 thus may have been exposed to very low antenna-generated electromagnetic fields during 1986, they were exposed to no antenna fields for 2 months prior to the 1987 winter field season and none during the field season itself.

A 15 A current was passed through the north-south antenna for 4% of the time during January-March of 1988, and a 75 A current was present in that antenns for 6% of the time in January-March of 1989. Thus, 1988 and 1989 are considered **partly operational** years. Up to and through the winter of 1989, the highest current passed through the antenna at any time was 75 A,

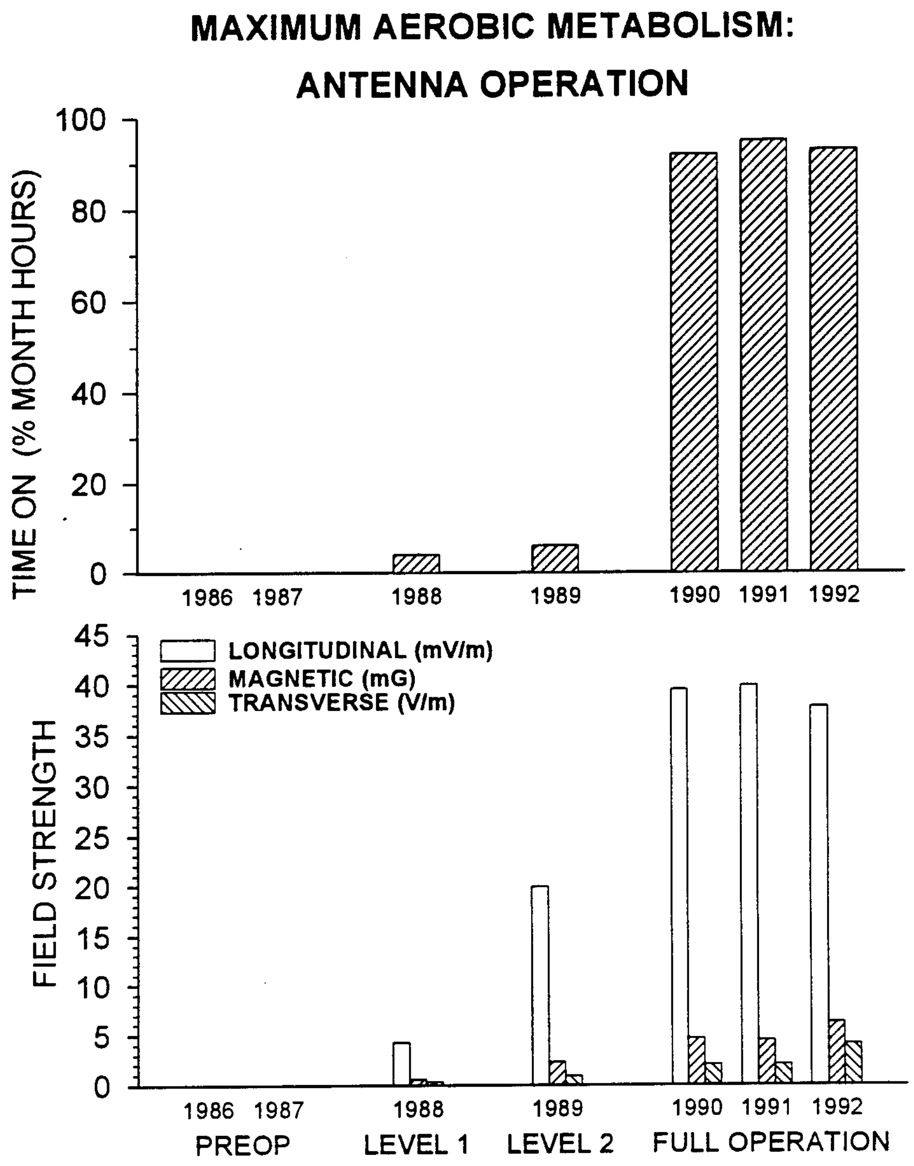


Figure 79. Antenna operational hours (% month-hours) and field strengths for antenna operation during winter metabolic studies. Because field strengths were generally not measured in winter months, the strengths shown are extrapolated. The field strengths for 1988, when winter operation was at 15 A, are extrapolated from periods of 15 A operation in 1987. Those for 1989, when winter operation was at 75 A, are from periods of 75-A operation in 1988. Winter operation was at 150 A (full strength) in 1990-1992, and for each of those years, field strengths are from operation at the identical amperage later in the same year

and the highest percentage of time operational was 7%.

Starting in May of 1989, the antenna current was elevated to 150 Amp, the percentage of time operational was raised to 70% or more, and for the first time the antenna was placed into frequency-modulated (MSK) operation (the percentage of time in MSK mode was initially 26% but rose to 100% by December). Test plots were highly exposed to antenna-generated fields thereafter. During January-March of 1990, 1991, and 1992, the antenna was in operation over 90% of the time. Those winters are classed as **fully operational.**

Years of Data Collection for Each Species. Our effort during the winter of 1985 was targeted at methods development and evaluation of captivity effects (see later). Only some metabolic measures were made using our definitive protocols. For deer mice, all determinations of peak metabolic rates in 1985 were on animals collected on the test plots. For chickadees, determinations were made on animals from test and control plots, but the control plot was not the definitive one (Michigamme) but, instead, Panola Plains. Because there were no control data for deer mice in 1985 and because the control data for chickadees were from a different plot than that used in all subsequent years, the 1985 data (although presented for descriptive purposes) have not been used in statistical analyses of plot effects.

Peak metabolic rates were determined for both deer mice and chickadees collected on consistent test and control plots (1T1 and 1C1) in all winters from 1986 to 1991. In 1992, only deer mice were studied. Chickadees were not investigated in 1992 as part of the phased reduction of research effort.

Captivity Effects. Although our goal in our studies of metabolism was to measure the peak metabolic rates of animals free-living in nature, we in fact had to hold the animals in captivity for a number of days to do our measurements. Between 1985 and 1988, data were gathered to answer the question of whether peak metabolic rates were altered during captivity under the conditions of our experiments. Forty deer mice and 32 chickadees captured during January-March of the four specified years were employed.

Our principal experimental design for these studies was as follows. We determined the peak metabolic rates of the animals as quickly as possible after capture (typically within 5 days) in the usual way (see Methods). Then, we continued to hold the animals in captivity (always in outdoor cages), and we remeasured their metabolic responses in helox during two subsequent target periods: 11-12 days after capture and 18 days after capture. For each animal, the remeasures were carried out at the ambient temperature that elicited the peak metabolic rate in the days immediately following capture. We then compared the remeasures of peak metabolic rate with the initial measure of the peak to see if **long-term** changes occurred. These experiments had the desirable feature that each animal served as its own control.

We evaluated the possibility of captivity-induced **short-term** changes in peak metabolic rate by taking advantage of the fact that, during initial peak determinations, the day after capture on which an animal displayed its peak varied from animal to animal. By chance, the ambient temperature that elicited an animal's peak might be employed on the very first day of study, or it might be employed on day 2, 3, 4, or 5 after capture; this was because we did not know what ambient temperature would elicit the peak for a particular animal and thus had to explore responses to various temperatures from one day to the next. The result was that some individuals of a species displayed their peak metabolic rate on day 1 after capture, whereas others did so on days 2-5. We compared the peaks measured on the various days after capture to determine if the passage of days immediately after capture was associated with a change in peak metabolic rate.

In both the long- and short-term studies, potential confounding effects of changes in body temperature and weight were extensively evaluated and dismissed.

The results of these studies were described in detail in our annual report for 1989 and have been published in the open literature (Hill, Lederle, and Beaver 1993). Suffice it to say here that initial peak metabolic rates measured on various individuals at 1-5 days after capture did not differ significantly as a function of day in either species ($P = 0.51$ for deer mice, $P = 0.67$ for chickadees). In chickadees, remeasures made at 11-12 days and 18 days after capture did not differ from initial peak determinations ($P = 0.20$ at 11-12 days, $P = 0.62$ at 18 days). In deer mice, remeasures made at 18 days did not differ from initial peaks ($P = 0.67$), but the remeasures made at 11-12 days did ($P = 0.02$). In the latter case, the metabolic rates at remeasure averaged 3.4% higher than initial peaks. We deem this effect not to be of great concern because the magnitude is so small as to be within the normal range of variation seen from one minute to the next in a single individual. Overall, our results indicate that the peak metabolic rates of deer mice and chickadees captured in winter did not change during 2.5 weeks of captivity in the outdoor cages we employed. Thus, the time an animal was in captivity was not a confounding factor in our principal experiments comparing peak metabolic rates on the test and control plots during the preoperational, partly operational, and fully operational periods.

Fundamental Statistical Considerations. An animal's peak metabolic rate is partly a function of its body weight. Specifically, based on the extensive literature on metabolism-weight relations (e.g., Marsh and Dawson 1989), whole-body metabolic rate (M) and body weight (W) in a species are expected to be related according to the following allometric equation:

$$M = aW^b$$

where a and b are constants. With this sort of relation, there exists a linear relation between log M and log W.

To compare peak metabolic rates between test and control plots and between antenna-operation periods, we have employed an analysis of covariance design. The logarithm of whole-body peak metabolic rate has been used as the dependent variable, and the logarithm of body weight has been used as the covariate. As noted, metabolic rate and weight are expected to be linearly related in the logarithmic domain. Because analysis of covariance removes linear effects of the covariate on the dependent variable, it is thus appropriate that the analysis be carried out in the logarithmic domain. Removal of effects of body weight on metabolic rate by covariate analysis facilitates detection of other potential effects on metabolic rate (*e.g.*, plot effects).

Normality Testing. To assure that the assumption of normality for our analyses was adequately met, all peak metabolic rates measured in the days immediately following capture during the course of this research — and all associated body masses — were subjected to the procedures recommended by D'Agostino *et al.* (1990).

For each species, the logarithms of whole-body peak metabolic rates were analyzed. The distribution of these values for the deer mice showed neither skewness nor kurtosis ($P > 0.85$). The distribution for the chickadees was not skewed ($P = 0.14$) but was kurtotic ($P = 0.02$). Two outliers were identified and removed from the chickadee data, one the highest value measured in the course of this research, the other, the lowest. Removal of these outliers rendered the distribution normal ($P > 0.10$ for both skewness and kurtosis). All subsequent analyses on the chickadees are for this adjusted data set.

For each species, the logarithms of the body weights of animals during measurement of their peak metabolic rates were also analyzed. The body weight used in each instance was the lower of the weights measured at the start and end of the metabolic determination. The distribution of the logarithms of body weights showed neither skewness nor kurtosis in either deer mice ($P > 0.17$) or chickadees ($P > 0.32$).

Quality Classes. For each animal tested, our goal was to define the peak metabolic rate as accurately as possible. Translated into a practical experimental protocol, the goal — as earlier stated — was to determine the animal's metabolic rate in helox at three successive ambient temperatures, 5°C apart (nominal), such that the rate at the middle temperature was higher than that at either of the other temperatures. The metabolic rate at the middle ambient temperature was then taken to represent the animal's peak metabolic rate.

Many factors could affect the success of implementing this ideal protocol. Sometimes, for example, animals died before the protocol was completed, and sometimes humane considerations dictated that animals already stressed not be stressed further. Sometimes, because of normal biological variation, the pattern of an animal's responses was too complex for simple interpretation.

In the face of these realities, the need arose to evaluate the quality of all estimates of peak metabolic rates. A quality-evaluation system was devised in 1988, using all data available from the 1985-1988 research seasons. The system proved to apply satisfactorily to all subsequent data sets.

Our approach to devising our quality-evaluation system was first to bring together the data sets for all animals that adhered to our ideal experimental protocol. Analyzed collectively, these data sets were used to develop guidelines for the evaluation of other, nonideal data sets. All the nonideal data sets were then examined one-by-one according to the guidelines. Most of the nonideal sets were judged through this process to be likely to provide good estimates of peak metabolic rates for the animals concerned. Peaks were derived from these sets. Other data sets were judged inadequate to yield valid estimates of peak metabolic rates and discarded from further analysis. For all those animals for which a peak was estimated, a quality rating was attached to the peak. The quality rating reflected the way in which the peak was estimated.

An important principle in the quality-evaluation process was to assure that the mere magnitude of a given measure of metabolic rate would not be used as a criterion for whether it represented a peak metabolic rate. The judgement of quality was based entirely on other considerations. One consideration that was given much importance was the pattern of change in metabolic rate; as already noted, if dropping the ambient temperature through two 5°C steps caused an animal's measured metabolic rate to rise and then fall, that peaking of metabolic rate was taken as strong evidence that the animal's peak had been found. Terminal body temperatures were also given much interpretive significance. As animals are driven toward their extremes of metabolic response, the body temperatures they maintain start to decline. Body temperatures decline further when animals' metabolic defenses against hypothermia are overwhelmed. Accordingly, patterns of change in body temperature can be used to help assess whether observed metabolic responses were likely to be near peak responses.

All quality ratings were done in ignorance of the source of the animals. That is, animals from test and control plots were commingled, without identification, during the process to assure identical treatment.

Ten quality rating classes were defined. Classes 1, 2, 3, and 4 represent peak determinations of highest quality. All peak determinations rated in these classes adhered closely to the ideal type of determination already described, and the class numbers merely distinguish data sets that differed in subsidiary details. Classes 0 and 5-9 represent peak determinations rated as acceptable but nonideal.

The quality classes are discussed and defined in detail in a 25-page document titled "Quality Ratings of Data on Peak Metabolic Rate," available on request.

Rates of Success in Obtaining Peak Metabolic Rates. A peak metabolic rate was not determined for every captured animal. As noted in the preceding section, data sets for some animals departed so far from the ideal that they were discarded as being too deficient to yield a valid estimate of the peak rate. Some animals escaped. A few were released prior to the determination of a peak metabolic rate for logistical reasons. In addition, some died. Deaths were particularly common among the chickadees. Some captured animals, especially chickadees, failed to make the transition to living in cages and eating the foods we supplied. During experiments in helox, body temperatures of animals sometimes fell undesirably low because of the cold stress. Deer mice, presumably because of their native proclivity to enter torpor at body temperatures as low as 15°C, nearly always survived experimentally induced hypothermia. Chickadees were less tolerant of hypothermia and more likely to die during a metabolic determination if the procedure accidently drove their body temperature to lower levels than intended. Deaths rates were also much higher in the chickadees than the deer mice during times between successive helox experiments, whether because of captivity alone or residual stresses from preceding experiments.

Of deer mice captured on the test plot between 1986 and 1992, peak metabolic rates were obtained on 88% (71 out of 81). Only 1.2% (one individual) died soon after being placed in captivity, and 1.2% died in the course of determination of the peak metabolic rate. Of mice captured on the control plot, we obtained peak metabolic rates on 86% (69 out of 80); 2.5% (two individuals) died soon after caging, and none died in association with peak determination. Because the percentages of animals successfully assayed from the test and control plots were high and similar, and because death rates were low and did not differ between the two plots, we are confident that comparisons between the test and control plots are unconfounded by biases in sampling or mortality.

Of chickadees captured between 1986 and 1991, peak metabolic rates were obtained on 40% (75 out of 186) of the birds from the test plot and 37% (65 out of 178) from the control plot. Among individuals from the test and control plots, 16% and 20%, respectively, died during the initial transition to captivity; and 34% of each group died at some point during the multi-day process of obtaining peak metabolic rates. The high mortality rates in chickadees provide greater opportunity than for the deer mice for results to be biased by procedural problems. However, because the percentages of captured animals successfully assayed from the test and control plots were similar, and because death rates were similar, we believe that comparisons between the test and control plots for the chickadees, like those for the deer mice, are unconfounded by biases in sampling or mortality.

Analysis of Data on Deer Mice. The first step in the analysis of the peak metabolic rates of deer mice was to address the methodological issue of whether peak determinations placed in secondary-quality classes (ratings 0 and 5-9) were different from those of primary quality (ratings 1-4). To do this, all peak determinations made on deer mice, regardless or year or plot, were pooled

(N = 151) and subjected to an analysis of covariance (in their logarithmic form) with a single factor: primary versus secondary quality rating. Variances were homogeneous (Bartlett's test, $P = 0.24$), and the slopes of the regressions were homogeneous ($P = 0.74$). The difference between the primary-quality and secondary-quality groups of data proved robustly nonsignificant ($P = 0.79$), indicating that the deviations from ideal methodology in obtaining the measures of "secondary quality" were inconsequential. Thus, for the analysis of plot and year effects in deer mice, all peaks were pooled regardless of their quality rating. Incidentally, there were no significant differences among peak metabolic rates in different rating categories <u>within</u> the primary-quality group ($P = 0.18$) or <u>within</u> the secondary-quality group ($P = 0.72$).

Prior to examining contrasts between test and control plots and between the various antenna-operation periods, analyses were made of potential differences among years within antenna-operation periods (preoperational, partly operational, fully operational). To do this the data for each operation period were subjected to two-way analysis of covariance, with the dependent variable being the logarithm of whole-body peak metabolic rate, the factors being years (within the operation period) and plots (test and control), and the covariate being the logarithm of body weight. Because the data sets were unbalanced, each of the two possible hierarchical (sequential) analyses of covariance was carried out (years first, plots second; plots first, years second). For each of the three operation periods, the slopes of the regressions were homogeneous ($P > 0.30$), variances were homogeneous (Bartlett's test, $P > 0.14$), and the two hierarchical analyses agreed in statistical outcome. The two years within the preoperational period (1986 and 1987) differed statistically ($P = 0.03$), but the years within the partly operational and fully operational periods did not differ ($P > 0.18$). No differences between test and control plots ($P > 0.14$) and no plot-year interactions ($P > 0.64$) were found within any operation period. Because the preoperation period for deer mice was the only operation period for either species (see later) that displayed interannual heterogeneity and because the two years in the period were known to be similar in antenna-operation characteristics, the period was retained intact for further statistical analysis.

Table 51 presents descriptive statistics for the deer mice. Years are pooled within antenna-operation periods because in general, as just described, no differences were found between years within a period. Years differed within the preoperation period, and Table 52 gives the breakdown. To compile Table 51 and Table 52, weight-specific peak metabolic rates were used. That is, each animal's peak metabolic rate was divided by the animal's body weight. Recall that all statistical hypothesis testing (by analysis of covariance) has been carried out on the whole-body peak metabolic rates with body weights entered as covariates. The weight-specific metabolic rates in Table 51 and Table 52 more immediately describe the experimental data, but the covariate analysis is the superior way of taking effects of weight into account for hypothesis testing.

Table 51. Summary of weight-specific peak metabolic rates measured on deer mice in 1985 (no control data) and in the preoperational, partly operational, and fully operational periods

Time Period and Plot		N	Peak Metabolic rate* [mL O_2 / (g x hr)] Mean	S.D.
Preliminary (1985)	Test	11	21.1	2.4
Preoperation (1986-87)	Test	17	19.2	1.6
	Control	18	20.2	1.6
Partly Operational (1988-89)	Test	16	19.0	1.7
	Control	17	19.7	1.7
Fully Operational (1990-92)	Test	38	18.2	2.1
	Control	34	18.6	1.7

*All measured peaks, regardless of their quality rating, are included.

After the above preliminaries, we now turn to our definitive analysis of potential contrasts between test and control plots before and after onset of Communications System operation. This was done by two-way analysis of covariance, with the dependent variable being the logarithm of

Table 52. Breakdown of weight-specific peak metabolic rates for deer mice for the two years in the preoperational period

Year and Plot		N	Peak Metabolic rate* [mL O_2 / (g x hr)] Mean	S.D.
1986	Test	8	19.9	0.8
	Control	9	20.7	1.9
1987	Test	9	18.5	1.9
	Control	9	19.6	1.1

*All measured peaks, regardless of their quality rating, are included.

whole-body peak metabolic rate, the factors being plots (test and control) and antenna-operation periods (preoperational, partly operational, and fully operational), and the covariate being the logarithm of body weight. Once again, because the data were unbalanced, each of the two possible hierarchical (sequential) analyses of covariance was carried out (plots first, operation periods second; operation periods first, plots second). The slopes of the regressions were homogeneous (P = 0.61), variances were homogeneous (Bartlett's test, P = 0.87), and the two hierarchical analyses agreed in statistical outcome. Table 55 presents the analysis of covariance. As can be seen, the test and control plots differed significantly (P = 0.04-0.05), and the operation periods did so as well (P = 0.001-0.002), but the interaction — which is the definitive test for potential Communications System effects — was robustly nonsignificant (P = 0.95).

The adjusted mean of the logarithm of peak metabolic rate (adjusted for weight by covariate analysis) pooled across operation periods was greater on the control plot than the test. This tendency for values on the control plot to be consistently higher than those on the test plot is evident in the weight-specific data presented in Table 51. The adjusted mean pooled across plots tended to decrease with the passage of time; this trend is also evident in Table 51. Reasons for the consistent difference between plots and the change of <u>both</u> plots with time are unknown. As to the plots, the body weights and temperatures (before and after assay) of the deer mice were not significantly different between the test and control plots (P > 0.37 for weights, P > 0.57 for temperatures, no significant interactions with operation period); thus, the differences in metabolic values between the plots cannot be attributed to other known properties of the animals. As to the temporal change in metabolic values, when we realized that values were tending to decline over time and that this was true for both species (see later), we at once reanalyzed a sample of our metabolic records from early years along with a sample of later records to assure that our data-analytical procedures had not changed. The reanalysis was done blind, and we determined that our data-analytical procedures had been consistent across time. Body weights were not different among operation periods (P > 0.32). Perhaps the change from the in-town holding facility to the holding facility at Panola Plains in 1988 at the behest of IITRI engineers was partly responsible for the decline in metabolic values over time; animals from both plots studied in the preoperation period were held in a different place than those studied in later periods.

As noted above, it is the interaction between operation periods and plots for metabolic values that is truly crucial for our evaluation of potential Communications System effects, and the interaction is robustly nonsignificant. The test and control plots differed from one another from the start of our research and remained different as values on both plots declined. The magnitude of the difference between the test and control plots did not change, however, as the Communications System antenna was first made partly operational and later made fully operational. We conclude that operation of the antenna has had no effect on the peak metabolic rates of deer mice in winter.

Analysis of Data on Chickadees. Once again, the first step in the analysis was to address the methodological issue of whether peak determinations placed in secondary-quality classes (ratings 0 and 5-9) were different from those of primary quality (ratings 1-4). To do this, all peak determinations made on chickadees, regardless or year or plot, were pooled (N = 159) and subjected to an analysis of covariance (in their logarithmic form) with a single factor: primary versus secondary quality rating. Variances were homogeneous (Bartlett's test, P = 0.64), and the slopes of the regressions were homogeneous (P = 0.47). The difference between the primary-quality and secondary-quality groups of data proved significant (P = 0.001), indicating that the deviations from ideal methodology in obtaining the measures of secondary quality were statistically consequential. Within the primary-quality group of data, there were no significant differences in peak metabolic rate among the rating categories (ratings 1-4) according to analysis of covariance (P = 0.41). Similarly, within the secondary-quality group, differences among the rating categories (ratings 0 and 5-9) were not statistically significant (P = 0.21). To examine whether known preexisting differences among birds might have contributed to their division into statistically different primary- and secondary-quality groups based on peak metabolic rate, body weights and initial body temperatures were examined. The chickadees that fell into the two quality groups based on their peak metabolic rates did not differ in body weight (P = 0.73) or in their body temperatures prior to peak determinations (P = 0.80).

From the analysis of covariance of primary- versus secondary-quality peaks, the adjusted mean peak metabolic rate for the primary-quality group of data (converted back out of the logarithmic domain) turned out to be 275.1 mL/h (N=108), whereas that for the secondary-quality group was 263.2 mL/h (N = 51). Values in the secondary-quality group of data thus tended to be lower than those in the primary-quality group, but only to a small degree (4%) that was highly significant statistically because of relatively low variances and large numbers of data. In subsequent analyses, we present results for the primary-quality rating classes alone and for all quality classes taken together. **The results for the primary-quality classes alone must be considered definitive.** However, the more encompassing treatments are presented as well because in fact only a small difference existed between the data in the primary- and secondary-quality groups.

As with the data for the deer mice, prior to examining contrasts between the test and control plots and the various antenna-operation periods, analyses were made of potential differences among years within antenna-operation periods (preoperational, partly operational, fully operational). To do this, the data for each operation period were subjected to two-way analysis of covariance, with the dependent variable being the logarithm of whole-body peak metabolic rate, the factors being years (within the operation period) and plots (test and control), and the covariate being the logarithm of body weight. In each instance, both possible hierarchical (sequential) analyses of covariance were carried out (years first, plots second; plots first, years second).

We focused principally, as earlier noted, on just the primary-quality classes of data for chickadees. For those data, in each of the three operation periods, the slopes of the regressions were homogeneous ($P > 0.42$), variances were homogeneous (Bartlett's test, $P > 0.63$), and the two hierarchical analyses agreed in statistical outcome. No differences between years ($P > 0.14$) or between test and control plots ($P > 0.12$), and no plot-year interactions ($P > 0.38$), were found within any operation period.

Table 53 presents the definitive (*i.e.*, primary-quality) descriptive statistics for the chickadees. Once again, as with the deer mice, weight-specific peak metabolic rates were used to compile the descriptive statistics, although statistical hypothesis testing was carried out on whole-body peak metabolic rates with body weights entered as covariates. See the section on deer mice for the rationale of handling weight in these two different ways for description and hypothesis testing.

We also, as noted earlier, present data for all quality classes combined for the chickadees. For this data set, as for the definitive one, no significant differences were found between years within antenna-operation periods. The comprehensive descriptive statistics are presented in Table 54.

After the above preliminaries, we now turn to our definitive analysis of potential contrasts between test and control plots before and after onset of Communications System operation. This was carried out on the peak metabolic rates of primary quality (ratings 1-4) using two-way analysis of covariance, with the dependent variable being the logarithm of whole-body peak metabolic rate,

Table 53. Summary of weight-specific peak metabolic rates measured on chickadees in 1985 and in the preoperational, partly operational, and fully operational periods

Time Period and Plot		N	Peak Metabolic rate [mL O_2 / (g x hr)] Mean	S.D.
Preliminary (1985)*	Test	5	25.0	1.1
	Control	6	24.6	1.5
Preoperation (1986-87)	Test	15	24.4	2.1
	Control	19	24.9	1.5
Partly Operational (1988-89)	Test	15	24.2	2.0
	Control	17	25.2	2.0
Fully Operational (1990-92)	Test	11	24.1	2.1
	Control	20	23.7	1.6

*Control data from a different plot than that used subsequently.

Only peaks in the primary-quality classes (ratings 1-4) are included. This is the definitive data set for chickadees (see text).

the factors being plots (test and control) and antenna-operation periods (preoperational, partly operational, and fully operational), and the covariate being the logarithm of body weight. Once again, because the data were unbalanced, each of the two possible hierarchical (sequential) analyses of covariance was carried out (plots first, operation periods second; operation periods first, plots second). The slopes of the regressions were homogeneous (P = 0.80), variances were homogeneous (Bartlett's test, P = 0.90), and the two hierarchical analyses agreed in statistical outcome. Table 55 presents the analysis of covariance. As can be seen, the test and control plots did not differ significantly (P = 0.12-0.19), but the operation periods did (P = 0.01-0.02). As with the deer mice, the interaction — which is the definitive test for potential Communications System effects — was robustly nonsignificant (P = 0.31).

The adjusted mean of the logarithm of peak metabolic rate (adjusted for weight by covariate analysis) pooled across plots tended to decrease with the passage of time from the preoperational to the fully operation periods. This trend is evident in the weight-specific data presented in Table 53.

Table 54. Summary of weight-specific peak metabolic rates measured on chickadees in 1985 and in preoperational, partly operational, and fully operational periods

Time Period and Plot		N	Peak Metabolic rate* [mL O_2 / (g x hr)] Mean	S.D.
Preliminary (1985)**	Test	7	24.7	1.1
	Control	12	23.8	1.7
Preoperation (1986-87)	Test	25	24.3	1.9
	Control	22	24.9	1.6
Partly Operational (1988-89)	Test	24	23.6	1.9
	Control	21	24.8	2.0
Fully Operational (1990-92)	Test	26	23.3	2.0
	Control	22	23.9	1.8

* This data set for the chickadees is informative but not definitive (see text). See the preceding table for the definitive data set on chickadees.

** Control data from a different plot than that used subsequently.

All measured peaks, regardless of their quality rating, are included.

Reasons for it are unknown. The body weights of the chickadees for which we obtained peak metabolic rates, by chance, were lower in the partly operational and fully operational periods (11.1 g, pooled across plots, in each period) than in the preoperational period (11.5 g, pooled across plots) ($P < 0.02$, no significant differences between plots, no period-plot interaction). However, lower body weights would tend to lead to higher, not lower, weight-adjusted metabolic rates because of the allometric relations between metabolism and weight previously discussed. See the section on deer mice for a discussion of some other potential considerations.

As noted, it is the plot-period interaction for peak metabolic rates that is truly crucial for our evaluation of potential Communications System effects, and for the chickadees it is robustly nonsignificant. Although measured peak metabolic rates for chickadees tended to decline with time over the course of this research, the test and control plots did not differ or significantly change in their relation to each other as the Communications System antenna was first made partly operational and later made fully operational. We conclude that operation of the antenna has had no effect on

Table 55. Analysis of covariance for deer mice. The logarithm of whole-body peak metabolic rate was the dependent variable

Source of Variation[a]	SS	df	MS	F	Probability of F
Within Cells	.78	133	.01		
Regression	.69	1	.69	118.17	<.001
Constant	4.74	1	4.74	810.99	<.001
Operation Period	.08	2	.04	7.06	.001
	.08	2	.04	6.75	.002
Plot (Test vs Control)	.02	1	.02	3.82	.053
	.03	1	.03	4.45	.037
Period-Plot Interaction	<.01	2	<.01	.05	.953

[a] The factors were plot (test versus control) and antenna-operation period (preoperational, partly operational, and fully operational). The covariate was the logarithm of body weight. The two possible hierarchical (sequential) analyses were performed because of the unbalanced nature of the data. The order of analysis in the hierarchical approach affects statistical values for the main effects. Thus, two sets of values are presented for main effects

the peak metabolic rates of chickadees in winter.

This conclusion from analysis of the definitive data set for chickadees is echoed by analysis of the full data set including all values for peak metabolic rate regardless of quality rating (see Table 54 for descriptive statistics). In the analysis of the full data set, plots differed (P = 0.004) as well as periods (P = 0.001). However, once again, the critical plot-period interaction was nonsignificant (P = 0.62).

DISCUSSION AND CONCLUSIONS

I. Tree Swallow Fecundity, Mortality, Growth and Maturation.

Fecundity and Mortality. We did not find any consistent, unequivocal, effect of the antenna system on any of the many variables we measured. Mortality rates of returning adults and first year birds were highly variable, suggesting there are many factors that influence survival.

Table 56. Analysis of covariance for chickadees. The logarithm of whole-body peak metabolic rate was the dependent variable, with only values in quality-rating classes 1-4 being used

Source of Variation[a]	SS	df	MS	F	Probability of F
Within Cells	.45	90	.01		
Regression	.09	1	.09	18.70	<.001
Constant	1.03	1	1.03	205.07	<.001
Operation Period	.04	2	.02	4.33	.016
	.05	2	.02	4.67	.012
Plot (Test vs Control)	.01	1	.01	2.48	.119
	.01	1	.01	1.75	.189
Period-Plot Interaction	.01	2	.01	1.18	.312

[a] The factors were plot (test versus control) and antenna-operation period (preoperational, partly operational, and fully operational). The covariate was the logarithm of body weight. The two possible hierarchical (sequential) analyses were performed because of the unbalanced nature of the data. The order of analysis in the hierarchical approach affects statistical values for the main effects. Thus, two sets of values are presented for main effects

Fecundity (clutch size) was much less variable, and as our analyses showed, not influenced by the operation of the antenna. Test plot values in the preoperation period were lower than controls by about 0.4 egg, on average, but the clutch size on the test plot then increased to the same levels as the control plot during level 1 and full operation. The overall variability in clutch size was low, which allowed us to confidently predict that we could have detected differences in means as small as about 8%. Yet, we could not find differences attributable to the Communications System.

Average numbers of eggs hatching and of young fledging from nests on test and control plots were similar within years, but highly variable among years due to weather conditions. The greater variability in these data prevented us from detecting effects as subtle as for clutch size. Still, we could have detected about a 20% difference in plot means with a certainty of 70% for hatching and fledging rates. Fledging rates were so highly variable among antenna operation periods that we could not have detected any effect — over 170% change would have been required to detect a difference with 70% certainty, a clear impossibility!

Intensive study of the fate of over 2,300 eggs, 1,700 nestlings and 900 nests over the nine years of the research program yielded no consistent trend that could be attributed to the Communications System. In most years, test and control plots had approximately equal mortality during the incubation and nestling phases. Total nest mortality was evenly divided among years with equal mortality between test and control plots and years where mortality was greater on the test plot. However, only two of five years during full operation of the Communications System had higher mortality on test plots.

Growth and Maturation. Growth of nestling tree swallows was studied intensively on over 800 nestlings over a seven-year period. The variables of growth we chose to measure were sensitive to the general health of the young and their parents. Furthermore, the pattern of growth appears to be relatively rigidly controlled by physiological processes and therefore has low variability. Had operation of the Communications System caused even small changes in growth, we could have detected them with fairly high certainty.

None of our measures on growth of nestling tree swallows indicated any consistent differences that could be attributed to the operation of the Communications System. Measures of body mass were least variable overall and produced the best power of detecting small differences in experimental means for plot and Communications System operation periods. Minimum detectable differences at 70% power in means for operation periods were about 9% for all but the fitted growth constant, for which it was about 18%. Minimum detectable differences at 70% power in means for plots were between 2% and 3%. The actual differences we found among operation and plot means were on the order of 5% or less.

Measures of tarsus, ulna and wing growth were similar to body mass in the values of minimum detectable differences for plot means. In fact, the detectable difference in maximum tarsus length at 70% power was less than 1%, the smallest value for any variable we measured. However, minimum detectable differences for operation periods were larger than for body mass, with values of ranging between about 9% and 30% for tarsus and ulna measures, and over 50% for wing growth. Therefore, if there had been consistent effects of the Communications System on body mass measures even as small as four to five percent, we would have been able to detect them.

The larger minimum detectable differences for operation period means seems to be due to the wide range of weather conditions that occurred during the study. Two of the three operation periods, preoperation and level 1, were each two years long, and the full-operation period was three years long. Within each operation period, there was at least one year of bad weather. Bad weather resulted in poorer growth of nestlings, and when combined with better growth in good years, resulted in greater variability within the operation period. This variability is reflected in the larger minimum detectable differences among operation periods. On the other hand, plot means within a year were similar to each other most years, regardless of the weather. Accordingly, minimum detectable differences for plot means are smaller than for operation period means.

The crucial test of an effect of the Communications System, however, is the strength of interaction between the operation period and plot means. We expected the electromagnetic fields of the Communications System to more strongly impact nestlings on the test plot compared to the control. If these fields were to impact growth, we expected to see the test plot means change as the system began operation, compared to the controls. As we noted in the results, we did find a number of instances of interactions between plot and operation period means. However, in no case could we unequivocally assign a change as due to the antenna system. We found two patterns of change in the means that were responsible for the significant interactions observed. The most common was *control plot means converge on test plot means, which remained relatively stable over the study.* This pattern occurred for body mass growth constant, inflection point, and age at maximum body mass, tarsus growth constant, inflection point and age at maximum tarsus length, and for age at eye opening and feather eruption. The second, less common, was *test and control plot means were similar and high in the preoperation phase but declined by different amounts during level 1 and full operation phases.* This pattern was found for ulna inflection point and wing growth constant. These two data sets differ in that the control plot mean was higher than the test plot during the pre-operation phase for ulna inflection point, but not for the other phases, whereas the means were similar for wing growth constant during the pre-operation and level 1 phases, but higher for the control plot during full operation. Neither of these patterns are what one would expect to find if the Communications System was having an effect on growth. Preoperation means should have been similar on test and control plots and then diverged during level 1 or full operation phases, or both phases, with the control plots being stable over the entire time period. We therefore attribute the changes in means we found to factors other than the Communications System.

We reinforced this conclusion with the results of the nestling exchange experiment. None of the variables that we found significant interaction effects for in the test-control plot study were also found as significant effects in the nestling transfer experiment. Instead, we found significant effects in the analysis of variance for body mass growth constant and inflection point, ulna inflection point, wing growth constant and age at eye opening. Of these variables, only body mass and wing growth constants could be interpreted as possible effects of the Communications System. However, we are very cautious about concluding these two variables are in fact responding to the electromagnetic fields of the Communications System because not all comparisons of **control** and **control-swap** treatments were significantly different from **test** and **test-swap** treatments (see page 104 and Figure 47, and Figure 48).

One final test of the possible effects of the Communications System on growth of nestling tree swallows was carried out by examining nestlings that grew up in nest boxes found at increasing distances from the antenna on the test plot. For this analysis, we constructed categories of estimated exposure levels to each of the electromagnetic fields. We then tested the growth response of nestlings using all growth variables studied (see pages 110-122). We found no consistent, significant effect of field strength on nestlings. The minimum detectable difference at 70% power for these tests ranged from about 8% to about 19% of the treatment means with the smallest values occurring for the growth measures tested against categories of the transverse field.

Overall, for fecundity, mortality, growth and maturation studies on tree swallows, we conclude that a consistent, unequivocal, effect of the Communications System could not be found for any measured variable. We had large samples sizes, and in most cases the variables we measured had low variability. We could have detected small changes with a reasonable level of statistical certainty in these variables had they occurred.

II. Deer Mouse Growth and Maturation Studies

Growth. We measured the growth rate for over 390 nestling deer mice over the six years of study on this task. Our findings on growth of nestling deer mice paralleled those for tree swallows. Variability was low, and we could have detected differences in plot means as small as about 4% and operation phase means of about 11% with 70% certainty. We found significant variation in growth in different years, presumably due to weather. In three of the six years, the means for test and control plots differed, but not in a consistent direction. In two years, control plot means for growth rate were higher than test plot means, and the reverse occurred for the other year. A significant interaction occurred for operation phase and plot, but the test plot mean was low during the preoperation phase and converged to the same level as control plot means during level 1 and full operation phases. The timing and direction of change in test plot means is not what we would expect if the Communications System was affecting growth in deer mice.

Maturation. The ages at eye opening and at incisor eruption were measured for over 370 nestling deer mice over the six years of study on this task. We found no effect of the Communications System on age at incisor eruption, but there was an effect on age at eye opening. Nestlings opened their eyes about one day earlier during level 1 operation and about 2.5 days earlier during full operation on the test plots, compared to the controls. Age at eye opening increased on control plots nearly every year from the start of the study, from about 15 days to over 17 days by the end of the study. Why control plot means increased is puzzling, and we have no explanation. Also difficult to explain is the fact that even though the test plot mean is significantly lower than the control, it is basically stable over the entire operation period. It is the control means that have changed by increasing significantly over the study. Are these patterns unequivocally an effect of the Communications System? If the trend for increasing age at eye opening observed on the control plot was due to some overall trend, such as a weather pattern, or change in population structure, then the effect of the Communications System could have been to counteract the trend for nestlings on the test plot. If, on the other hand, the overall pattern was for a stable age at eye opening, but some factor specific to the control plot was causing increased age at eye opening there, then the stability of the age at eye opening on the test plot would not be due to the Communications System. We have examined all our data and to date can not find anything that would suggest control plot nestlings were exposed to a factor specific to that plot that would have increased the age of eye opening. Litter sizes were about the same, handling and measuring nestlings were done the same and usually by the same project personnel within a given year, and so on. We can, with our current data set, only conclude that the test plot means are lower due to electromagnetic fields produced by the Communications System. We have no idea what the mechanism may be; nor do we know if the effect is detrimental to nestlings.

III. Homing Studies

Tree Swallows. In our homing studies of tree swallows, we have displaced and followed the fate of over 390 birds during the seven years of this study task. We have consistently found that birds from test plots are more likely to return to their nest and that birds that do return get to their nest faster than control birds. Since these differences have been present from preoperation periods right through to full operation, we do not attribute them to the operation of the Communications

System. However, we have examined homing behavior for test-plot birds that were tested on days when the antenna system was not operating compared to days when it was during 1987 and 1988. In later years, the antenna system was on all the time during homing studies. We found that birds were equally likely to return whether the antenna was on or off, but that birds tested during the time the antenna was on returned home significantly faster. Thus, this appears to be a clear effect of the Communications System. We do not know how the birds may be using the electromagnetic fields to enhance their rates of return.

We examined this effect further by analyzing only those birds from the test plot that were tested on days when the antenna was operating in 1987 and 1988, plus all birds in 1989 through 1993 tested when the antenna was in continuous operation, with birds from the control plot. We found the same strong pattern as for the entire data set for test birds to perform better than controls in frequency and speed of return. However, we found that test-plot birds were much faster in return speed in 1987 through 1989 than control birds, and then they gradually declined to the control bird rate from 1990 through 1993. Thus, the proposed effect of the Communications System would have been to gradually reduce the preexisting difference between test and control plot birds as the strength of the electromagnetic fields increased over several years. It is hard to imagine why tree swallows would be responding to increasing field strength in this way if they were gaging field strength on a minute-by-minute basis during their navigation. Furthermore, in each successive year, birds not previously used in homing studies and, for the most part, not having bred on the study plot previously were used in homing tests. How could the effect appear to be accumulating in test plot birds under these circumstances? At this writing, we do not have an explanation for the pattern and can only conclude that the effect of the Communications System is to enhance short-term homing ability, but in the long term, appears to have a slowly accumulating negative impact on homing rates of test-plot birds, bringing them to the same level as birds from control plots.

Small Mammals. In our studies of small-mammal homing, we examined the homing ability of over 240 chipmunks and 320 deer mice. We never found any differences in homing frequency for chipmunks for test and control plots. Deer mice showed significant differences in two adjacent years out of the eight years of study, but the direction of the difference was not consistent. Return frequency was lower on the control plot in 1989 and on the test plot in 1990. We conclude that small mammals are not exhibiting any effect of the Communications System.

IV. Developmental Studies

Developmental Abnormalities. Abnormalities were scored for over 1,000 developing embryos of tree swallows over the nine years of this study task. The percentage of abnormal embryos varied from as high as nearly 20% to as low as 5% over these years. For operation period of the Communications System or plot of origin of the eggs, we did not find any statistically significant differences in frequency of abnormalities. Because these data are frequencies, we do not have any way to estimate the power of our performed tests. Still, the sample size is large, and the data were taken over three years of preoperation, one year of level 1 and four years of full operation of the Communications System. We therefore feel confident that we would have detected an effect of the Communications System if one had occurred.

Egg Mass and Volume. Egg mass has changed rather strikingly over the years of the study, with comparatively low values in 1985 followed by an increase in 1986 that persisted through 1989 followed by a decline to 1985 levels in 1990 that persisted through 1993. We found significant interaction of plot means and operation period means, but these differences were not likely caused by the operation of the Communications System. Means on test plots remained relatively constant over all operation phases. Control plot means increased above test plot means during level 1 operation and then declined to test plot levels during full operation. A similar pattern occurred for egg volumes, both measured and calculated, for a subsample of these same eggs. The large sample size and relatively low variability in egg mass and volume allowed us to detect differences in plot means as small as 1% and in operation period means as small as 4% to 5% with a 70% certainty. We are therefore confident that we would have detected an effect of the Communications System if it had caused an average effect greater than from 1% to 5% of the overall mean.

V. Maximum Aerobic Metabolism

Deer Mice. Data on peak metabolic rate was obtained for over 150 deer mice over the eight years of this study task. Our findings revealed effects due to plot and to operation period, but not due to the interaction of operation period and plot. There were initial differences in the average values for peak metabolic rate between plots, and these values changed over the period of operation of the Communications System, but not differentially on the test and control plots.

Black-capped Chickadees. Data on peak metabolic rate was obtained for over 150 birds during the eight years of this study task. Our findings revealed effects due to operation period but not due to plot. Most importantly, there was no significant interaction of plot and operation period.

Thus there was no indication of an effect on either species used in the maximal aerobic metabolism study.

LITERATURE CITED

AIBS 1985. Biological and human health effects of extremely low frequency electromagnetic fields. Report of the committee on biological and human health effects of extremely low frequency electromagnetic fields. Arlington, Virginia. American Inst. of Bio. Sci.

Alsop, F.M. 1918. The effect of abnormal temperatures upon the embryogeny of chick embryos. Anat. Rec. 15:307- 331.

Astrand, P.O., and K. Rodahl. 1977. Textbook of Work Physiology. New York. McGraw-Hill.

Axelsson, J. 1954. Influence of size of eggs on growth rate of embryos and chicks. World's Poultry Congr., Proc. 10th., 1954:65-66.

Babott, H.G. 1937. Effect of temperature, humidity and other factors on hatch of hen's eggs and on energy metabolism of chick embryos. U.S.D.A. Tech. Bull. 553:1-45.

Beaver, D.L., R.W. Hill, and J.H. Asher, Jr. 1984. U.S. Navy extremely low frequency communications system ecological monitoring program, small mammals and nesting birds, Annual Report, 1983. (Submitted to Illinois Institute of Technology Research Institute and the U.S. Navy).

Beaver, D.L., R.W. Hill, and J.H. Asher, Jr. 1985. U.S. Navy extremely low frequency communications system ecological monitoring program, small mammals and nesting birds, Annual Report, 1984. (Submitted to Illinois Institute of Technology Research Institute and the U.S. Navy).

Beaver, D.L., R.W. Hill, and J.H. Asher, Jr. 1986. U.S. Navy extremely low frequency communications system ecological monitoring program, small mammals and nesting birds, Annual Report, 1985. (Submitted to Illinois Institute of Technology Research Institute and the U.S. Navy).

Beaver, D.L., R.W. Hill, and J.H. Asher, Jr. 1987. U.S. Navy extremely low frequency communications system ecological monitoring program, small mammals and nesting birds, Annual Report, 1986. (Submitted to Illinois Institute of Technology Research Institute and the U.S. Navy).

Beaver, D.L., R.W. Hill, and J.H. Asher, Jr. 1988. U.S. Navy extremely low frequency communications system ecological monitoring program, small mammals and nesting birds, Annual Report, 1987. (Submitted to Illinois Institute of Technology Research Institute and the U.S. Navy).

Beaver, D.L., R.W. Hill, and J.H. Asher, Jr. 1989. U.S. Navy extremely low frequency communications system ecological monitoring program, small mammals and nesting birds, Annual Report, 1988. (Submitted to Illinois Institute of Technology Research Institute and the U.S. Navy).

Beaver, D.L., R.W. Hill, and S.D. Hill. 1990. U.S. Navy extremely low frequency communications system ecological monitoring program, small mammals and nesting birds, Annual Report, 1989. (Submitted to Illinois Institute of Technology Research Institute and the U.S. Navy).

Beaver, D.L., R.W. Hill, and S.D. Hill. 1991. U.S. Navy extremely low frequency communications system ecological monitoring program, small mammals and nesting birds, Annual Report, 1990. (Submitted to Illinois Institute of Technology Research Institute and the U.S. Navy).

Beaver, D.L., R.W. Hill, and S.D. Hill. 1992. U.S. Navy extremely low frequency communications system ecological monitoring program, small mammals and nesting birds, Annual Report, 1991. (Submitted to Illinois Institute of Technology Research Institute and the U.S. Navy).

Berman, E., L. Chacon, D. House, B.A. Koch, W.E. Koch, J. Leal, S. Lovtrup, E. Mantiply, A.H. Martin, G.I. Martucci, K.H. Mild, J.C. Monahan, M. Sandstrom, K. Shamsaifar, R. Tell, M.A. Trillo, A. Ubeda, and P. Wagner. 1990. Development of chicken embryos in a pulsed magnetic field. Bioelectromagnetics 11:169-187.

Brooks, G.A., and T.D. Fahey. 1985. Maximal oxygen consumption. In G.A. Brooks (ed): Exercise Physiology: Human Bioenergetics and its Applications. New York, Macmillan. pp. 9-10.

Brosh, R.M., J.R. Gauger, and J.E. Zapotosky. 1985. ELF communications system ecological monitoring program: measurements of ELF electromagnetic fields for site selection and characterization - 1984. Tech. Report E06549-14, IIT Research Institute, Chicago, IL.

Brosh, R.M., J.R. Gauger, and J.E. Zapotosky. 1986. ELF communications system ecological monitoring program: Electromagnetic fields measurements and engineering support -- 1985. Tech. Report E06549-24, IIT Research Institute, Chicago, IL.

Butler, R.W. 1988. Population dynamics and migration routes of tree swallows, *Tachycineta bicolor*, in North America. J. Field Ornithology 59:395-402.

Chapman, L.B. 1955. Studies of a tree swallow colony. Bird-Banding 26:45-70.

Clark, A.B., and D.S. Wilson. 1985. The onset of incubation in birds. Amer. Natur. 125:603-611.

Cohen, M.N., R.S. Malpass, and H.G. Klein. 1980. Biosocial mechanisms of population regulation. New Haven. Yale University Press.

Cohen, R.R. and D.J. Hayes. 1984. A simple unattached nest box trapping device. North American Bird Bander, #9, pp. 10-11.

Cravens, W.W. 1952. Vitamin deficiencies and antagonists. Ann. N.Y. Acad. Sci. 5:188-195.

D'Agostino, R.B., A. Belanger, and R.B. D'Agostino, Jr. 1990. A suggestion for using powerful and informative tests of normality. American Statistician, 44:316-321.

Delgado, J.M.R., J. Leal, J.L. Monteagudo, and M. Garcia. 1982. Embryological changes induced by weak, extremely low frequency electromagnetic fields. J. Anat. 134:533-551.

DeSteven, D. 1978. The influence of age on the breeding biology of the Tree Swallow *Iridoprocne bicolor*. Ibis 120:516-523.

Dixon, F.J. 1952. The effects of radiation on the chick embryo. Ann. N.Y. Acad. Sci. 55:216-220.

Enk, J.O. and J.R. Gauger. 1985. ELF communications system ecological monitoring program: measurements of ELF electromagnetic fields for site selection and characterization - 1983. Tech. Report E06549-10, IIT Research Institute, Chicago, IL.

Everitt, B.S. 1977. The Analysis of Contingency Tables. Chapman and Hall, London.

Garrison, J.C., and Wyttenbach, C.R. 1985. Notochordal development as influenced by the insecticide dicrotophos (Bidrin). J. Exp. Zool. 234:243-250.

Gill, J.L. 1978. Design and analysis of experiments. Ames, Iowa. The Iowa State Univ. Press.

Gilman, P.K., and F.H. Baetjer. 1904. Some effects of the Roentgen ray on the development of embryos. Amer. J. Physiol. 10:222-224.

Goodposture, K.A. 1955. Recovery of a chickadee population from the 1951 ice storm. Migrant 26(2):21-33.

Graue, L.C. 1974. Orientation of Homing Pigeons (*Columbia livia*) exposed to electromagnetic fields at project Sanguine's Wisconsin test facility, final report. Washington, D.C., USDN, Office of Naval Research p. 23.

Green, R.H. 1979. Sampling design and statistical methods for environmental biologists. New York. Wiley.

Hamburger, V., and H.L. Hamilton. 1951. A series of normal stages in the development of the chick embryo. J. Morphol. 88:49-92.

Hamilton, H.L. 1952. Sensitive periods during development. Ann. N.Y. Acad. Sci. 55:177-187.

Hamilton, H.L. 1965. Lillie's development of the chick. New York. Holt, Rinehart and Winston.

Haradem, D.P., J.R. Gauger, and J.E. Zapotosky. 1987. ELF communications system ecological monitoring program: Electromagnetic fields measurements and engineering support -- 1986. Tech. Report E06549-37, IIT Research Institute, Chicago, IL., 52 pp.

Haradem, D.P., J.R. Gauger, and J.E. Zapotosky. 1988. ELF communications system ecological monitoring program: Electromagnetic fields measurements and engineering support -- 1987. Tech. Report E06595-1, IIT Research Institute, Chicago, IL., 54 pp.

Haradem, D.P., J.R. Gauger, and J.E. Zapotosky. 1989. ELF communications system ecological monitoring program: Electromagnetic fields measurements and engineering support -- 1988. Tech. Report E06595-5, IIT Research Institute, Chicago, IL., 69 pp.

Haradem, D.P., J.R. Gauger, and J.E. Zapotosky. 1990. ELF communications system ecological monitoring program: Electromagnetic fields measurements and engineering support -- 1989. Tech. Report E06620-5, IIT Research Institute, Chicago, IL., 77 pp.

Haradem, D.P., J.R. Gauger, and J.E. Zapotosky. 1991. ELF communications system ecological monitoring program: Electromagnetic fields measurements and engineering support -- 1990. Tech Report E06628-3, IIT Research Institute, Chicago, IL., 87 pp.

Haradem, D.P., J.R. Gauger, and J.E. Zapotosky. 1992. ELF communications system ecological monitoring program: Electromagnetic fields measurements and engineering support -- 1991. Tech. Report E06200-4, IIT Research Institute, Chicago, IL., 81 pp.

Haradem, D.P., J.R. Gauger, and J.E. Zapotosky. 1993. ELF communications system ecological monitoring program: Electromagnetic fields measurements and engineering support -- 1992. Tech. Report D06205-1, IIT Research Institute, Chicago, IL., 101 pp.

Haradem, D.P., J.R. Gauger, and J.E. Zapotosky. 1994. ELF communications system ecological monitoring program: Electromagnetic fields measurements and engineering support -- 1993. Tech. Report D06209-1, IIT Research Institute, Chicago, IL., 99 pp.

Hart, J.S. 1957. Climatic and temperature induced changes in the energetics of homeotherms. Rev. Can. Biol. 16:133-174.

Hensler, G.L. and J.D. Nichols. 1981. The Mayfield method of estimating nesting success: A model, estimators and simulation of results. Wilson Bull. 93,42-53.

Hill, R.W. 1972a. Determination of oxygen consumption by use of the paramagnetic oxygen analyzer. J. Appl. Physiol. 33:261-263.

Hill, R.W. 1972b. The amount of maternal care in *Peromyscus leucopus* and its thermal significance for the young. J. Mamm. 53:774-790.

Hill, S.D., D.L. Beaver, P.E. Lederle, and D.L. Herman. 1993. An investigation of the effect of ELF electromagnetic radiation on embryological development in free-living tree swallows, *Tachycineta bicolor*. Electricity and Magnetism in Biology and Medicine. M. Blank (Ed.) San Francisco Press, Inc, San Francisco, CA.

Hill, R.W., P.E. Lederle, and D.L. Beaver. 1993. Effects of captivity on peak rates of oxygen consumption of winter-caught deer mice and black-capped chickadees. Pp. 131-139 in C. Carey, G.L. Florant, B.A. Wunder, and B. Horwitz (eds.), *Life in the Cold. Ecological, Physiological, and Molecular Mechanisms*. Westview Press, Boulder, CO.

Hinrichs, M.A. 1927. Modification of development on the basis of differential susceptibility to radiation. IV. Chick embryos and ultraviolet radiation. J. Exp. Zol. 47: 309-342.

Houston, M.I. and C.S. Houston. 1987. Tree swallow banding near Saskatoon, Saskatchwan. N. Amer. Bird Bander 12:103-108.

Hoyt, D.F. 1979. Practical methods of estimating volume and fresh weight of bird eggs. Auk 96:73-77.

Hussell, D.J.T. 1983a. Age and plumage color in female tree swallows. J. Field Ornith. 54:312-318.

Hussell, D.J.T. 1983b. Longevity and fecundity records in the Tree Swallow. N. Amer. Bird Bander 7:154.

Hutt, F.B., and C. Crew. 1929. Studies in embryonic mortality in the fowl. I. The frequency of various malpositions of the chick embryo and their significance. Proc. Roy. Soc. Edinburgh 49:118-130.

Hutt, F.B., and A.W. Greenwood. 1929. Studies in embryonic mortality in the fowl. III Chick monsters in relation to embryonic mortality. Proc. Roy. Soc. Edinburgh 49:145-155.

Hutt, F.B., and A.M. Pilkey. 1930. Studies in embryonic mortality in the fowl. IV. Comparative mortality rates in eggs laid at different periods of the day and their bearing on theories of the origin of monsters. Poultry Science 9:194-203.

Johnson, L.G., and E.P. Volpe. 1973. Patterns and Experiments in Developmental Biology. W.C. Brown Co.

Juutilainen, J., M. Harri, K. Saali, and N. T. Lahtinen. 1986. Effects of 100-Hz magnetic fields with various wave forms on the development of chick embryos. Radiat. Environ. Biophys. 25:65-74.

Juutilainen, J., E. Laala and K. Saali. 1987. Relationship between field strength and abnormal development in chick embryos exposed to 50 Hz magnetic fields. Int. J. Radiat. Biol. 52:787-793.

Juutilainen, J. and K. Saali. 1986. Development of chick embryos in 1 Hz to 100 kHz magnetic fields. Radiat. Environ. Biophys. 25:135-140.

Keeton, W.T., T.S. Larkin, and D.M. Windsor. 1974. Normal fluctuations in the earth's magnetic field influence pigeon orientation. J. Comparat. Physiol. 95:95-104.

Kluijver, H.N. 1951. The population ecology of the Great Tit, *Parus m. major*, L. Ardea 39:1-135.

Koskimes, J. 1950. The life of the Swift, *Micropus apus* (L.), in relation to the weather. Annales Academia Scientiarum Fenmicae, Series A, IV, Biologica 12:1-151.

Krebs, J.R. 1971. Territory and breeding density in the Great Tit, *Parus major*. Ecology 52:2-22.

Lack, D. 1954. The natural regulation of animal numbers. London. Oxford University Press.

Lack, D. 1966. Population studies of birds. Oxford, England. Clarendon Press.

Landauer, W. 1943. Sex and season in relation to malformations of chicken embryos. Anat. Rec. 86:365-372.

Larkin, R.P., and D.J. Sutherland. 1977. Migrating birds respond to Project Seafarer's electromagnetic field. Science 195:777-778.

Leon, Y., C. Valero, C. Miner, J. Represa, and F. Giraidez. 1992. Low frequency electromagnetic fields inhibit cell proliferation in chick embryo cochleovestibular ganglion. The First World Congress for Electricity and Magnetism in Biology and Medicine. Lake Buena Vista, Florida. Abstract Book. p 16.

Litovitz, T.A., C.J. Montrose, and P. Doinov. 1992. Spatial and temporal coherence affects the response of biological systems to electromagnetic fields. The First World Congress for Electricity and Magnetism in Biology and Medicine. Lake Buena Vista, Florida. Abstract Book. p 16.

Litovitz, T.A., C.J. Montrose, P. Doinov, K.M. Brown, and M. Barber. 1994. Superimposing spatially coherent electromagnetic noise inhibits field induced abnormalities in developing chick embryos. Bioelectromagnetics 15:105-113.

Low, S.H. 1933. Further notes on the nesting of the Tree Swallows. Bird-banding 4:76-87.

Maffeo, S., A.A. Brayman, M.W. Miller, E.L. Carstensen, V. Ciaravino, and C. Cox. 1988. Weak low frequency electromagnetic fields and chick embryogenesis: failure to reproduce positive findings. J. Anat. 157:101-104.

Magnusson, A. 1984. My famgsmetod for holkfaglar. Var Fagelvarld 4:318.

Mahoney, S.P., and Threlfall, W. 1981. Notes on the eggs, embryos and chick growth of common guillemots *Uria aalge* in Newfoundland. Ibis 123:211-218.

Marsh, R.L., and W.R. Dawson. 1989. Avian adjustments to cold. Adv. Comp. Environ. Physiol. 4:205-253.

Martin, H. 1988. Magnetic fields and time dependent effects on development. Bioelectromagnetics 9:393-396.

Martin, A.H. 1992a. The effect of ELF magnetic fields with various wave forms: frequencies and length of exposure on the development of the chick embryo. The Annual Review of Research on Biological Effects of 50 and 60 Hz Electric and Magnetic Fields. Milwaukee, Wisconsin. Project Resumes. p A-6.

Martin, A.H. 1992b. Development of chicken embryos following exposure to 60-Hz magnetic fields with differing waveforms. Bioelectromagnetics 13:223-230.

Martin, J.H. and W.M. Insko, Jr. 1935. Incubation experiments with turkey eggs. Kentucky Agr. Exp. Sta. Bull. 359:151-177.

Mayfield, H. 1961. Nesting success calculated from exposure. Wilson Bulletin 73:255-261.

Mayfield, H. 1975. Suggestions for calculating nesting success. Wilson Bulletin 87:456-465.

Metzgar, L.H. 1967. An experimental comparison of Screech Owl predation on resident and transient White-Footed Mice *Peromyscus leucopus*. J. Mamm. 48:387-391.

Morse, D.H. 1980. Behavioral Mechanisms in Ecology. Cambridge. Harvard University Press.

Murphy, E.C. 1978. Seasonal variation in reproductive output of house sparrows: the determination of clutch size. Ecology 59:1189-1199.

Nice, M.M. 1954. Problems of incubation in North American birds. Condor 56:173-197.

O'Connor, R.J. 1978. Nest-box insulation and the timing of laying in the Wytham woods population of Great Tits Parus major. Ibis 120:534-537.

Paynter, R.A. 1954. Interrelations between clutch-size, brood-size, prefledging survival, and weight in Kent Island Tree Swallows. Bird-Banding 25:35-58, 102-110, 136-148.

Pembrey, M.S., M.H. Gordon, and R. Warren. 1894. On the response of the chick, before and after hatching, to changes of external temperature. J. Physiology 17:331-348

Perrins, C.M. 1965. Population fluctuations and clutch size in the Great Tit, *Parus major*. J. Anim. Ecol. 34:601-647.

Perry, J.S., and I.W. Rowlands. 1973. The environment and reproduction in mammals and birds. J. Repr. Fert. Suppl. No. 19.

Pollock, K.H., J.D. Nichols, C. Brownie, and J.E. Hines. 1990. Statistical inference for capture-recapture experiments. Wildlife Monogr. 107: 1-97.

Reese, A.M. 1912. The effects of narcotics upon the development of the hen's eggs. Science 35:633-634.

Rendell, W.B. and R.J. Robertson. 1990. Influence of forest edge on nest-site selection by Tree Swallows. Wilson Bulletin 102:634-644.

Ricklefs, R.E. 1967. A graphical method of fitting equations to growth curves. Ecology 48:978-983.

Ricklefs, R.E. 1983. Avian postnatal development. Pages 1-83 *in* D.S. Farner and J.R. King, Editors, Avian Biology. Volume VII. Academic Press, New York, USA.

Riddle, O. 1930. Studies on the physiology of reproduction in birds. XXVII. The age distribution of mortality in bird embryos and its probable significance. Amer. J. Physiol. 94:535-547.

Ridgeway, L.P., and D.A. Karnofsky. 1952. The effects of metals on the chick embryo: toxicity and production of abnormalities in development. Ann. NY. Acad Sci. 55:203-215.

Romanoff, A.L., L.L. Smith, and R.A. Sullivan. 1938. Biochemistry and biophysics of the developing hen's egg. III. Influence of temperature. Mem. Cornell Univ. Agrl. Exp. Sta. 216:1-42.

Rosenmann, M., and P.R. Morrison. 1974. Maximum oxygen consumption and heat loss facilitation in small homeotherms by He-O_2. Amer. J. Physiol. 226:490-495.

Royama, T. 1966. Factors governing feeding rate, food requirement and brood size of nesting Great Tits, *Parus major*. Ibis 108:313-347.

Siskin, B.F., I. Fowler, C. Mayraud, J.P. Ryaby, J. Ryaby, and A. Pilla. 1986. Pulsed electromagnetic fields and normal chick development. Bioelectricity 5:25-34.

Slobodkin, L.B. 1968. Aspects of the future of ecology. Bioscience 18:16-23.

Sokal, R.R., and F.J. Rohlf. 1981. Biometry. New York. W. H. Freeman and Company.

Southern, W.E. 1969. Orientation behavior of Ring-billed Gull chicks and fledglings. Condor 71:418-425.

Southern, W.E. 1971. Gull orientation by magnetic cues: a hypothesis revisited. Annals New York Acad. Sci. 188:295-311.

Southern, W.E. 1972a. Magnets disrupt gull orientation during first-flights. Bioscience 22:476-479.

Southern, W.E. 1972b. Influence of disturbances in the earth's magnetic field on Ring-billed Gull orientation. Condor 74:102-105.

Southern, W.E. 1973. Orientation behavior of Ring-billed Gull chicks (*Larus delawarensis*) exposed to project Sanguine's electric and magnetic fields. Office Naval Res.,Dept. of Navy.

Southern, W.E. 1974. The effects of superimposed magnetic fields on gull orientation. Wilson Bulletin 86:256-271.

Southern, W.E. 1975. Orientation of gull chicks exposed to Project Sanguine's electromagnetic field. Science 189:143-145.

Southern, W.E. 1976. Migrational orientation in Ring-billed Gull chicks. Auk 92(1):78-85.

Stiles, K.A., and R.L. Watterson. 1937. The effects of jarring upon the embryogeny of chick embryos. Anat. Rec. 70:7-12.

Stockard, C. 1914. The artificial production of eye abnormalities in the chick embryo. Anat. Rec. 8:33-41.

Taylor, L.W., C.A. Gunns, and B.D. Moses. 1933. The effects of current interruption in electrical incubation. Bull. Univ. Calif. Col. Agrl. Exp. Sta. 550:1-19.

Ubeda, A., J. Leal, M.A. Trillo, M.A. Jimenez and J.M.R. Delgado. 1983. Pulse shape of magnetic fields influences chick embryogenesis. J. Anat. 137:513-536. The First World Congress for Electricity and Magnetism in Biology and Medicine. Lake Buena Vista, Florida. Abstract Book. p 16.

Ubeda, A., M.A. Trillo, L. Chacon, M.A. Martinez, and J. Leal. 1992. Sensitivity of chick embryos in late gastrula to a weak pulsed magnetic field. The First World Congress for Electricity and Magnetism in Biology and Medicine. Lake Buena Vista, Florida. Abstract Book. p. 16.

Wang, L.C.H. 1978. Factors limiting maximum cold-induced heat production. Life Sci. 23:2089-2098.

Watson, A. 1964. Aggression and population regulation in Red Grouse. Nature 202:506-507.

Watterson, R.L., and G.C. Schoenwolf. 1984. Laboratory studies of Chick, Pig, and Frog Embryos. Guide and Atlas of Vertebrate Embryology. Fifth ed. Burgess Publishing Co.

Wickler, S.J. 1980. Maximal thermogenic capacity and body temperatures of White-Footed Mice (*Peromyscus*) in summer and winter. Physiol. Zool. 53:338-346.

Wilkinson, L. 1988. The system for statistics. Evanston, IL: SYSTAT, Inc.

Wilkinson, L. 1990. The system for statistics. Evanston, IL: SYSTAT, Inc.

Windle, B.C.A. 1893. On certain early malformations of the embryo. J. Anat. Physiol. 27:436-453.

Windle, B.C.A. 1895. On the effects of electricity and magnetism on development. J. Anat. Physiol. 29:346-351.

Wyttenbach, C.R., and Hwang, J.D. 1984. Relationship between insecticide-induced short and wry neck and cervical defects visible histologically shortly after treatment of chick embryos. J. Exp. Zool 229:437-446.

Zach, R. 1988. Growth curve analysis: a critical reevaluation. Auk 105: 208-209.

Zach, R., and K.M. Mayoh. 1982. Weight and feather growth of nestling tree swallows. Can. J. Zool. 60:1080-1090.

Zar, J.H. 1984. Biostatistical analysis. Englewood Cliffs, NJ. Prentice-Hall.

Zwilling, E. 1956. Teratogenesis. pp. 699-719. In B. Willier, P.A. Weiss, and V. Hamburger (eds): Analysis of development. Philadelphia. W.B. Saunders.

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APPENDIX

List of Publications and Presentations

Publications:

Beaver, D.L., R.W. Hill, and P.E. Lederle. 1993. Assessment of the effects of extremely low frequency electromagnetic radiation on growth and maturation in nestling Tree Swallows. In: Electricity and Magnetism in Biology and Medicine. M. Blank (Ed.) San Francisco Press, San Francisco, 925-926.

Hill, R.W., D.L. Beaver, J.A. Asher, Jr. 1988. An excellent, inexpensive lamp for small animal surgery and examination. Lab. Animal Sci. 38, 212-213.

Hill, R.W., P.E. Lederle, and D.L. Beaver. 1993. Effects of captivity on peak rates of oxygen consumption of winter-caught deer mice and black-capped chickadees. Pp. 131-139 in C. Carey, G.L. Florant, B.A. Wunder, and B. Horwitz (Eds.), *Life in the Cold. Ecological, Physiological, and Molecular Mechanisms*. Westview Press, Boulder, CO.

Hill, R.W., D.L. Beaver, and P.E. Lederle. 1993. Ecological studies on effects of ELF electromagnetic fields: Maximal cold-induced rate of oxygen consumption in mice and birds. In: Electricity and Magnetism in Biology and Medicine. M. Blank (Ed.) San Francisco Press, San Francisco, 822-824.

Hill, R.W., P.E. Lederle, and D.L. Beaver. 1994. Temperatures that elicit peak metabolic rates: Statistical distributions and implications. The Physiologist (abstract, in press).

Hill, S.D., D.L. Beaver, P.E. Lederle, and D.L. Herman. 1993. An investigation of the effect of ELF electromagnetic radiation on embryological development in free-living tree swallows, *Tachycineta bicolor*. Electricity and Magnetism in Biology and Medicine. M. Blank (Ed.) San Francisco Press, Inc., San Francisco, 100-101.

Hussell, D.J.T., T.E. Quinney, P.O. Dunn, D.L. Beaver, P.E. Lederle, E.H. Burtt Jr., S.R. Derrickson, E.M. Landre, S.L. Leathery, L.A. Wakelyn, N.T. Wheelwright, and D.A. Wiggins. 1990. Geographic variation in food abundance and clutch size of Tree Swallows

Tachycineta bicolor. Proceedings of XXth International Ornithological Congress, New Zealand.

Lederle,P.E., D.L. Beaver, and R.W. Hill. 1988. Total albinism in a nestling tree swallow. Jack-Pine Warbler, 66: 119.

Lederle, P.E., B.C. Pijanowski, and D.L. Beaver. 1985. Predation of Tree Swallows by the least chipmunk. The Jack-Pine Warbler 63: 135.

Pijanowski, B.C. 1992. A revision of Lack's Brood Reduction Hypothesis. American Naturalist, 139:1270-1292.

Presentations:

Hill, R.W., D.L. Beaver, and J.A. Asher, Jr. 1984. A comparison of aerobic thermogenic capacity in *Peromyscus melanophrys* and *P. leucopus*. 64th Annual Meeting of the American Society of Mammalogists, Arcata, CA.

Beaver, D.L., R.W. Hill, and J.A. Asher, Jr. 1986. Ecological Studies of tree swallows. Lapeer Audubon Society, Dryden, MI.

Beaver, D.L., R.W. Hill, and J.A. Asher, Jr. 1987. Breeding biology of the tree swallow in the Upper Peninsula of Michigan. 82nd Annual Meeting of the Michigan Audubon Society, Lansing, MI.

Beaver, D.L., R.W. Hill, and J.A. Asher, Jr. 1987. Ecological studies of small mammals and nesting birds in the Upper Peninsula of Michigan. Winter Series Seminars, Department of Zoology, Michigan State University, East Lansing, MI.

Beaver, D.L., R.W. Hill, and S.D. Hill. 1989. Ecological Studies of tree swallows exposed to extremely low frequency electromagnetic fields. 54th Annual Meeting of the Michigan Bird Banders Association, Lansing, MI.

Beaver, D.L., P. E. Lederle and R. W. Hill. 1989. Characteristics of nestling tree swallows (*Tachycineta bicolor)* in relation to weather induced mortality. 70th Annual meeting of the Wilson Ornithological Society, St. Mary's College, Notre Dame, Indiana.

Beaver, D.L., R.W. Hill and P.E. Lederle. 1990. The effects of short-term exposure to extremely low frequency electromagnetic fields on growth of nestling tree swallows: A field experiment. ANNUAL REVIEW OF RESEARCH ON BIOLOGICAL EFFECTS OF 50 & 60 HZ ELECTRIC AND MAGNETIC FIELDS. U.S. Department of Energy, Denver, Colorado.

Hill, R.W., D.L. Beaver and P.E. Lederle. 1990. The ELF Communications System in Michigan: Does it affect the maximal cold-induced rates of oxygen consumption of nearby mice and birds? ANNUAL REVIEW OF RESEARCH ON BIOLOGICAL EFFECTS OF 50 & 60 HZ ELECTRIC AND MAGNETIC FIELDS. U.S. Department of Energy, Denver, Colorado.

Beaver, D.L., R.W. Hill, and S.D. Hill. 1994. Population biology and growth of tree swallows exposed to extremely low frequency electromagnetic fields. Faculty Seminar, Department of Biological Sciences, Oakland University, Rochester, MI.

Hill, R. W., P.E. Lederle, and D.L. Beaver. 1994. Regulation, Integration, Adaptation: A Species Approach. Annual Meeting of the American Physiological Society, Intersociety Meeting, Oct29-Nov 2, 1994.