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Bird migration through an imposed ELF field was studied at the U.S. Navy Wisconsin Test Facility at Clam Lake, Wisconsin. More than 15,000 birds were followed with a small, mobile, short range, high resolution search radar, the ORNITHAR, as they flew over the WTF antenna system which was activated in pre-determined sequences without the knowledge of the observers in the mobile radar. Observations in the vicinity of the transmitter at the WTF revealed a significant association of several migratory behavior variables with antenna state.

20. (cont.)

The most regular of these was a 5° to 20° deviation in the track direction of migrants when the north-south antenna leg was activated. This and other effects did not occur on all nights of observation and neither the occurrence not the magnitude of the effect could be predicted from weather variables or direction or intensity of migration.

Subsequent radar observations near the WTF antenna but remote from the transmitter site failed to reveal any effects regularly associated with antenna state such as those noted near the transmitter. The factors responsible for the observed effects near the transmitter site are not known but may still be due to an electromagnetic field. A computer simulation of constant compass heading bird migration from Wisconsin south to wintering areas in the southern U.S. revealed that if the deviations in avian orientation observed during activation of the north-south antenna leg at the WTF transmitter site had been continued for the remainder of the night, the resulting displacement of birds in their wintering grounds would have been comparable to the effect of wind drift and minor compared to the observed or simulated distribution of migrants.

Observations of low altitude bird migration at several sites near the WTF and in four areas of the U.S. having magnetic anomalies showed that temporary deviations in direction of bird migration are common.

We conclude that the effect of the WTF on free flying migrant birds is most apparent within one kilometer of the transmitter and that deviations of the magnitude observed at the transmitter site occur naturally in low altitude avian migrants.

Final Report

To Office of Naval Research

Contract N00014-77-C-0024

With the Marine Biological Laboratory

Woods Hole, Massachusetts 02543

LIMITING CONDITIONS FOR EFFECTS OF ELF ON FREE FLYING MIGRANT BIRDS

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ABSTRACT

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INTRODUCTION

1.1 History of the project

Since 1974 we have investigated the effects of extremely low frequency (ELF) fields on free flying migrant birds. These investigations were performed at the Wisconsin Test Facility (WTF) of the U.S. Navy at Clam Lake, Wisconsin. The relevant parts of this test facility for our discussion are the two crossed antenna segments, each about 14 miles long, running roughly north-south and east-west. At the intersection of these two antenna legs is the transmitter facility (termed transmitter site) which houses personnel as well as the ELF transmitter in a large aluminum and steel building approximately 70 m by 30 m by 10 m high. The characteristics of the electrical and magnetic fields created by the antenna system will be found in our previous final report for Contract N00014-75-00341.

By far the major part of bird migration in the U.S. occurs at night and thus it was necessary to detect birds by non-visual means. Small, mobile, low power radars have proven to be the best technique, although we also used light amplifying "starlight" telescopes and a vertically directed ceilometer. Two radars were used in the first two years of observation: a small tracking radar operated by Ronald Larkin and Pamela Sutherland of The Rockefeller University, and our ORNITHAR, a highly mobile research radar with an effective range of about 1 km. In all observations we utilized a blind testing procedure in which the antenna system was turned on and off in a predetermined sequence not known to the experimenters, while data on bird migration were recorded with the radars. Further information on this procedure will be found in the final report cited above.

Early observations with the ORNITHAR in the fall of 1974 strongly suggested that the mean direction of migration as observed near the transmitter site was shifted when the antenna was activated. More extensive ORNITHAR observations in the spring of 1975 confirmed this finding, but showed that the shift occurred when the north-south leg was active, but no reliable effect was noted when both legs were active or when only the east-west leg was active. Observations along the east-west antenna about halfway between the transmitter building and the western end of the antenna also failed to reveal any reliable effect of the antenna (only the east-west antenna was activated in these experiments). Observations with the tracking radar in the spring of 1975 did not show the deviation of average direction described above, probably because of the very much smaller number of birds detected (about 1/10th as many per hour), but did reveal an increased tendency for birds to depart from straight and level flight when the antennas were activated as opposed to when they were inactive. Larkin and Sutherland have published these results (Larkin and Sutherland, 1977) and ascribe the behavioral changes to a reaction of free flying migrants to ELF fields at very low power levels, a conclusion with which we concurred in our previous final report (op. cit.).

The aims of the present project were to clarify, if possible, the discrepancies between the two sets of radar data and more fully describe the phenomenon observed with the ORNITHAR by a thorough analysis of the extensive data collected during the fall of 1975. We also hoped to determine the limiting conditions for the effect by two experiments: a changing sites experiment in which we observed at three distances from the north-south antenna, and a changing power levels experiment in which the radar would remain stationary but the peak current in the antenna would be varied.

For all of these experiments, made in 1977, it was decided to operate away from the transmitter building. Since the ORNITHAR does not require external power, there was no advantage in operating near the transmitter, and a remote site would be free from noise and lights present at the transmitter. A second consideration was that it proved impossible to either measure or calculate the electric and magnetic fields at the transmitter site due to the complex interactions of the transmitter itself, its feed lines and the antenna proper (A. Valentino, pers. comm.). The situation halfway between the transmitter and the end of an antenna leg was considerably simpler and probably conforms closely to the field calculations presented in our previous report (op. cit.).

We also felt that it was important to evaluate the deviations observed in connection with ELF radiation with any normal perturbations of low level migration by natural phenomena, especially naturally occurring magnetic fields. To this end a very limited series of observations were initiated with the ORNITHAR, as virtually nothing is known of the effect of natural topography on the movements of birds at night within 100 m of the ground.

A final step in estimating the effects of ELF on migrants was a computer simulation which would indicate the possible result of a bird maintaining its deviated heading after departing Wisconsin.

1.2 Definition of terms

Track: direction of movement relative to the earth's surface.

Heading: direction in which a bird is oriented in flight; its direction of movement relative to the airmass.

Groundspeed: speed of a bird relative to a stationary earth.

Airspeed: speed of a bird relative to the airmass.

(Heading and airspeed are calculated from track and groundspeed by vector addition of the wind velocity.)

Mode: status of the WTF antenna during an observation period, i.e., both antennas off, both on, north-south antenna on, east-west antenna on.

Day: date of observation expressed as the number of days after January 1. Note that "day 274" does not imply daytime observation: most radar observation was at night.

Replication: a complete set of experimental and control conditions, usually repeated several times during a night of observation.

THE STUDY SITE

2.1 Ecology and avifauna

The U.S.N. Wisconsin Test Facility at Clam Lake, Wisconsin, is located in an extremely flat area of second growth coniferous forest about 58 km south of Lake Superior. The terrain is composed of an apparently random mozaic of timber, cut over lands, and lakes and marshes. Aerial photographs reveal no clear leading lines of the topography in the study area. Figure 2.1 gives the major features of the terrain of the study area with the observation sites used in 1977.

As identification of bird species is virtually impossible on radar, three methods were used to estimate the probable identity of the bird targets that were seen on the radar. 1: We took a daily bird census of an area which included the major habitart regions of the Wisconsin Test Facility; 2: we gathered bird counts from local bird watchers of the species of birds moving through the area during the study period; and 3: we acquired data from the several wildlife refuges in the northern Michigan and Wisconsin area as to the species and numbers of birds, especially waterfowl, that were moving through the refuges during the study period. All data were analyzed for the migration patterns and densities of birds moving through the area of the test site during the test periods. Table 2.1 lists, in the order found in the American Ornithologists Union Checklist (1957 and Supplements), all the bird species seen, as recorded by the above mentioned methods, during the two test periods of fall migration from late September to mid-October in 1975 and 1977.

Table 2.2 shows the numbers of migrants seen on the daily bird census of the test facility and by local observers in the Clam Lake, Wisconsin area. Several species, such as geese, Robins, Yellow-rumped Warblers, and juncos, show major movements through the area, as indicated by changes in the density of species observed. These species show the greatest density changes but we consider changes in species seen only in small numbers as also being important. In some cases Table 2.2 records the movements of only a few members of a species (loons, grebes, hawks, woodpeckers and some warblers and sparrows). Since these species are known to migrate through northern Michigan and Wisconsin during September and October we consider it probable that a significant number of birds detected by radar were of these species.

Information gathered for us at Seney Wildlife Refuge in northern Michigan, at Horicon and Necedah Wildlife Refuges, both in Wisconsin, and by the State of Wisconsin Department of Natural Resources, Area Headquarters located in Park Falls, Wisconsin, has shown the dates of the densest waterfowl migration, including both geese and ducks, through those areas for the test periods in both 1975 and 1977. In both years the greatest movement of birds into the four areas listed above occurred from about 28 September to 2 October. The greatest density of waterfowl in the areas ranged from about 10 October at Seney (the most northerly) to about 14 to 16 October in the more southerly refuges. After those dates, the birds started moving south out of the areas. As can be seen, the peak movement of waterfowl into the area of the Test Facility fell within the dates of our time in Wisconsin.

Figures 2.2 through 2.10 show the distribution of wintering areas of the species we consider to be the most common migrants through the study area during our fall observations. These charts were prepared from data supplied by C. Robbins of the U.S. Fish and Wildlife Service (pers. comm.) and reflect the probable migratory goals of birds moving through the area of northern Michigan and Wisconsin.

Analysis of these data indicate that we observed a great variety of species moving through the study area. The majority of birds were probably waterfowl (fast fliers as seen on radar) and song birds (slower fliers). Many of these birds are using the Mississippi flyway, showing a flight toward the south, but several species are moving south-southwest to the Gulf coast of Texas and Mexico, while a few species may move to the Atlantic coast, or on to the Caribbean or northern South America (see Figures 2.2 - 2.10).

2.2 Overview of migration detected with radar

Radar revealed intense migratory activity over the study site, especially during the mid-fall. The heaviest migrations we have recorded anywhere in the continental U.S. with the ORNITHAR were recorded during this study in 1975; migratory activity is at least as great, if not greater, than that along the eastern U.S. coast, traditionally considered to be one of the most active sites of fall migration.

Spring migration is considerably less active than fall migration. The mean numbers of birds detected per minute during the spring of 1975 was .589, while a mean of 17 per minute was detected during the fall, with some nights having more than 100 per minute.

Figure 2.11 gives the distribution of mean track directions for spring and fall migrations, and Figure 2.12 gives the distribution of observed groundspeeds for the fall data. (Most tracks detected during the spring were too short to give reliable speed measurements.) Both Figures 2.11 and 2.12 reflect the distribution of data used for this study rather than a true representation of the numbers of birds passing over the Wisconsin test site. We attempted to get nearly equal N for each night of observation; and on nights of heavy migration when more than 36,000 birds would pass over the study site in a night, we sampled data to keep the N between 100 and 1000 whenever possible. Thus, in the plots shown here, nights of heavy migration when most of the birds were in fact moving are under-represented.

The principal directions of migration in the fall were to the south and southeast, as is common for most radar studies of autumnal bird migration in central and northeastern North America. Movements to the north reflect the commonly observed phenomenon of reverse migration (see Eastwood, 1967).

The observed groundspeeds probably do not differ greatly from airspeeds as winds were usually light, with an average tailwind component estimated from weather maps of about 10 km/hr. The large numbers of birds traveling at more than 50 km/hr suggest that many of the birds we were observing were waterfowl or other strong fliers. Song birds were also certainly represented as shown by those birds moving at less than 50 km/hr. The radar data thus suggest that we sampled a wide range of species (as would be expected from the distributional data discussed above) including both small song birds and the larger waterfowl. As a sample of the entire avian population passing through the area we have probably emphasized the waterfowl both because any radar is more sensitive to large birds and because our observations were chosen to cover the later part of the migratory season when the more economically important species would be moving.

We have compared the radar data with the daily ground bird counts and the information from the refuges listed above for both falls, and we have found that there was a good correlation between the two. On all nights of dense migration on the radar, there were either high counts of birds during that day, representing birds that would move out that night, or high numbers of birds the following day, representing the birds which moved into the area during the previous night. The following presents the nights of the densest migrations as seen on radar during the falls of 1975 and 1977, along with the corresponding ground data.

dense migration as seen on radar	visual sightings	
1975		
30 Sept*	1 Oct	maximum influx of waterfowl recorded at Horicon W.R. for fall 1975
		- maximum number of waterfowl recorded at Necedah W.R.
		- high number of birds seen on daily ground count in WTF area
3 Oct	2 Oct	- movement of waterfowl into Horicon W.R.
	3 Oct	- high ground count in WTF area

* This was the most dense migration seen on radar during the entire four-year study period.

5 Oct	4 Oct & 5 Oct	- two of the four days with the highest number of birds seen on the ground counts in WTF area
7 Oct	7 Oct	- movement of waterfowl into Horicon W.R.
9 Oct 10 Oct	9 Oct	- large number of geese seen on ground count in WTF area
	10 Oct & 11 Oct	- movement of waterfowl in Horicon W.R.
	10 Oct	- major movement of ducks into Seney W.R.
		- largest number of geese seen at Seney W.R. on this day for 1975 season
14 Oct 15 Oct 16 Oct	14 Oct	- largest number of geese recorded at Necedah W.R. for 1975 season
	15 Oct & 16 Oct	- other two days of highest number of birds seen on daily ground count in WTF area
	16 Oct	- largest number of geese recorded at Horicon W.R. for 1975 season

1977

29 Sept	28 Sept & 29 Sept	- large number of birds seen on daily ground count in WTF area both days
		- goose migration at Park Falls both days
1 Oct	1 Oct & 2 Oct	- greatest influx of waterfowl recorded at Horicon W.R. for fall 1977
		- two days of the highest numbers of birds seen on daily ground count in WTF area
5 Oct	5 Oct	- high ground count in WTF area
	6 Oct	- movement of waterfowl into Horicon W.R.
14 Oct	14 Oct & 15 Oct	- large ground count in WTF area on both of these days

The weather during the two falls had a great deal to do with the differences seen between the migration patterns recorded in the two years. Frequent dense migrations occurred during our study period in the fall of 1975: the weather was warmer and drier in the area of northern Wisconsin than usual. Most species of birds left the area late, with warblers migrating through the area as late as the end of September and through October. The time during our study period in 1977, on the other hand, was cooler than normal, with a great deal of rain, resulting in the fact that on many nights there was very little migration, and that on nights of medium to heavy rain we were not able to make radar observations at all. However, during both falls, changes seen in the density of migration on radar were also reflected in changes in numbers of birds seen on the ground moving through the area.

Table 2.1

List of bird species seen during test periods (29 Sept to 17 Oct 1975 and 28 Sept to 17 Oct 1977) in the area of Clam Lake, Wis. and at the Wildlife Refuges in northern Michigan and Wisconsin.

Common Loon (Gavia immer)

Pied-billed Grebe (Podilymbus podiceps)

Canada Goose (Branta canadensis)

Blue Goose (Chen caerulescens)

Snow Goose (Chen hyperborea)

Mallard (Anas platyrhynchos)

Black Duck (Anas rubripes)

Canvasback (Aythya valisineria)

Ring-necked Duck (Aythya collaris)

Common Merganser (Mergus merganser)

Marsh Hawk (Circus cyaneus)

Red-tailed Hawk (Buteo jamaicensis)

Broad-winged Hawk (Buteo platypterus)

Sparrow Hawk (Falco sparverius)

Ruffed Grouse (Bonasa umbellus)

Great Blue Heron (Ardea herodias)

Solitary Sandpiper (Tringa solitaria)

Barred Owl (Strix varia)

Belted Kingfisher (Megaceryle alcyon)

Yellow-shafted Flicker (Colaptes auratus)

Pileated Woodpecker (Dryocopus pileatus)

Yellow-bellied Sapsucker (Sphyrapicus varius)

Hairy Woodpecker (Dendrocopos villosus)

Downy Woodpecker (Dendrocopos pubescens)

Gray Jay (Perisoreus canadensis)

Blue Jay (Cyanocitta cristata)

Common Raven (Corvus corax)

Table 2.1 (cont.)

Common Crow	(*Corvus brachyrhynchos*)
Black-capped Chickadee	(*Parus atricapillus*)
White-breasted Nuthatch	(*Sitta carolinensis*)
Red-breasted Nuthatch	(*Sitta canadensis*)
Robin	(*Turdus migratorius*)
Hermit Thrush	(*Hylocichla guttata*)
Veery	(*Hylocichla fuscescens*)
Golden-crowned Kinglet	(*Regulus satrapa*)
Ruby-crowned Kinglet	(*Regulus calendula*)
Cedar Waxwing	(*Bombycilla cedrorum*)
Northern Shrike	(*Lanius excubitor*)
Loggerhead Shrike	(*Lanius ludovicianus*)
Tennessee Warbler	(*Vermivora peregrina*)
Yellow-rumped Warbler	(*Dendroica coronata*)
Palm Warbler	(*Dendroica palmarum*)
Ovenbird	(*Seiurus aurocapillus*)
Northern Waterthrush	(*Seiurus noveboracensis*)
Red-winged Blackbird	(*Agelaius phoeniceus*)
Common Grackle	(*Quiscalus quiscula*)
Evening Grosbeak	(*Hesperiphona vespertina*)
Pine Siskin	(*Spinus pinus*)
Slate-colored Junco	(*Junco hyemalis hyemalis*)
Tree Sparrow	(*Spizella aborea*)
Chipping Sparrow	(*Spizella passerina*)
White-crowned Sparrow	(*Zonotrichia leucophrys*)
White-throated Sparrow	(*Zonotrichia albicollis*)
Fox Sparrow	(*Passerella iliaca*)
Swamp Sparrow	(*Melospiza georgiana*)
Song Sparrow	(*Melospiza melodia*)

Table 2.2

Numbers of migrant birds seen in one week blocks in Clam Lake area, 1975 & 1977

	9/28 - 10/4	10/5 - 10/11	10/12 - 10/18
Common Loon		1	
Pied-billed Grebe	9	3	3
Canada Goose	X		
Blue & Snow Goose		24	
Mallard	4		
Black Duck			3
Canvasback			1
Common Merganser		1	
Marsh Hawk		1	
Red-tailed Hawk			1
Broad-winged Hawk			1
Sparrow Hawk	X		
Great Blue Heron		X	1
Solitary Sandpiper	2		
Yellow-shafted Flicker	1	3	
Yellow-bellied Sapsucker	3	1	
Blue Jay	10	5	3
Common Crow	13	1	7
Robin	26 + X	28	5
Hermit Thrush	14	11	4
Veery	3		1
Golden-crowned Kinglet	2	3	
Ruby-crowned Kinglet	1 + X		
Tennessee Warbler	8	1	
Yellow-rumped Warbler	62 + 100	6	3
Palm Warbler	2	X	

X = sighting made, but with no record of numbers

Table 2.2 (cont.)

	9/28 - 10/4	10/5 - 10/11	10/12 - 10/18
Ovenbird	2		
Northern Waterthrush	1		
Red-winged Blackbird		X	
Common Grackle			X
Pine Siskin		X	40
Slate-colored Junco	147 + X	127 + X	116 + X
Tree Sparrow		2	2
Chipping Sparrow	1		
White-crowned Sparrow	X		
White-throated Sparrow	5		
Fox Sparrow	2	X	
Swamp Sparrow			1
Song Sparrow	4	1	X

X = sighting made, but with no record of numbers

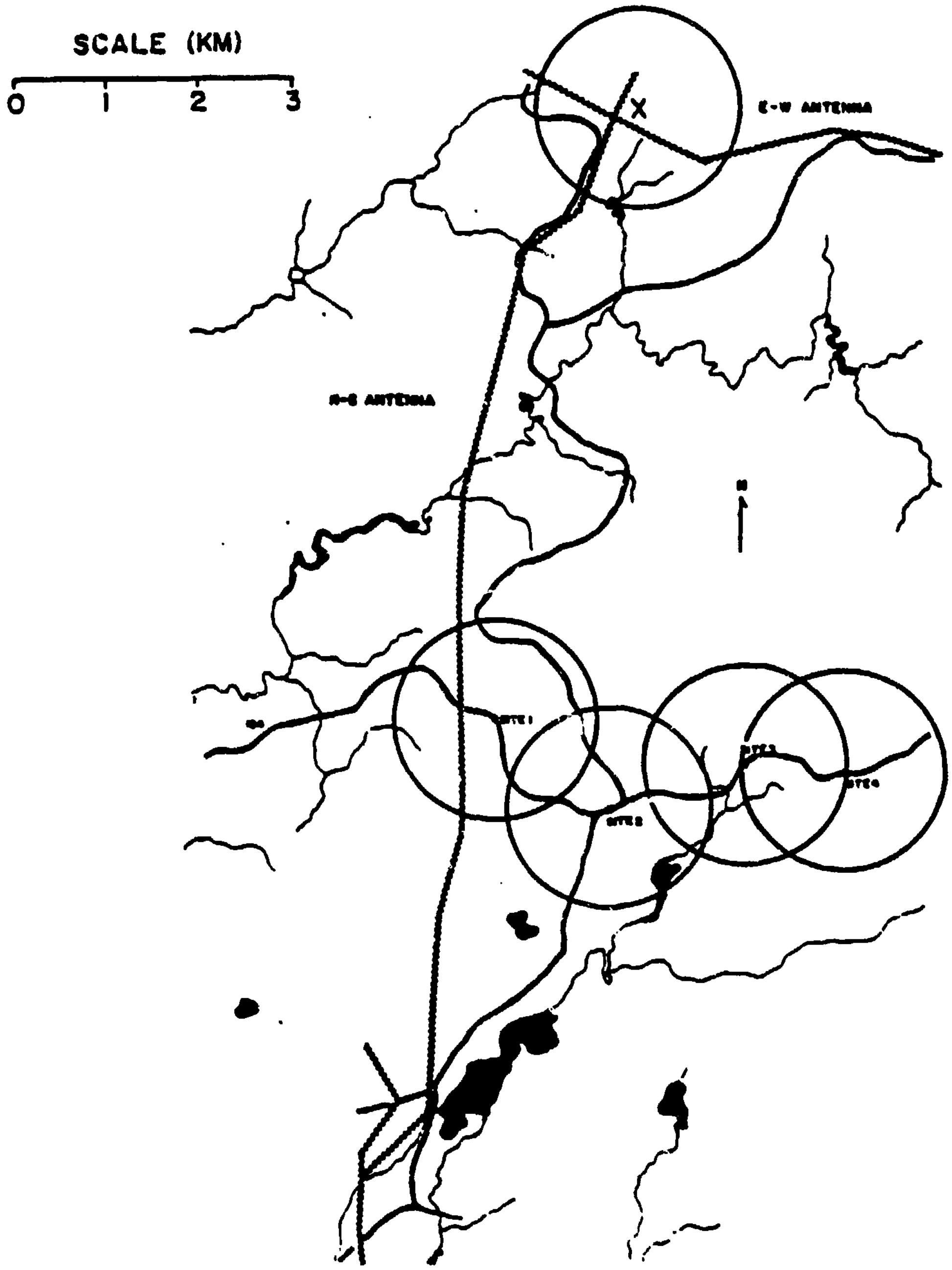


Figure 2.1

Map of the study area showing the north-south leg of the WTF antenna, its intersection with the east-west antenna, the four observation sites used in 1977, and the principal lakes and roads. X indicates the transmitter site; circles give the approximate range of the radar.

Figures 2.2 - 2.10

The following nine maps show the distribution of the wintering areas (data supplied by Chandler Robbins, pers. comm.) of the migrant species most commonly seen in the study area during the fall of 1975 and 1977. Location of WTF marked by an X in northern Wisconsin.

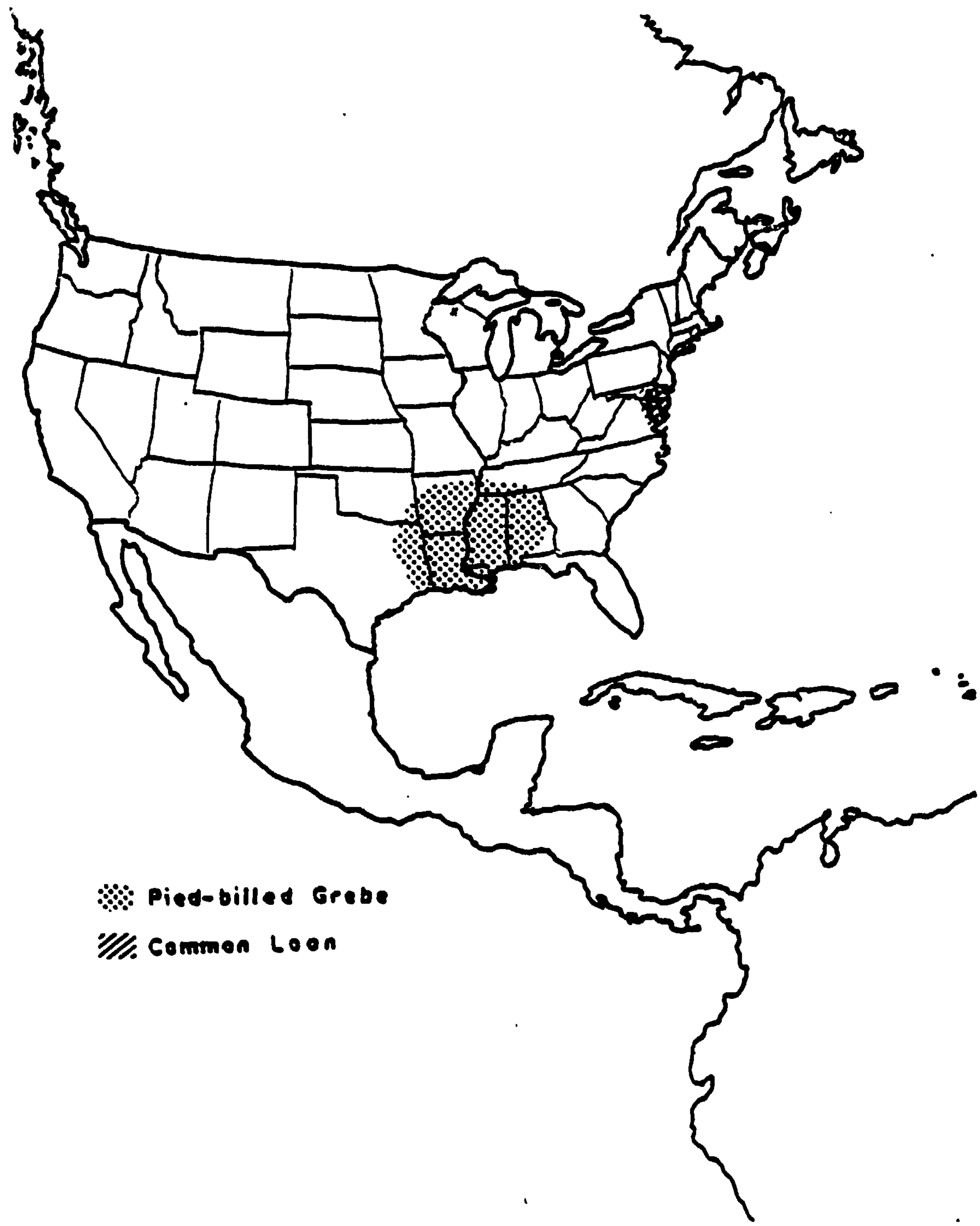


Figure 2.2

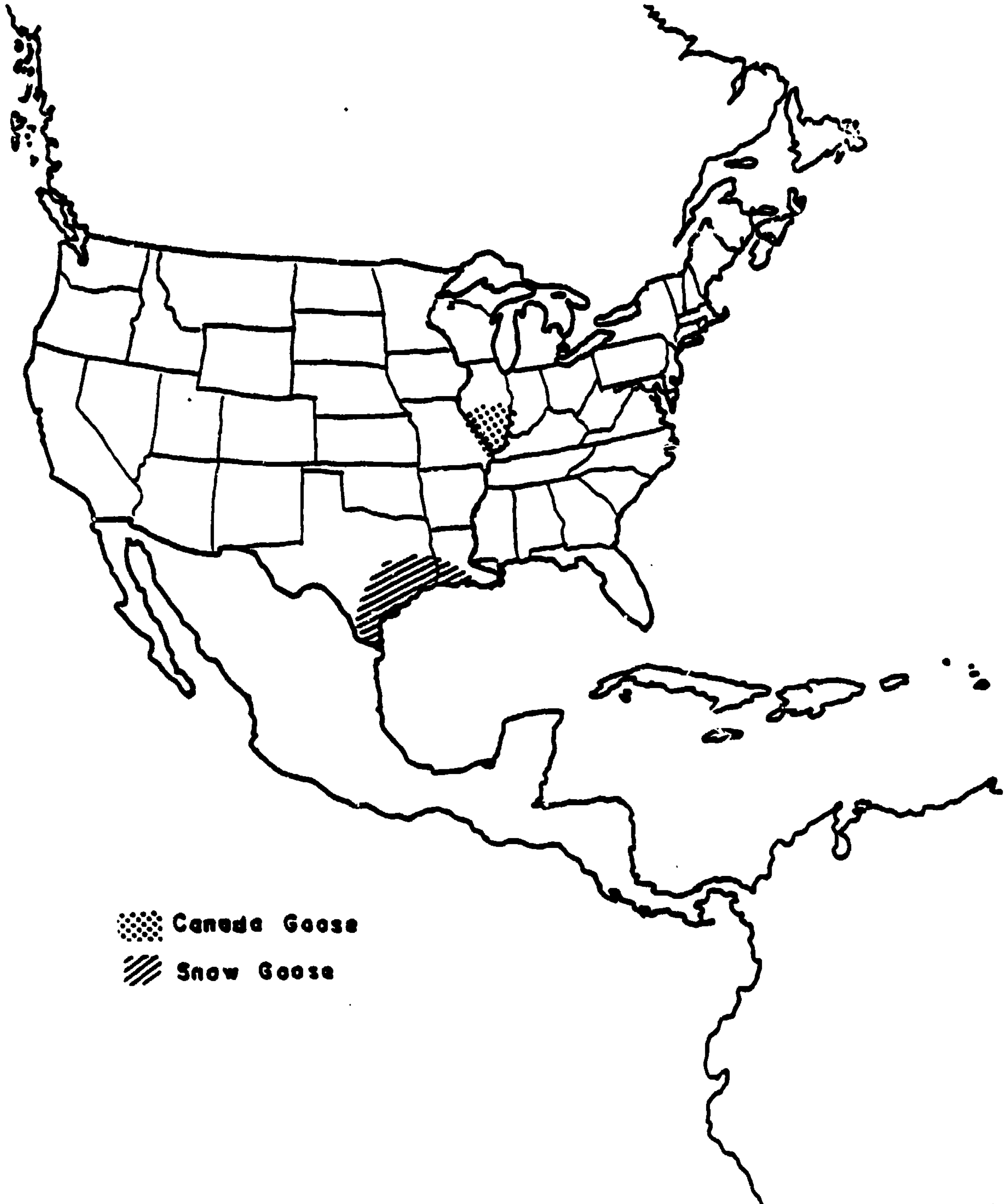


Figure 2.3

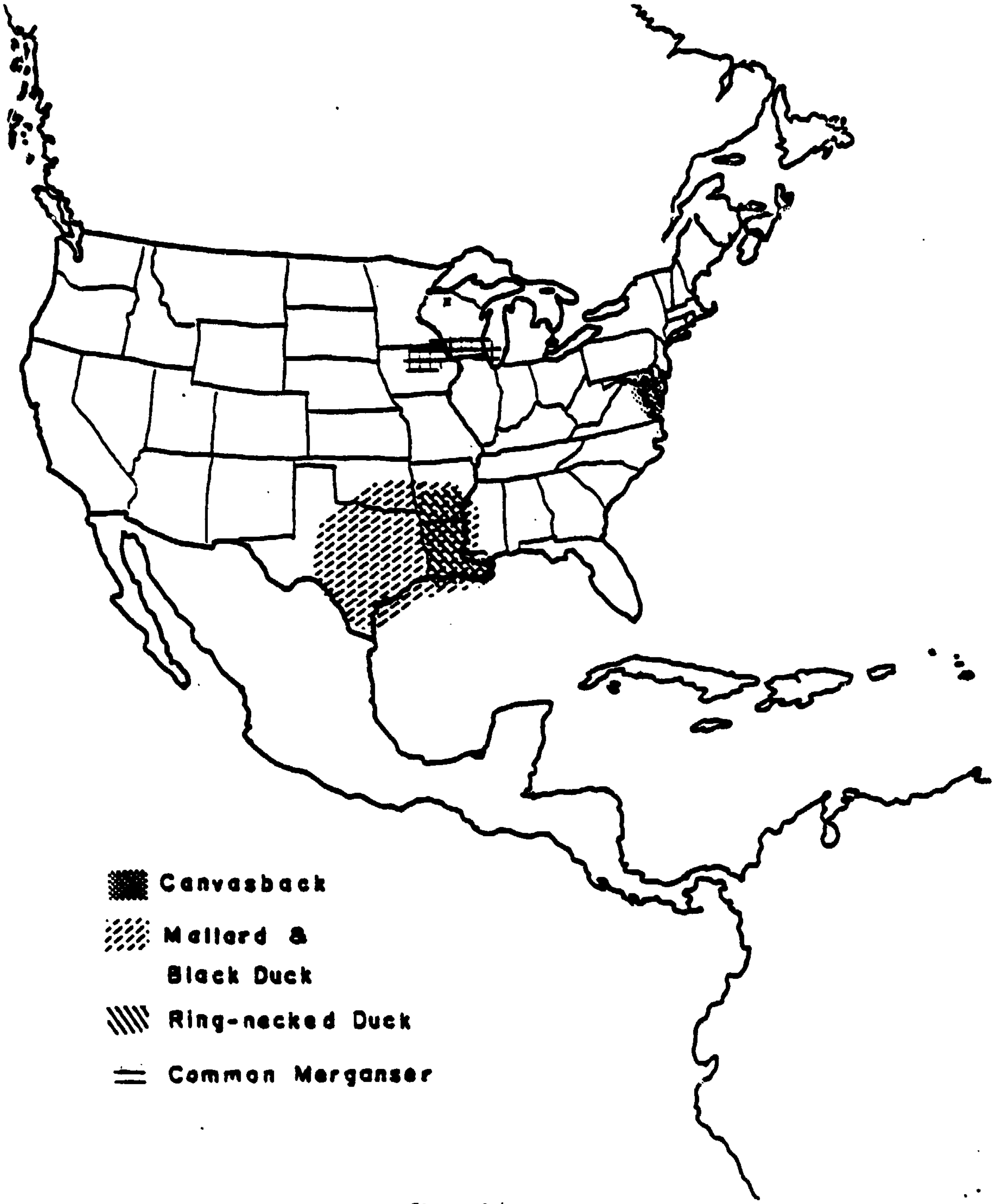
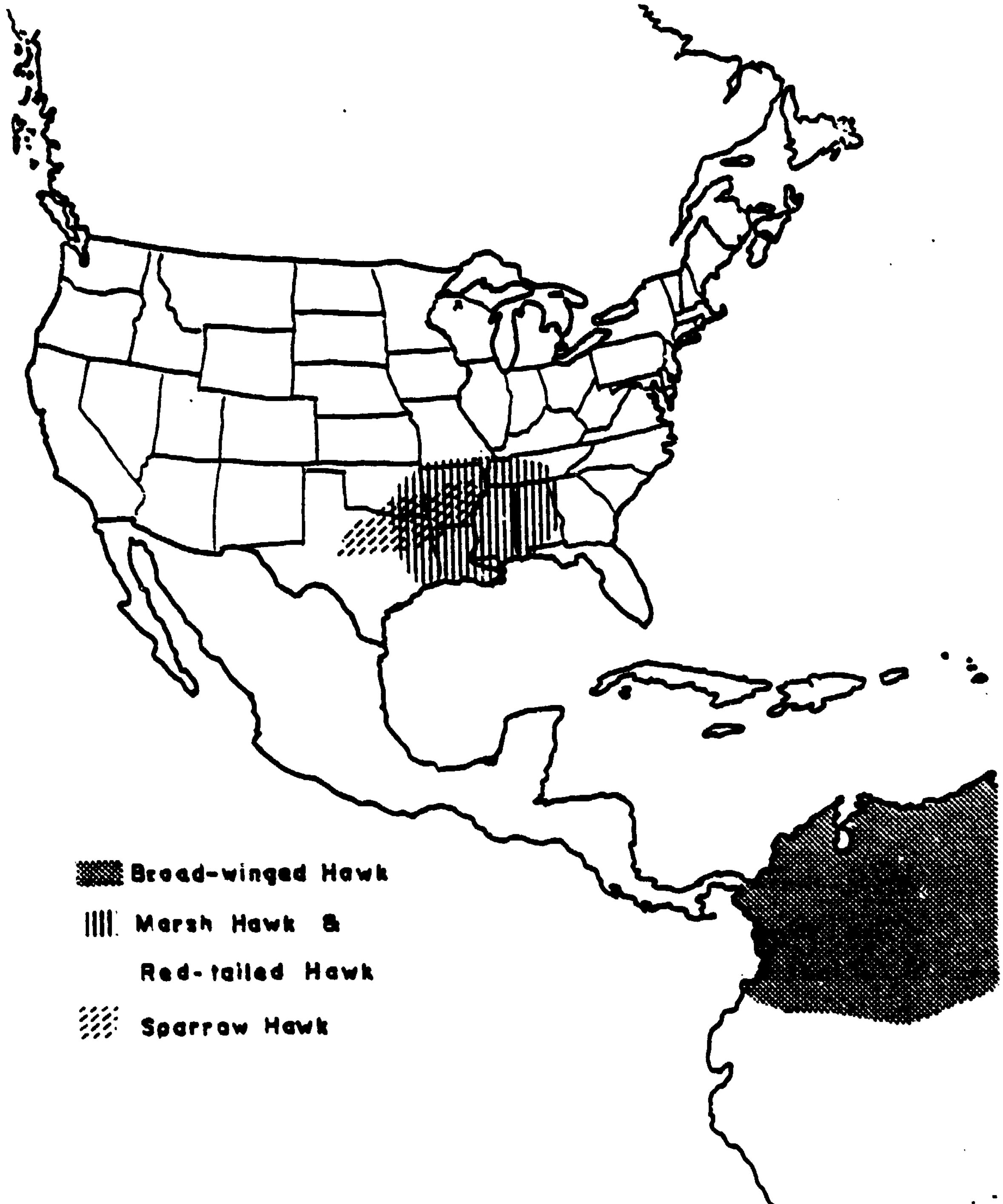

Canvasback
Mallard &
Black Duck
Ring-necked Duck
Common Merganser

Figure 2.1



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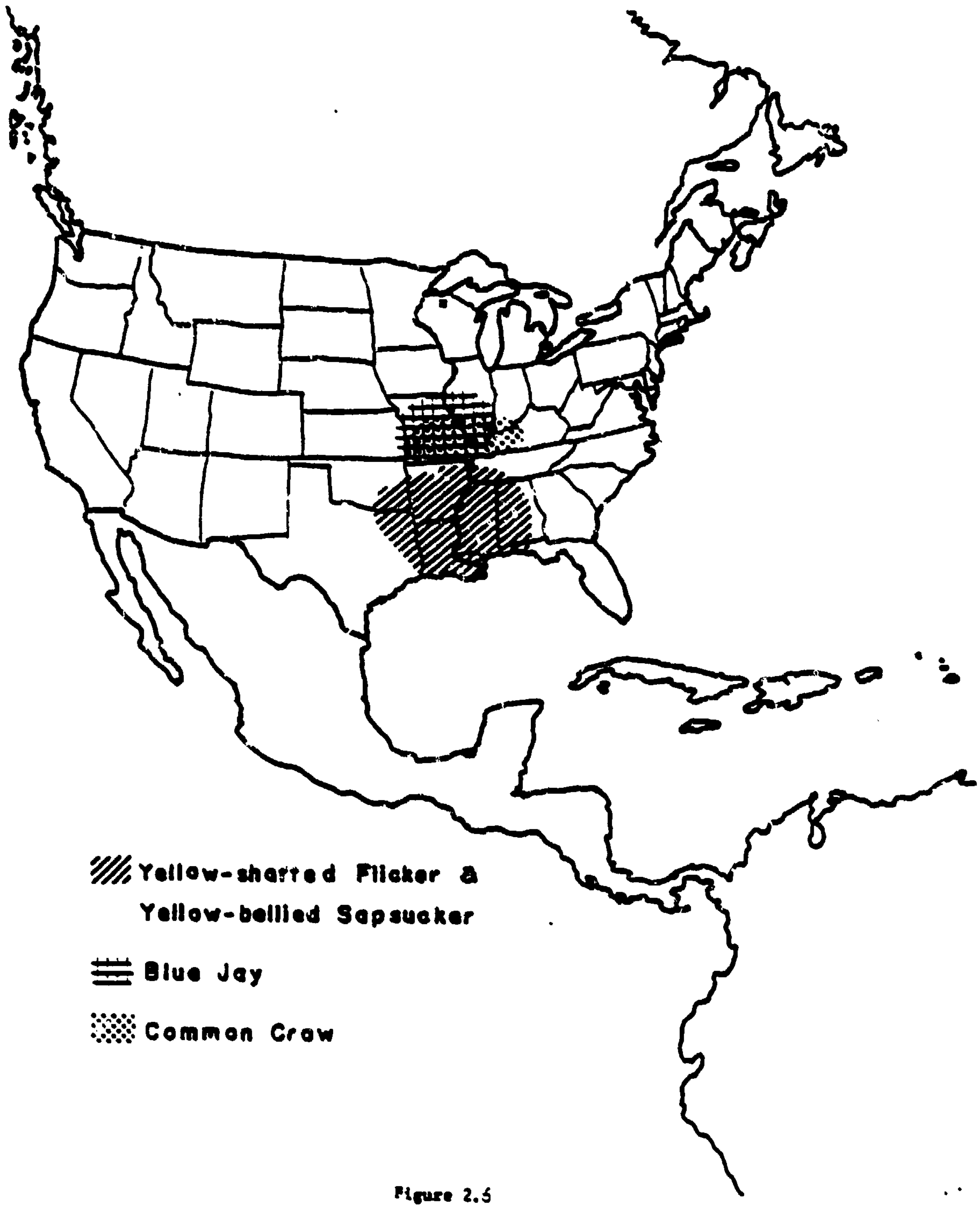

Yellow-shafted Flicker &
Yellow-bellied Sapsucker
Blue Jay
Common Crow

Figure 2.5

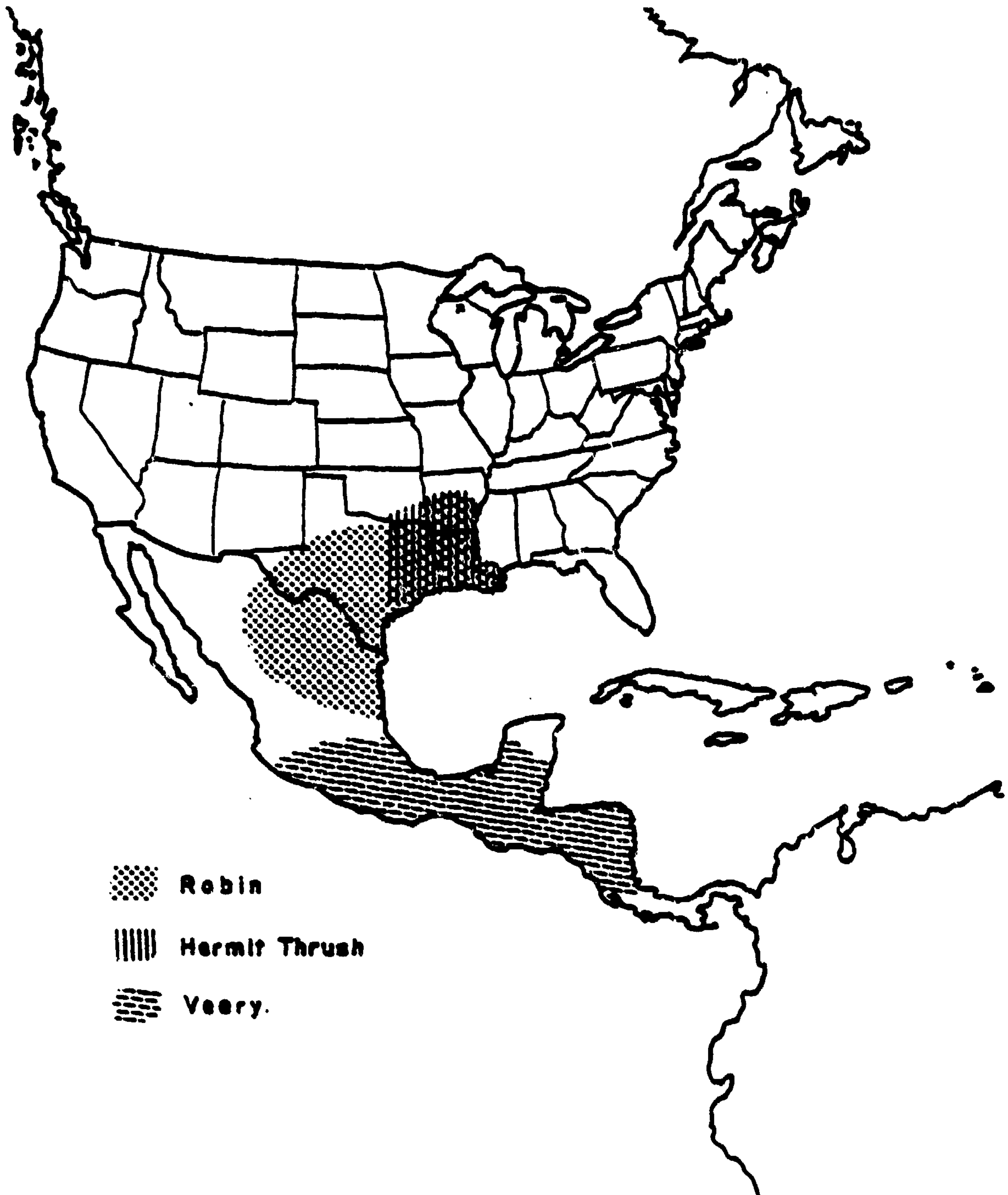


Figure 2.7

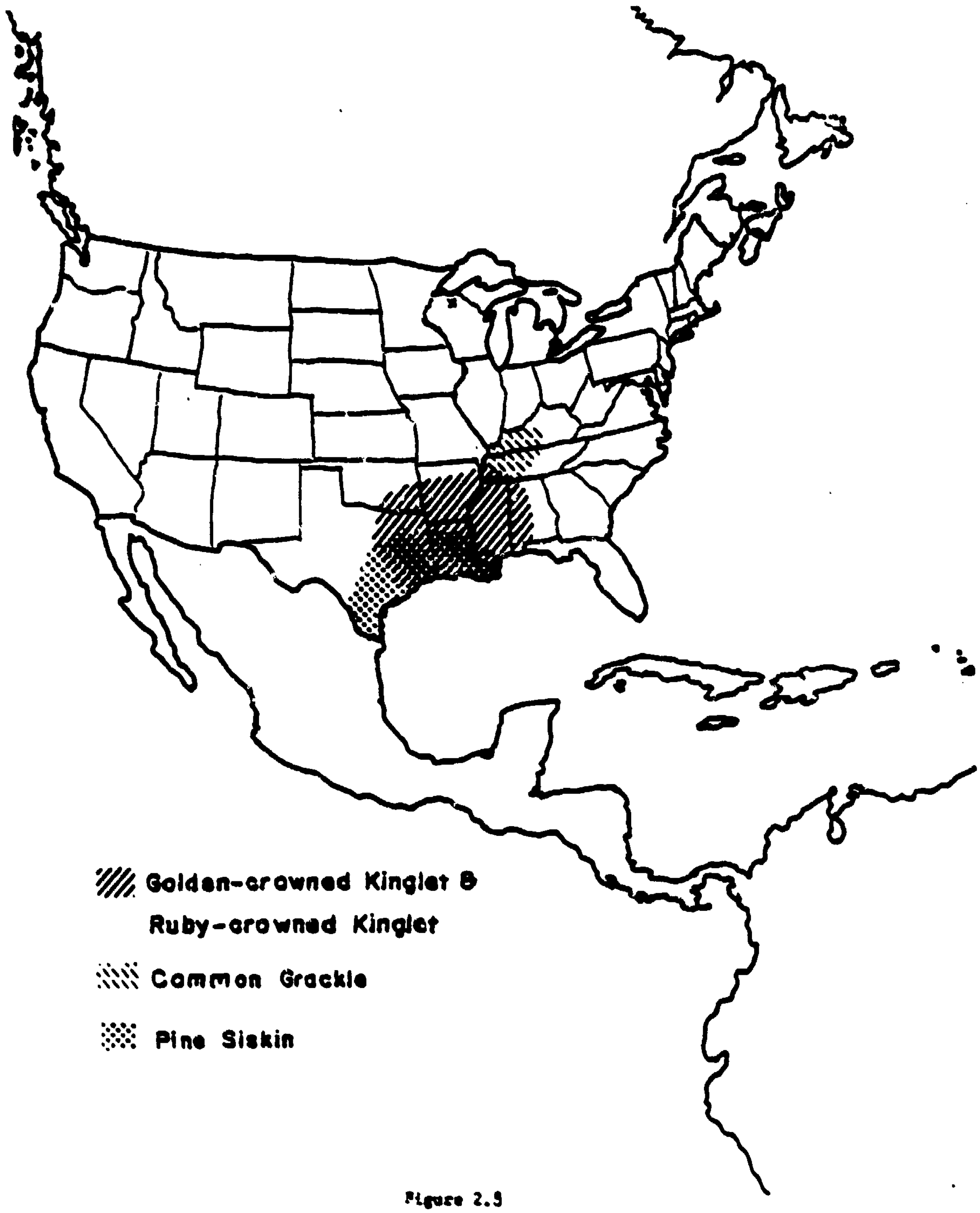

Golden-crowned Kinglet &
Ruby-crowned Kinglet
Common Grackle
Pine Siskin

Figure 2.3

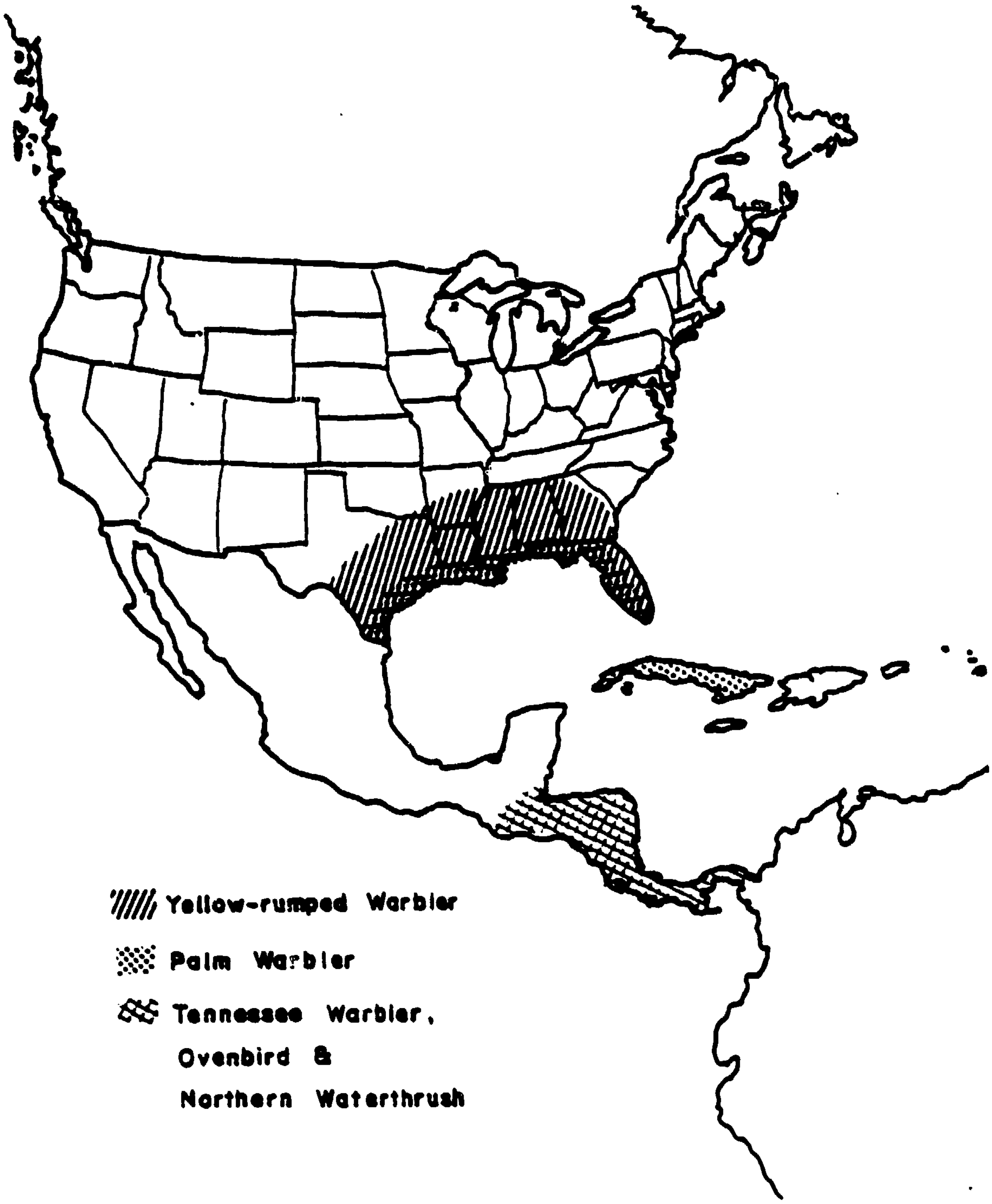

Yellow-rumped Warbler
Palm Warbler
Tennessee Warbler,
Ovenbird &
Northern Waterthrush

Figure 2.9

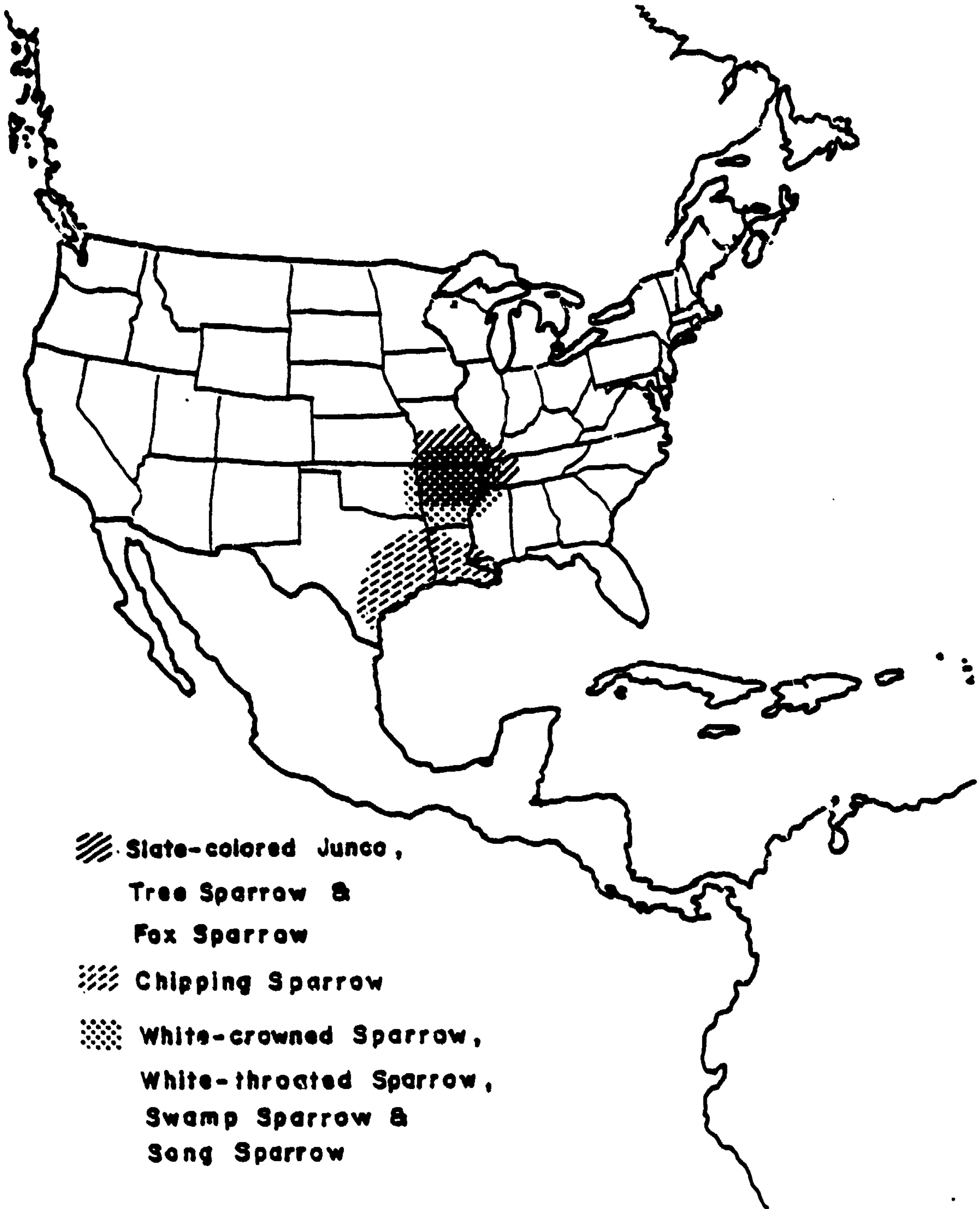
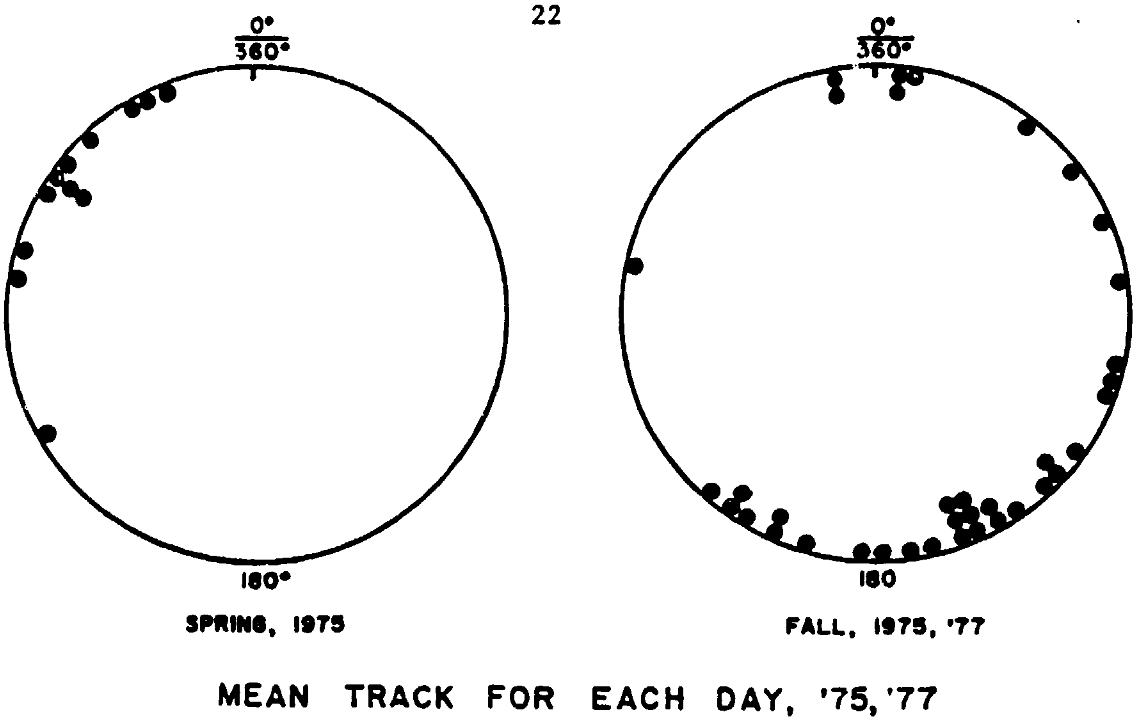

Slate-colored Junco,
Tree Sparrow &
Fox Sparrow
Chipping Sparrow
White-crowned Sparrow,
White-throated Sparrow,
Swamp Sparrow &
Song Sparrow

Figure 2.10



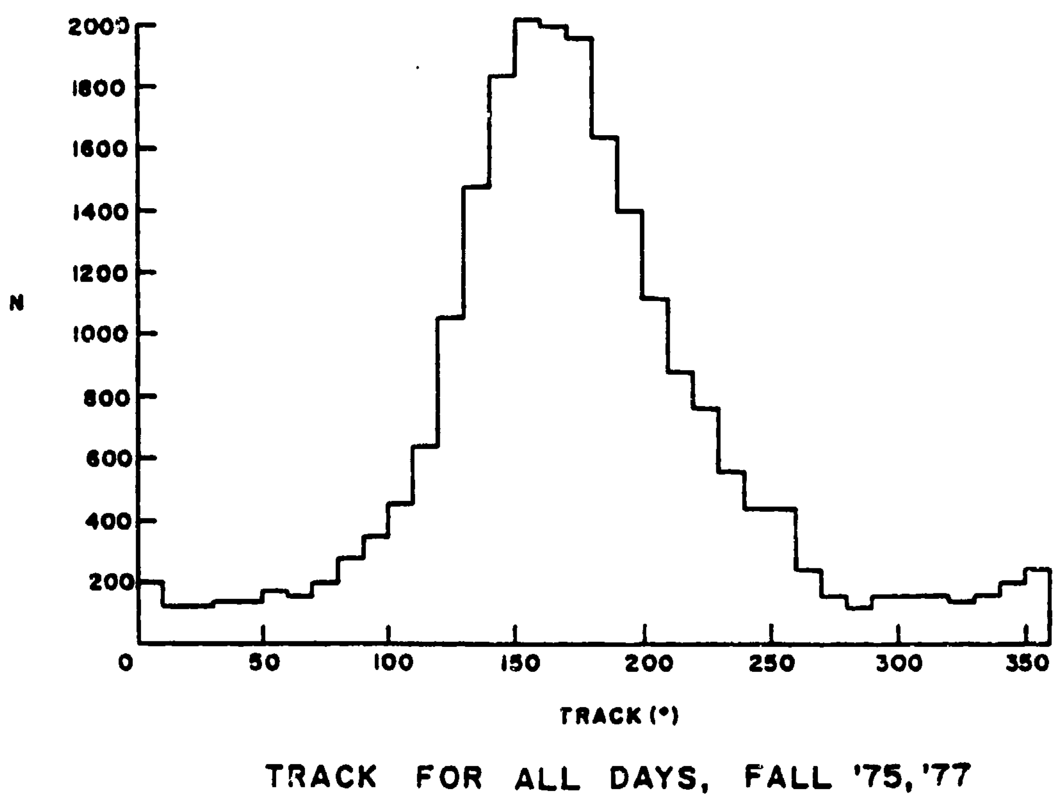


Figure 2.11

Distribution of tracks for 1975 and 1977. The two circles show the distribution of nightly mean track directions for spring and fall. The histogram shows the distribution of all track directions, recorded in fall observations.

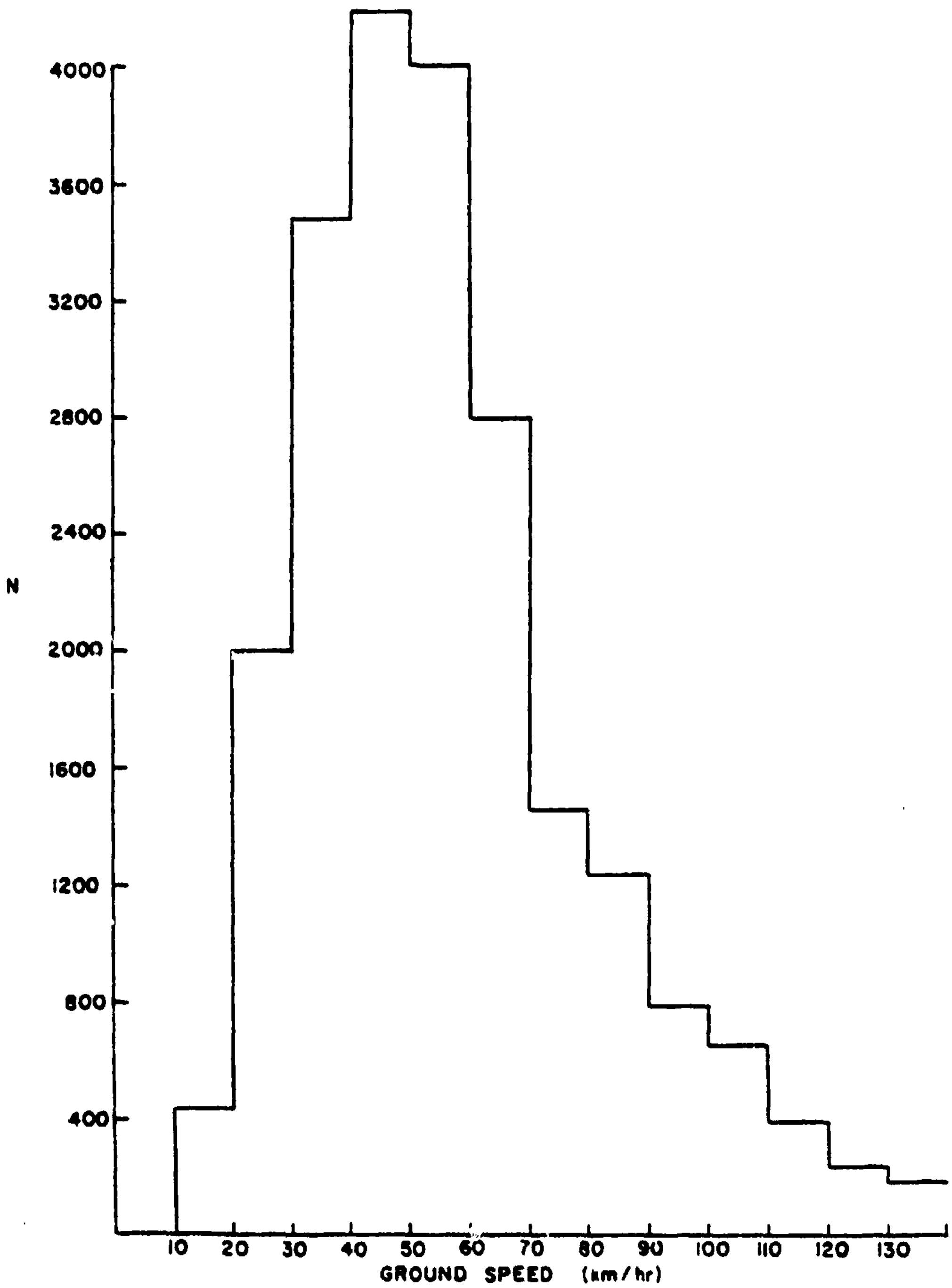


Figure 2.12

Distribution of observed groundspeeds from fall data in 1975 and 1977.

THE OBSERVED EFFECT OF ELF ON MIGRANT BIRDS: STUDIES AT THE TRANSMITTER SITE

3.1 Introduction

During the fall of 1975 from 29 Sept to 16 Oct the tracks of more than 100,000 birds were recorded by the ORNITHAR radar in Wisconsin. These data were selected for analysis so as to maintain an average of between 50-200 tracks per experimental condition whenever possible. This resulted in a total of 10,932 scored tracks for this period. These tracks were analyzed to determine the time variation in migratory behavior, and the possible effects of an imposed ELF field on the migrants. We also were interested in a comparison of the effects observed with our radar and with the tracking radar used by Larkin and Sutherland.

3.2 Methods

The ORNITHAR radar is a short range, high resolution, mobile search radar which closely approximates a human observer with binoculars in its ability to detect birds (range about 1 km; ground level to about 200 m) but can function at night or under poor visibility conditions. A 3 kW peak power X band (3 cm wavelength) modified marine radar is mounted on a small van; all power and data recording systems are self-contained, affording great mobility, with set-up time being about 1 minute in established observation sites. The radar is operated at 0.08 microseconds for maximum resolution at .27 rpm. The slotted waveguide antenna produces a fan-shaped beam 2.5° wide horizontally and 30° wide vertically at the 3 db points.

A detailed description of the procedures used for activation and inactivation of the antenna system at the transmitter site will be found in our previous report (op. cit.). In summary, the antenna system was turned on and off between four conditions: both antennas on, the north-south antenna on, the east-west antenna on, and all power shunted into a dummy load ("off"). The order of activation of the antenna was pseudo random, i.e., all four conditions were repeated within each hour and were unknown to the observers in the ORNITHAR radar. Each condition of steady antenna state was identified only as mode 1, 2, 3... etc. for purposes of labeling on the radar data. During all phases of the scoring of data this terminology was used up to the point of analysis by computer when the antenna states were identified.

A peak antenna current of 300 A was used which gave peak calculated electric fields of about 0.15 to .06 volts/m and magnetic fields of about .02 to .001 gauss over the range of the radar (see calculated field contour maps in our previous report, op. cit.).

Data from the PPI display of the ORNITHAR radar are recorded on Super 8 mm film, such that one revolution of the radar antenna is recorded on one frame of the film. The film is then projected on sheets of white paper and the positions of all moving targets detected visually are traced from the film. (Despite continued efforts, it has not been possible to devise a computer program that will effectively recognize low amplitude echoes moving slowly through radar noise and ground return; the human visual system remains the instrument of choice for this task.) The points of each track are then connected, and these X - Y coordinates are recorded through a digitizer on computer cards.

A program written by B. Cohen then converted these data into a best estimate of the true path of a bird over the earth's surface. Objects actually moving in a straight path but at an elevation angle greater than 15° will show spherical distortion in their radar track. Such tracks were recognized and corrected with an estimate of their altitude (Cohen and Williams, in prep.). A regression line was then fitted to the data using the method of finding the major axis in which error estimates are not dependent upon the slope of the line. The variables determined for each track are described in Table 3.1.

3.3 Time variation in migratory behavior

Figure 3.1 presents a detailed analysis of data from day 286 in which the data for each minute of observation are averaged separately. The upper portion of the figure shows the density of migration throughout the night. The break in data is due to a temporary power failure in the data recording camera. The lower portion of the figure gives data for two selected portions of the night. This figure clearly shows the two principal sources of variation: variation between individual birds, and changes in the general population of migrants over the course of several hours. The single largest source of variation is the behavior of individual birds. This is particularly evident when the number of birds drops below 10 for any given point as is the case in the lowest graph in Figure 3.1 (compare the variability from 2015 to 2030 with that from 2330 to 2345). It was for this reason that we sought to maintain an N of between 50 and 200 for any experimental period.

The upper portion of Figure 3.1 also reveals the slow changes that occur in the behavior of birds over a single night of observation. The density of migration was much greater during the first hour of observation than that during the last three hours. Figure 3.2 gives the average direction for each 15 min experimental period during three selected nights, one heavy (day 274) and one light (day 272) early in the season, and one heavy (day 286) late in the 1975 season. For the first night we analyzed all tracks of birds detected by the radar (as was done for the spring data in our previous report, op. cit.). For the second, we analyzed 3 minutes from the center of each experimental period (these data were as far as possible in time from any effects of change in antenna state). For the third night we analyzed all tracks detected at more than .4 km from the radar in an effort to look only at the larger birds (presumably waterfowl).

All three nights clearly show the tendency for slow changes in direction during the night. Figure 3.3 shows that such changes are not restricted to direction of migration. The first graph of Figure 3.3 indicates that there were two peaks of migratory activity during day 272: one at about 2145 and the second beginning about 2230. The following graphs in this figure show that the change in density at about 2230 was accompanied by simultaneous change in several other parameters of migratory behavior. Birds migrating later in the night were faster moving, more variable in speed, detected at greater range, turned more and were traveling in a more easterly direction than were birds detected earlier in the night. It would clearly be unwise to compare a long experimental period covering the early part of the night with a long control period covering the later part of the night. During the period of transition (2215 to 2315) it would be desirable to have more than one pair of experimental and control conditions as there was considerable change within this hour.

3.4 Direction

The association of a deviation in the direction of bird migration with antenna state was investigated by plotting the deviation of the average direction of each experimental condition from the nearest "off" condition. These data are presented in Figure 3.4.

As with previous studies, some nights showed a clear pattern of deviations with the north-south antenna condition resulting in a consistent deviation of 5 to 20° from the control conditions (days 274, 278 and 286), the east-west and "both" conditions showing no clear pattern.

There was no apparent association between nights showing such deviations and weather factors or magnetic disturbances as measured by K factor.

Figures 3.2 and 3.4 show that the shifts in direction of migration as the antenna is activated are often consistent within a night. On day 286 there is very little response as the antenna conditions are changed, although all but one experimental condi[illegible]on are clockwise from the control. On day 272 any effects of the antenna system may have been masked by the slower changes discussed above and the low number of birds migrating that night. Day 274, however, clearly shows a regular change in migratory behavior as the antennas are turned on and off.

These regular shifts in average orientation constitute the most convincing evidence available to date on the effect of antenna state on direction. Conventional "linear" statistics cannot be used on directional data due to the overlap of 0° and 360°. Although a number of two sample tests are available for circular data, the only multisample test [illegible] parametric and as shown in Figure 3.3 data often departed from a normal distribution (bimodal or trimodal in this case). In previous reports we have ascribed a lack of such a pattern on some nights to a low N of tracks; this is probably not the case for the present data as all days had more than 400 tracks. Although inspection of Figure 3.4 shows that the north-south data tended to deviate more consistently to one side of the mean than the east-west or both conditions, the difference is not statistically significant. Repeating the chi-square test used in our previous report for spring data showed no significant difference in the distributions of the mean deviation of the experimental modes from the "off" condition ($X^2 = 4.34$ df $= 4$) when data from all experiments were summed.

3.5 Effects of antenna condition on other variables

Table 3.2 shows the results of repeated one way analyses of variance of several variables vs. antenna condition for each day of observation at the transmitter site in 1975. Despite the highly significant result for some variables on some days there is no obvious pattern of response. The days that showed the directional deviations, 274, 278 and 286, also show significant association of other variables with antenna state, but which variables show significant difference varies between even these days. In addition, since we have performed repetitive statistical tests we should expect some significant results on the basis of chance alone.

The conclusion from a full analysis of the 1975 data taken at the transmitter site was that there appeared to be a consistent effect of antenna state on the behavior of migrants on some nights, but that it was not consistent across all nights of observation. Further analysis of these data was suspended when data from the 1977 season indicated that the effect noted near the transmitter building was not seen at remote sites along the north-south antenna (see Sections 4 and 5).

3.6 Non-linearities in tracks vs. antenna state

Data taken on day 286 in 1975, when we experienced our heaviest migration of large, fast birds, were used to duplicate as closely as possible the analysis of Larkin and Sutherland. Two thousand two hundred sixteen tracks were traced and measured by hand and deviations from a straight line were estimated by eye relative to a set of specific criteria: all points within 20 m of a straight line, tracks departing 20 to 40 m from a straight line and departures greater than 40 m. Turning tracks were coded as right or left turns. Apparent turns due to spherical distortion (Cohen and Williams, in prep.) were corrected for antenna state and observed number of turning tracks. We grouped birds, as Larkin and Sutherland did, into turning and straight tracks vs. antenna "on" or "off" and antenna changing or constant. In addition, we broke down the types of turns into several different groupings of categories. We also selected only those tracks of birds crossing an active antenna and tested for an association between antenna state and turns. None of these tests gave significant results. Thus we conclude that on day 286 the number of turns is not associated with the state of activation of the ELF antenna. Inspection of Larkin and Sutherland's data shows that much of their effect was due to data from two nights rather than a constant effect noted on all nights. One might well conclude that our failure to find a similar effect on night 286 was not surprising (although the mean direction of birds during activation of the antenna was always west of the "off" condition). This explanation is not sufficient because we have also analyzed the data we collected in the spring of 1975 (simultaneously with Larkin) and also find no effect of antenna state on turns. Our data for the spring are not coded for transitional phases of antenna activation, only whether a given antenna was "on" or "off". Testing for number of turns during the spring of 1975 with antenna "on" vs. antenna "off", we find no significant association either for all data for all days summed or for any single day.

There does not appear to be a simple explanation for the difference in results between the two radars, especially when they were operating at the same time within 50 m of each other. Larkin and Sutherland used a tracking radar with about twice the range of our search radar but they tried to track low altitude birds as often as possible. The ORNITHAR detected horizontal turns similar to those depicted in Larkin and Sutherland's (1977) figures and both radars detected about the same percentage of turns although we obtained four times as many tracks. The primary differences between the two sets of data are: Larkin and Sutherland obtained tracks 2 to 10 times as long as ours with both altitude and horizontal position. Larkin and Sutherland often continued tracking after our radar ceased operations at 0000 hrs local time. Their tracks were somewhat higher than ours but there was considerable overlap. Hand scoring of data may also contribute to the differences in the two studies. In our laboratory we have found that two different research assistants using the same set of scoring criteria produced significantly different numbers of tracks and numbers of turning tracks from radar films taken on the same night. Thus, since both sets of data were hand scored, different sorts of non-linearities may have been emphasized in the two studies. For this reason we felt it was most important to obtain more objective measures of the non-linearity of tracks. [The measures which we developed (DEVIAT and MEANSQ) did not, however, show any noticeable tendency to correlate with directional change due to antenna state.]

3.7 Signal averaging

One of the aims of this study was to investigate the effects of duration of exposure to ELF on free flying migrant birds over the WTF. If birds were sensitive to ELF they might react immediately to the imposed field or there might be an increasing effect as the birds were exposed to the field around an active antenna. As shown in Figure 3.1, detailed minute by minute analysis of the behavior of birds after the activation of an antenna does not readily show a consistent trend. The inherent variability of migrants allows one to see increasing effects, decreasing effects or no change, depending upon which portion of the record one selects. We therefore elected to use signal averaging across several experimental modes to look for more general effects. We treated the north-south and the east-west legs of the antenna independently, neglecting any additive effects of both antennas. We analyzed the data in two ways. In the antenna "on" condition, we pooled the data for each minute after the east-west or north-south antenna was turned on. This includes two minutes of transition at each end of the 15 minute period while the antenna was being brought up to full power or reduced from full power. These data are shown in Figures 3.5 and 3.6. For the antenna "off" condition, we pooled the data for each minute in the 15 minute period after an antenna was turned off and also included the previous two minute transition phase as the antenna was being reduced from full power as shown in Figures 3.5 and 3.6. In both the antenna "on" and "off" conditions we give the averaged mean values of a variable for the preceding condition.

This technique was developed with day 272 since the smaller number of cases on that day could be stored easily on the computer. The data from day 272 indicate that there does not appear to be any general trend of change for any of the variables we have tested. The transition phases do not appear to be greatly more variable than the steady state phases. Regressions were performed for the variables shown in Figures 3.5 and 3.6 and also for NORMRES and the percentage of curves due to high altitude flight (all the data in Figures 3.5 and 3.6 exclude these curves). None of these correlations was significant. Our original plan had been to perform a similar analysis with days 274, 278 or 286 which showed the change of direction. The analysis was halted when the data from 1977 suggested this effect was restricted to the transmitter site. Due to the large N of cases on these days a signal averaging analysis would have consumed 1/4 of the remaining resources of the project.

3.8 Conclusions

We conclude that on certain nights the average direction of migration in the area of the transmitter at the WTF shifts 5° to 20° when the north-south antenna leg is activated. The magnitude of the effect is not predictable from weather or migratory behavior (direction, speed, etc.) variables. On certain days other aspects of migratory behavior are also affected but not in a systematic manner. The importance of this effect is discussed in Section 5.4.

Table 3.1

Variables recorded for bird tracks

SITE - location of radar observations

DAY - day of the year

TIME - time of night (hrs, min)

FR - number of frames of radar film per minute

NTRAK - identifying number of the bird track

CURV - a code indicating whether the apparent curvature of the track is due to spherical distortion (angle of elevation of bird exceeds 15°)

LIMIT - number of data points in the track (estimated)

NC - number of observed data points in the track (excluding frames in which the bird was not seen)

XCRV1, YCRV1 - coordinates of the first data point

LENGTH - distance between the endpoints of the track (m)

SUMLEN - sum of the distances between all data points (m)

SPD - groundspeed of the bird (km/hr)

HEAD - track of the bird (deg) - i.e. direction of movement not adjusted for wind

COEFVAR - coefficient of variation of speed

$$= \frac{\text{standard dev. of interpoint distances}}{\text{mean of interpoint distances}} \times 100$$

XMEAN - mean of x-coordinates

YMEAN - mean of y-coordinates

RES = MEANSQ - mean square residual (m)

$$= \frac{\sum(\text{distance* from obs. pt. to regression line})^2}{(\text{number of points})-1}$$

*measured along a line perpendicular to the regression line

RMAX - maximum observed range of the bird from the radar (m)

H - altitude of the bird (m) for tracks showing spherical distortion

HERR - standard deviation of the error associated with determination of H

DEVIAT - ratio of the total track length to the straight line distance between the endpoints of the track

$$= \frac{\text{sum of interpoint distances}}{\text{distance between endpoints of track}}$$

Table 3.1 (cont.)

PDEVIAT - difference between track length and straight line path as a percentage of track length

$$= \frac{\text{(sum of interpt. dist.) - (endpt. dist.)}}{\text{(endpoint distance)}} \times 100$$

NORMRES - normalized mean square residual

$$= \frac{\text{MEANSQ}}{\text{average interpoint distance}} \times 100$$

NAVG - Average perpendicular distance from the north-south antenna leg

ENAVG - Average perpendicular distance from the east-west antenna leg

Table 3.2

Significance levels for analysis of variance by antenna condition for twelve variables. Observations at the transmitter site in 1975.

DAY	LIMIT	NC	LENGTH	SUMLEN	SPD	COEFVAR	RMAX	MEANSQ	NAVG	EMAVG	HEAD [1]	DEVIAT	N
272					*								447
274	***	***	***	***				**					907
276	**	**					*	*			*	*	1752
278							**		**	*	*		1655
280			*	*			***			*	*		585
282										*			1228
284							***			*			955
286 [2]					*						*		1152
289							*						1176
											Total		9857

* p < .05 ** p < .01 *** p < .001

Notes:
1. Circular analysis of variance as in Mardia (1972).
2. Only LENGTH, SPD, RMAX, and HEAD were tested.

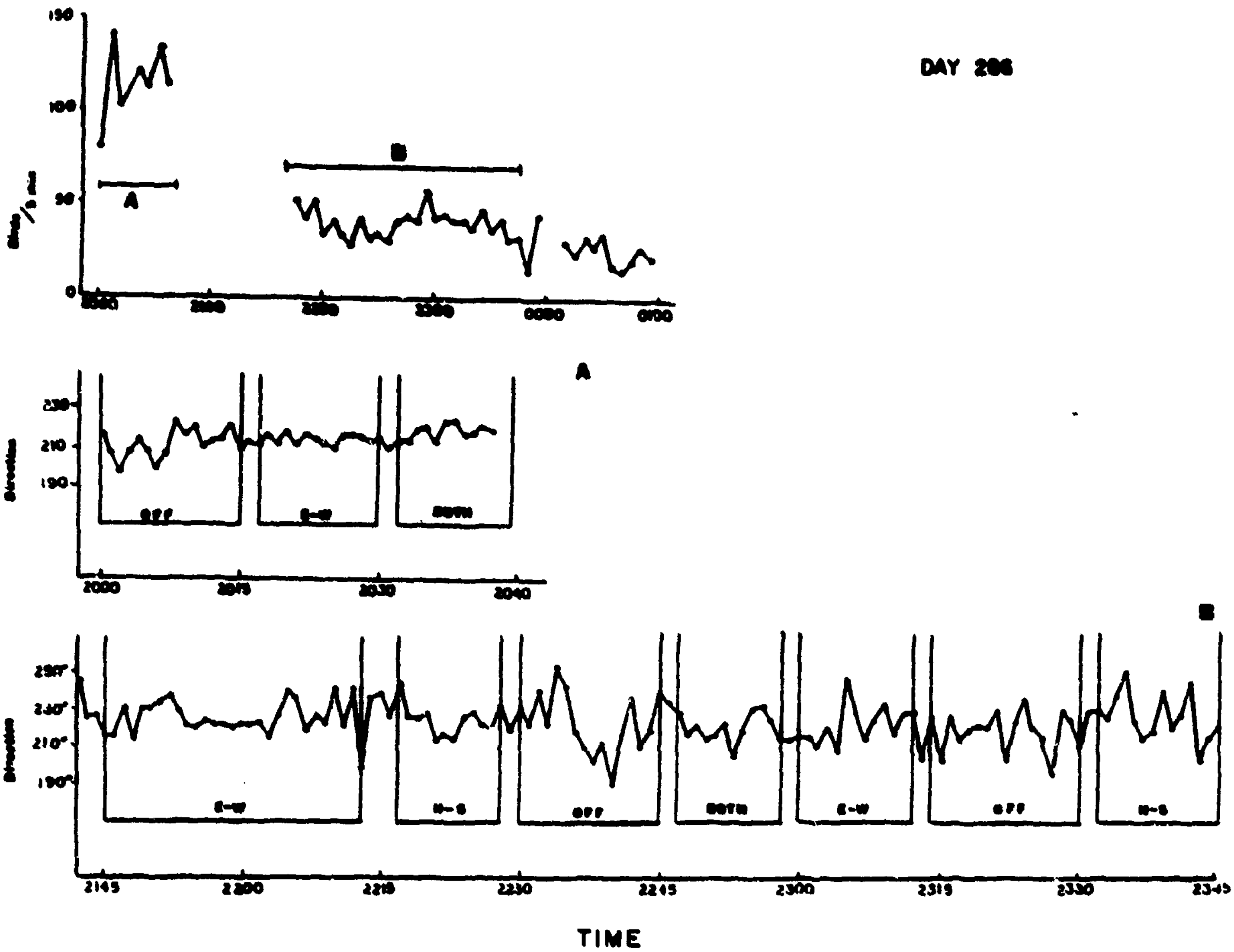


Figure 3.1

Density of migration and minute to minute variation in average direction of migration for day 286. Upper portion of the figure shows density of migration averaged over 5 minute periods for entire night, bars indicate time periods for which directional data is given in lower part of the figure. Lower portion of the figure gives two portions of the data on direction of migration averaged for one minute periods vs. time. Experimental periods are indicated by bars and vertical lines. Areas between bars are transitional periods when antenna current was being changed.

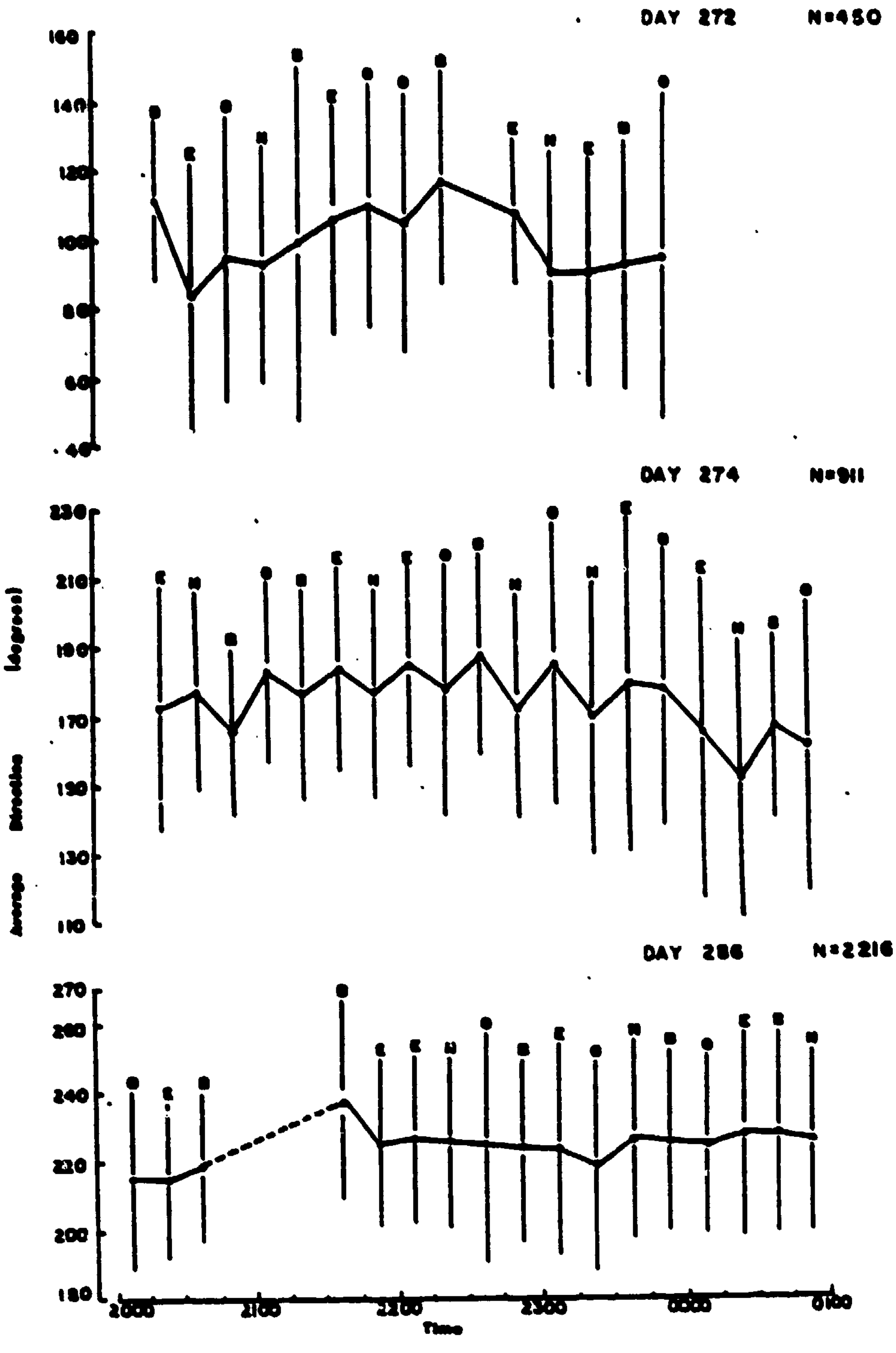


Figure 3.2

Average direction of migration for each 15 minute experimental and control period for three nights during the fall of 1975. Day 272 includes all detected bird tracks. Day 274 includes only data from three minutes near the middle of each experimental period. Day 286 includes only those tracks detected at a range greater than 0.4 km. (203 tracks detected at shorter range are omitted from this analysis of day 286).

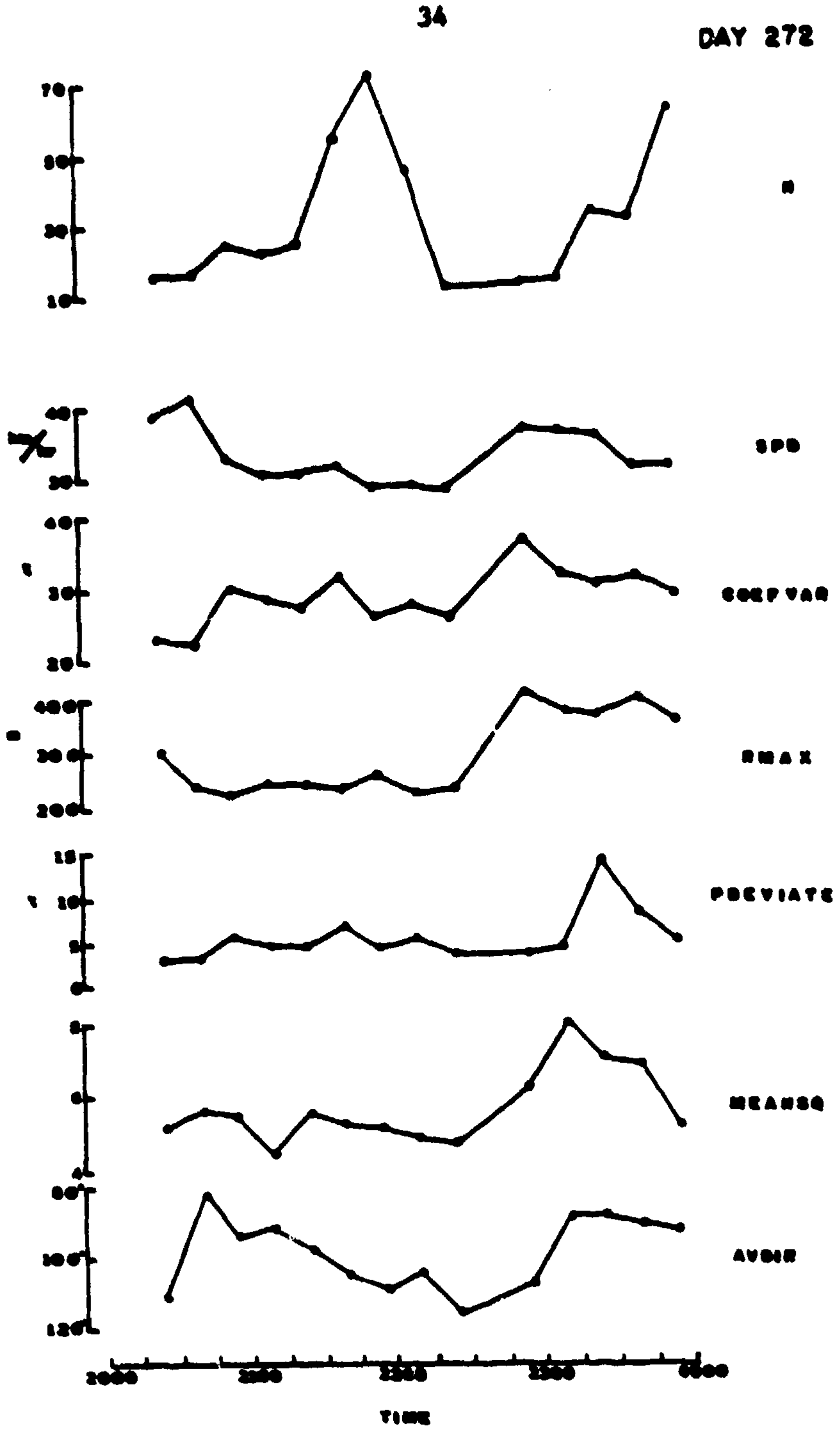


Figure 3.3

Seven measures of migratory behaviour of birds plotted vs. time of day 272. Note the simultaneous change in several of these measures at about 2300 hrs. See text for description of these variables. (Note that the graph of average direction of migration has been inverted to facilitate comparison.)

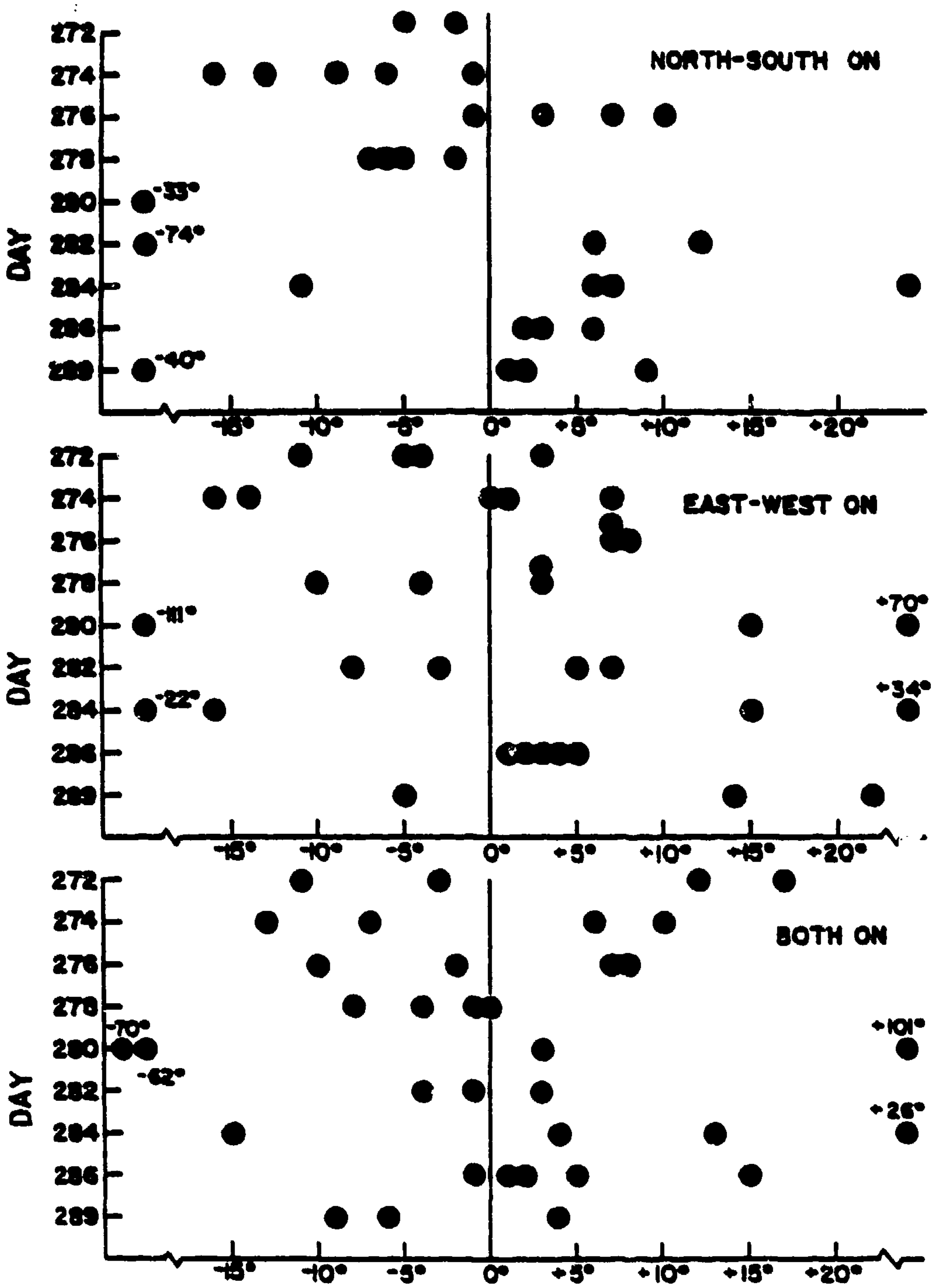


FIGURE 3.4 DEVIATION FROM NEAREST CONTROL

Figure 3.4

Deviation of the average direction of each experimental condition from the nearest control ("off") condition, given for each day in fall, 1975. Deviations of each replication on each day are shown.

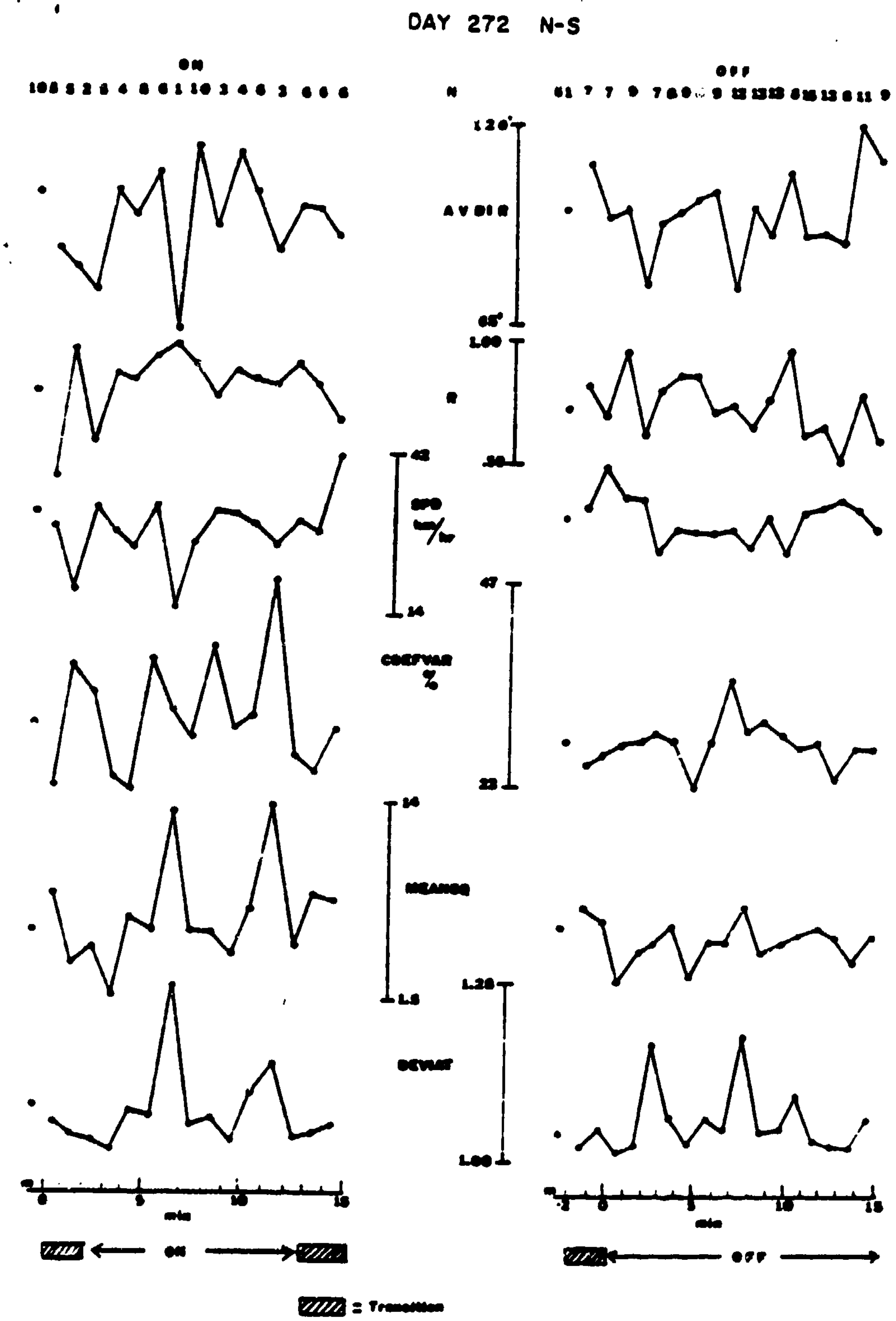


Figure 3.5

Signal averaging of data collected for the north-south antenna leg, day 272, 1975. See text for description of method and definition of terms.

DAY 272 E-W

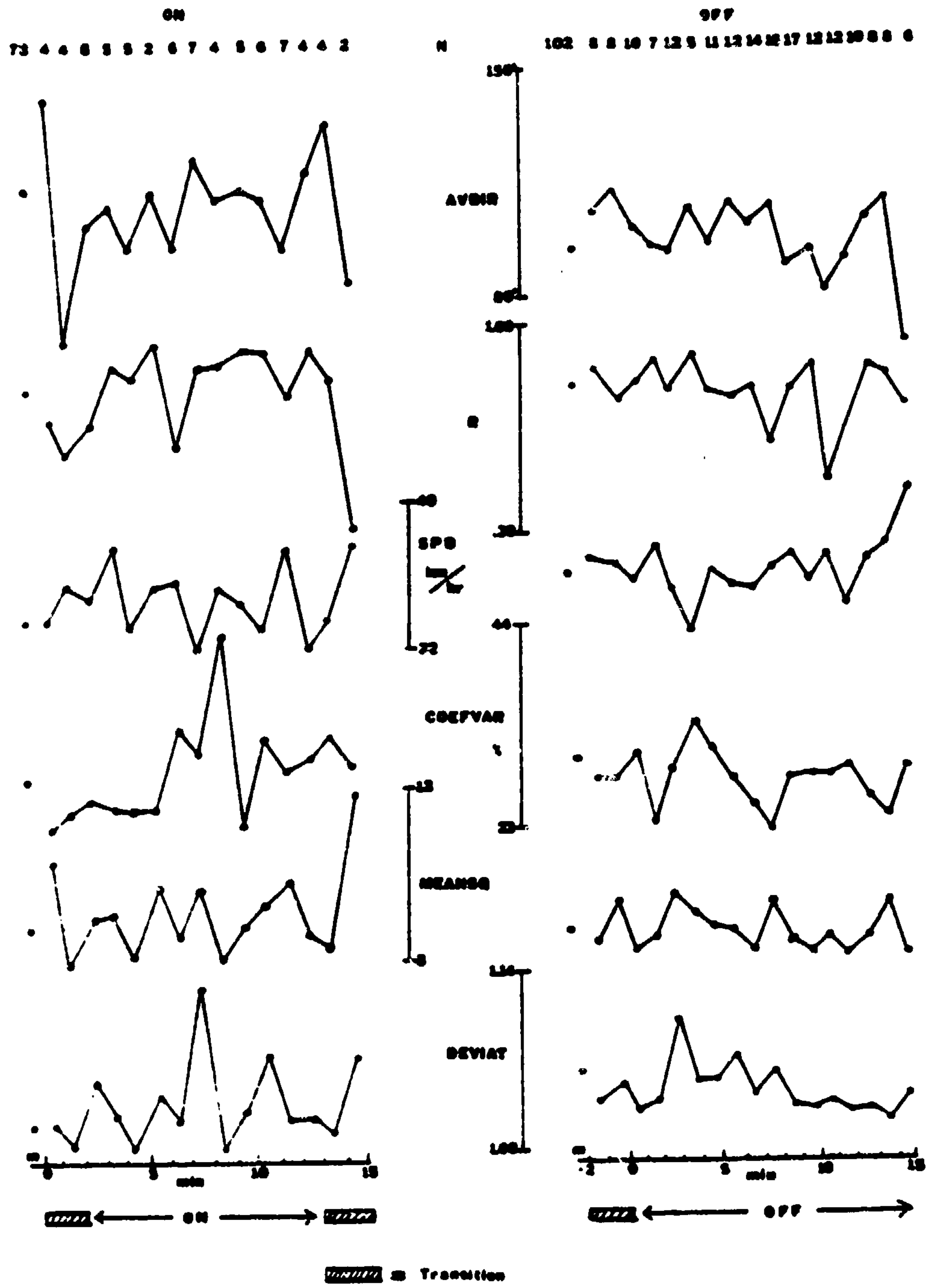


Figure 3.6

Signal averaging of data for the east-west antenna leg, day 272, 1975. See text for description of method and definition of terms.

CHANGING SITES EXPERIMENT

4.1 Introduction

During the fall of 1977 we observed at various distances from the north-south antenna while that antenna was alternately activated and turned off by the personnel at the transmitter site. The aim of these experiments was to determine the area within which the effect noted previously at the transmitter site was operative. We had no *a priori* reason for selecting a particular range of distances and chose to observe at a site next to the antenna, about 1.5 km away and about 3 km away. During the experiments we became dissatisfied with the amount of ground return at the 3 km site and chose an alternate s^t about 4 km.

4.2 Methods

Sites (shown in Figure 2.1) were chosen along fire lane 164 which runs approximately perpendicular to the north-south antenna leg. On 27, 29, 30 Sept and 2, 3, 5, and 6 Oct 1977, radar observations were made between 2000 hrs and 0200 hrs local time (0200 and 0600 GMT). Fire lane 164 runs through a low-lying, swampy area to the east of the antenna leg that is devoid of major natural magnetic anomalies. All four sites were similar in topography and vegetation.

The ORNITHAR radar (see Section 3.2) was positioned at three different sites each night according to a predetermined schedule. Sites 1, 2, and 3 (see Figure 2.1) were sampled on 27, 29, 30 Sept and 2 and 3 Oct. Sites 1, 2, and 4 were sampled on 5 and 6 Oct. Table 4.1 gives the distances of the sites from the antenna and the electric and magnetic field intensities at each site.

The location of the ORNITHAR van was marked by two surveyor's stakes set into the ground next to the left wheels of the van. The van could then be realigned parallel to the stakes upon returning to the site for the next replication. To find the compass heading of the radar cursor, which always points toward the front of the van, the heading of the van was measured in relation to the North Star, using a transit; the van was lined up in the transit telescope via two vertical markers placed on opposite ends of the roof on one side.

Radar ground return varied at each site. Sites 1 and 4 showed the least amount of ground return; at 1/2 n. mile range, 15% of the display was obscured. At site 2 approximately 20% of the screen was obscured, and at site 3 about 25%.

During an experiment the ORNITHAR was moved as rapidly as possible between the observation sites. At each site the north-south antenna would be turned on and off in a predetermined pattern by the personnel at the transmitter site with two "on" and two "off" conditions at each site. Observers at the radar did not know whether the antenna was on or off. The radar observers did, however, regulate the length of stay at each observation site. On nights of moderate to heavy migration (27, 29 and 30 Sept) each on or off period lasted only 7 minutes and we were able to make two complete replications of the experiment (two periods of observations at each site). On nights with light migration (2, 3 and 5 Oct 1977) it was necessary to observe for 12 minutes on each antenna condition to gain enough bird tracks for analysis and thus we were able to make only a single replication of the experiment.

Data were recorded and analyzed as described in Section 3.2.

4.3 Results

At no site did we observe the regular changes in direction that we had recorded in observations at the transmitter site. Figure 4.1 shows the distribution of average direction for each experimental mode (a period of observation with the antenna on) plotted relative to the nearest control or "off" condition. We had expected to find a relatively large effect at site one and decreasing effects at the more remote sites. This is very clearly not the case. Not only is a chi-square test of the distribution of the deviations not significantly different from a uniform distribution, but no individual days or site showed the characteristic regular alternation of directional means, as was expected from our observations at the transmitter site.

In Figure 4.2 we plot the average direction of each control mode as in Figure 4.1 but referenced to the grand mean for the day. Figure 4.2 shows the effect of the different observation sites as opposed to the effect of antenna activation at any one site. The numbers of migrants on each side of the mean at different sites are significant at $p < .01$.

We also investigated the association of antenna state with several variables other than direction at the four observation sites. These data, presented in Table 4.2, fail to show any consistent pattern of association and in general show a lower level of significance than data taken at the transmitter site in 1975.

4.4 Conclusions

The differences in the observed direction of migration might have been due to artifacts of radar coverage at the four sites, such as different patterns of ground return, but inspection of the raw data yielded no apparent difference in the ability of the radar to detect birds flying in certain directions at the four sites. It seems reasonable to conclude that low altitude migrants (less than 100 m) are in fact subject to regular changes in direction of flight as they move over the land. These might well be due to local winds (which are exceedingly difficult to measure over an area of several square kiolmeters), or to changes in the orientation of the birds with minor topographical changes. We know of no previous work on the subject of small scale changes in the orientation of nocturnal migrants at altitudes of less than 100 m. It is interesting to note that the deviations in direction due to antenna state noted at the transmitter site are well within the range of deviations in direction observed at different sites under constant antenna conditions; this point is discussed further in Section 5.4.

Table 4.1

Changing sites experiment: distances of each site from the antenna, and the peak electric and magnetic field strengths at each site.

Site	Perpendicular distance from N-S antenna (km)	Magnetic field strength at 150 m* (gauss)	Electric field strength at 150 m* (volts/meter)
1	0.38	0.004	0.098
2	1.58	0.00046	0.045
3	3.03	0.00025	0.027
4	4.11	0.00018	0.019

* calculated values from Lanera, 1978.

Table 4.2

Levels of significance of nine variables from a one-way analysis of variance by observation site for the changing sites experiment, fall 1977.

	LIMIT	NC	LENGTH	SUMLEN	SPD	COEFVAR	RES	RMAX	DEVIAT	N
SITE ONE										
270			*	*				*		192
272					*					558
273									*	242
275					**					114
276	***	**	***	***						82
278										229
279										82
SITE TWO										
270								*		138
272								*		439
273			*	*						196
275										75
276										77
278										172
279							*			36
SITE THREE										
270		*	*	***						272
272										277
273										139
275										118
276										70
SITE FOUR										
278					*					108
279										39

* $p < .05$ ** $p < .01$ *** $p < .001$

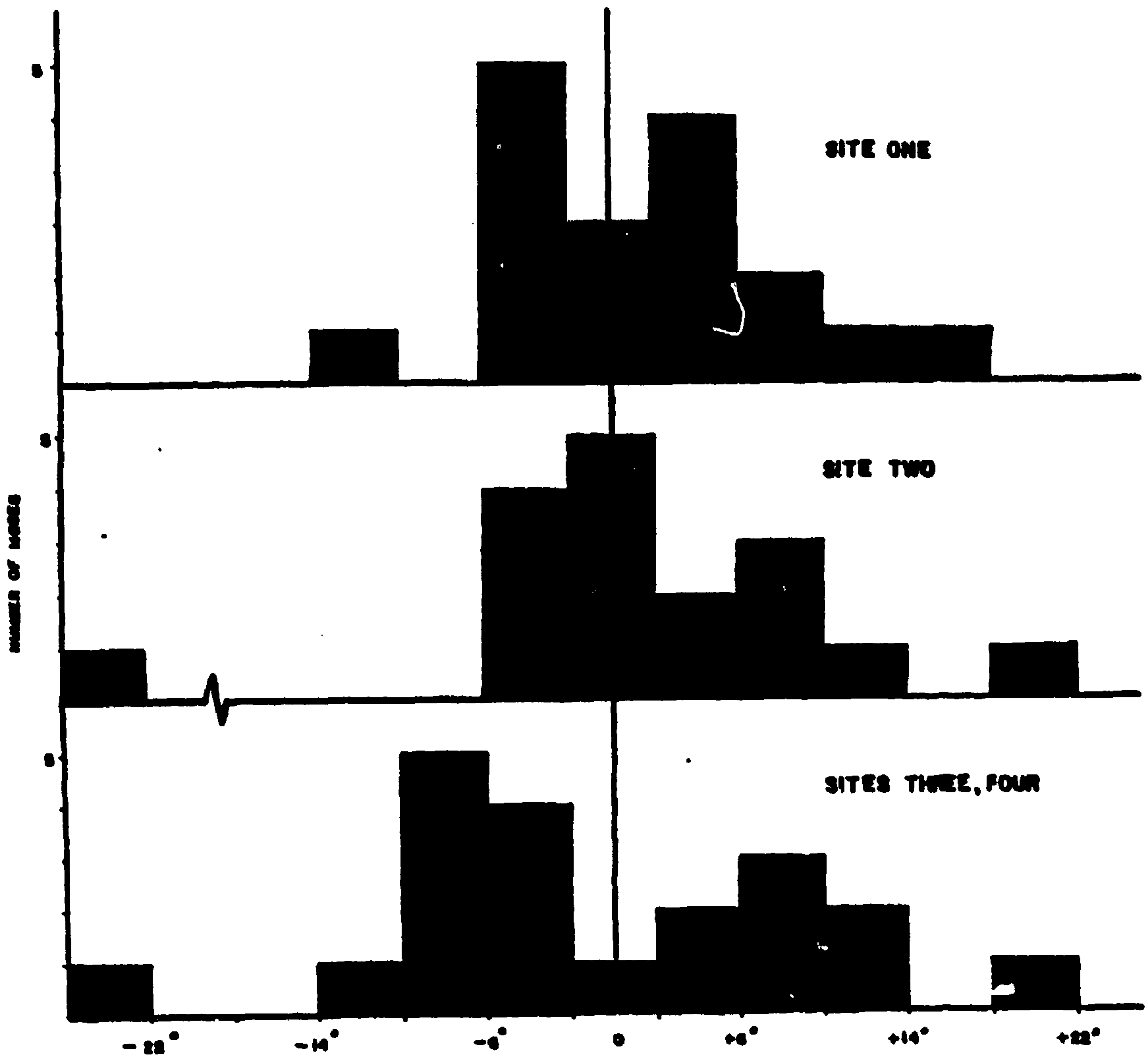


Figure 4.1

Deviation of mean track direction from nearest control ("off") condition. The figure includes all data from 1977.

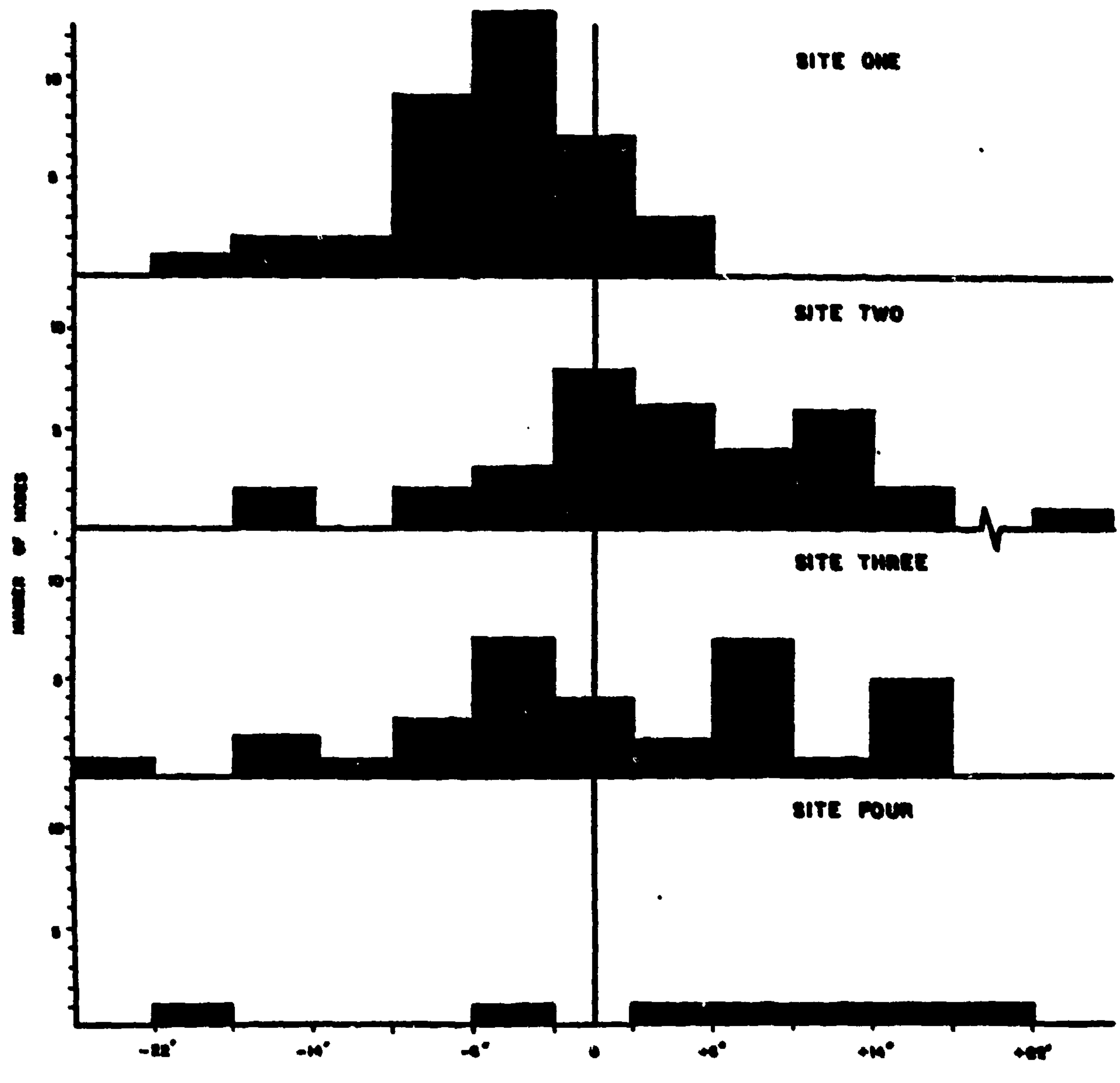


Figure 4.2

Deviations of mean track direction from mean track direction for the entire night, for observations in fall, 1977. All control modes at four sites shown in figure 2.1. Note effects of site on mean direction.

CHANGING POWER LEVELS EXPERIMENT

5.1 Introduction

In addition to measuring the effects of ELF radiation on migrant behavior at different distances from the north-south line (Section 4), the intensity of the antenna's field was varied while the radar remained at a given site. For this series of experiments, the radar was positioned at site 1, Figure 2.1, and the power input to the north-south antenna line was systematically varied between 0, 75, 150, and 300 A. The strength of electromagnetic radiation at any given point in the antenna's field is directly proportional to the power input to the line. Thus inputs of 75 or 150 A reduce the average ELF field intensity to which migrants are exposed by factors of 1/4 or 1/2, respectively, compared to the 300 A input used in other experiments.

5.2 Methods

Two different experimental designs were used, one for nights of heavy migration and one for light or moderate migration nights. Dense migrations permitted the use of additional controls to better compensate for natural fluctuations in birds' directions and speeds over time. On nights of heavy migration, the antenna was turned on for 5 min at a time at a given power level, allowing a 2 min transition phase before and after this period, and then left off for 5 min. At the beginning of the night, the antenna operator was instructed to chose one of six prescribed sequences of power levels with matched controls and repeat it four times. A sample sequence is shown below:

150, OFF, 75, OFF, 300, OFF

As in all our tests, the radar operator was not aware which of the sequences was being used. On light or moderate migration nights, the antenna was left on or off for 10 min at a time rather than 5 min to insure a sufficient sample size of bird tracks for each stimulus presentation. Longer stimulus presentations required the use of fewer control periods. Therefore, a partial latin square design was used and there was only one control condition for each repetition of the three power levels. One out of three such squares was chosen by the transmitter operator at the beginning of the night without the knowledge of the radar operator. A sample square is shown below:

OFF, 75, 150, 300
75, 150, 300, OFF
150, 300, OFF, 75
300, OFF, 75, 150

Three nights in the fall of 1977 were chosen for the changing power levels experiments, 1, 13, and 15 Oct. 1 Oct was a night of intense southward migration (mean track for the night, 183°, and mean density, 12 birds/min); 13 Oct, a night of light reverse migration (mean track, 56°, and mean density, 0.1 birds/min); and 15 Oct, a night of light southeast migration (mean track, 162°, and mean density, 0.9 birds/min). Thus the experimental design used for 1 Oct was the one for heavy migration nights, and for 13 and 15 Oct, the one for light migrations.

5.3 Results

The migration variables monitored in this series of experiments were the same as those used in the changing sites experiments. A separate one-way analysis of variance was done on each variable for each day. For the heavy migration night, each of the matched controls was considered as a separate treatment condition. Thus for this night there were six treatment conditions in all, and for the light nights there were only four. The levels of significance of the circular one-way analysis on the directions of the birds' tracks are given in Table 5.1. No significant differences in the migrants' mean track were detected between the different power levels on any of the days. Inspection of Figure 5.1 reveals no consistent trends among the experimental conditions across days. The results of the one-way analyses on the linear variables are also summarized in Table 5.1. Each entry in the table corresponds to the P-value from a one-way analysis. There were no detectable height-curves among the tracks for 13 Oct; therefore a one-way analysis was not necessary for H or HERR since all tracks for that day were assigned an altitude of 0 m. Only four out of thirty-one tests turned out significant at the .05 level and no consistent trends for significant differences in a given variable are evident across days. The few tests which did turn out to be significant are probably the result of natural fluctuations in the sample populations, unrelated to the antenna's functioning. Three of the four significant results occurred on 13 Oct where there were only 6-8 birds in each treatment category. Finally, further inspection of the tables reveals no consistent trend for a reduction in the number of birds detected when the antenna was on, and thus no evidence that birds avoid the antenna's electromagnetic field. A chi-square test for deviation from a uniform distribution yielded values of 5.7 for day 274, 5 for day 286, and 1.9 for day 288 (for all three days, $p < .05$, $df=3$).

Figures 5.2 and 5.3 show the distribution of tracks of birds for the two days, 274 (1 Oct) and 288 (15 Oct), by antenna condition. Figures 5.4 and 5.5 show the distribution of groundspeeds similarly. There is clearly no tendency for alteration in these variables with antenna state, and analysis of variance showed no significant effects of antenna state.

5.4 Conclusions

Observations at site 1, remote from the transmitter, show no consistently detectable differences in the parameters we monitored due to the operation of the antenna at any power level. When the data from site 1 in Section 4 are considered with the above data we conclude that the effects of antenna state noted at the transmitter site were not replicated at sites equally distant from the antenna proper but remote from the transmitter facility. Ten nights of observation at site 1 produced none of the regular changes in direction seen in 3 out of 9 nights of observation at the transmitter site. Comparison of Table 3.2 with Tables 4.2 and 5.1 also shows lower levels of significance at site 1. It thus would appear reasonable to assume at the present time that the alteration of the behavior of freely flying migrant birds noted previously at the transmitter site may have been due to the action of some factor other than the ELF field of the antenna. It should be noted that this factor may still be an electromagnetic field generated by the complex field inducing structures at the transmitter site; our studies indicate only that this factor is not operative at a remote site along the north-south antenna leg.

Table 5.1

Levels of significance for eleven variables from a one-way analysis of variance of the changing power levels data, fall 1977. Levels of significance for direction were taken from a circular one-way analysis of variance.

DAY	DIRECTION	LIMIT	NC	LENGTH	SUMLEN	SPD	COEFVAR	RES	RMAX	DEVIAT	H	N
274			*									1168
286				*	*		*					25
288												163

* $p < .05$ ** $p < .01$ *** $p < .001$

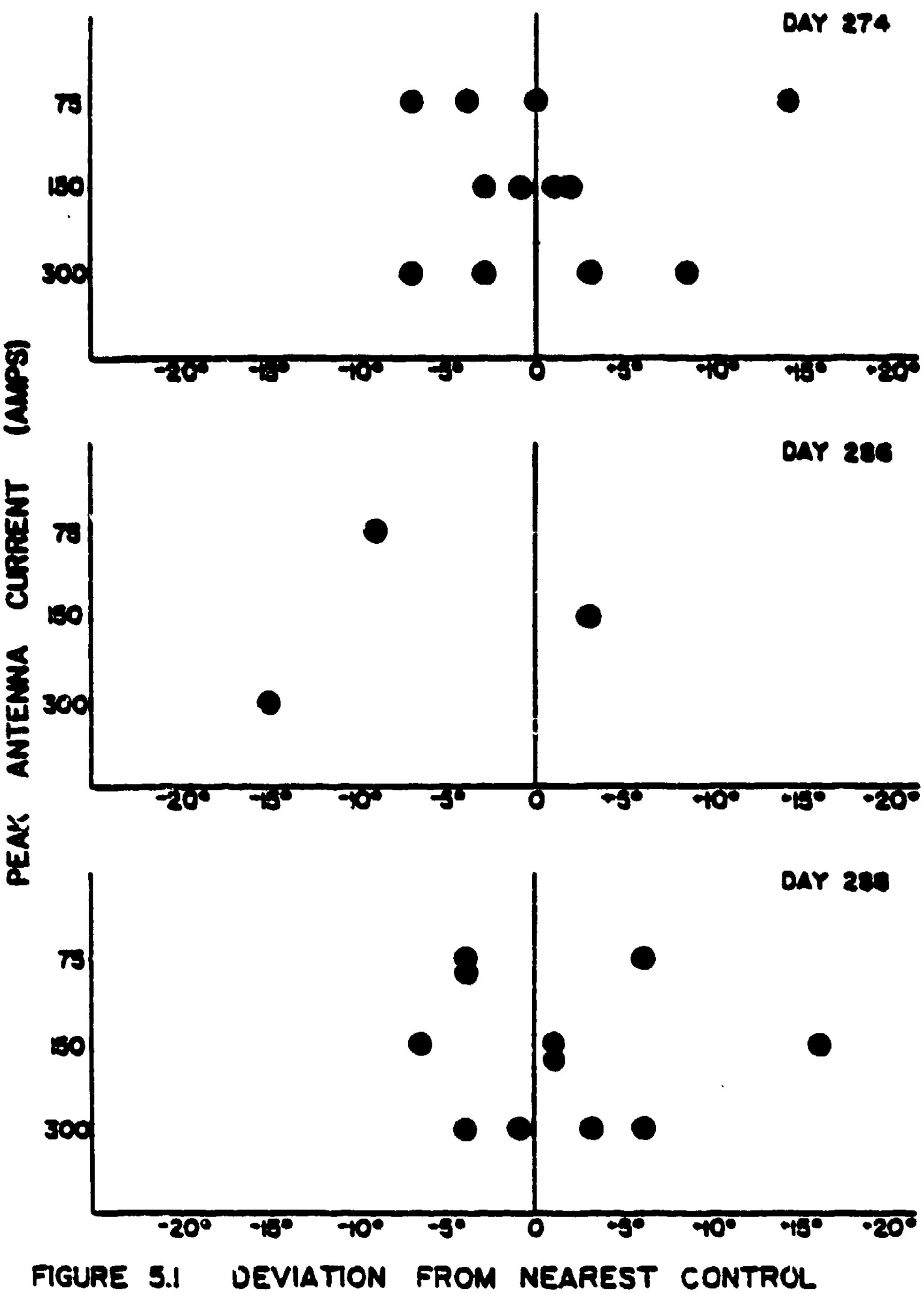


Figure 5.1

Changing power levels: deviations of the mean track for an experimental period from the nearest control ("off") condition, for three days in 1977. Due to very low numbers of birds observed on day 286, all data for each power level were pooled.

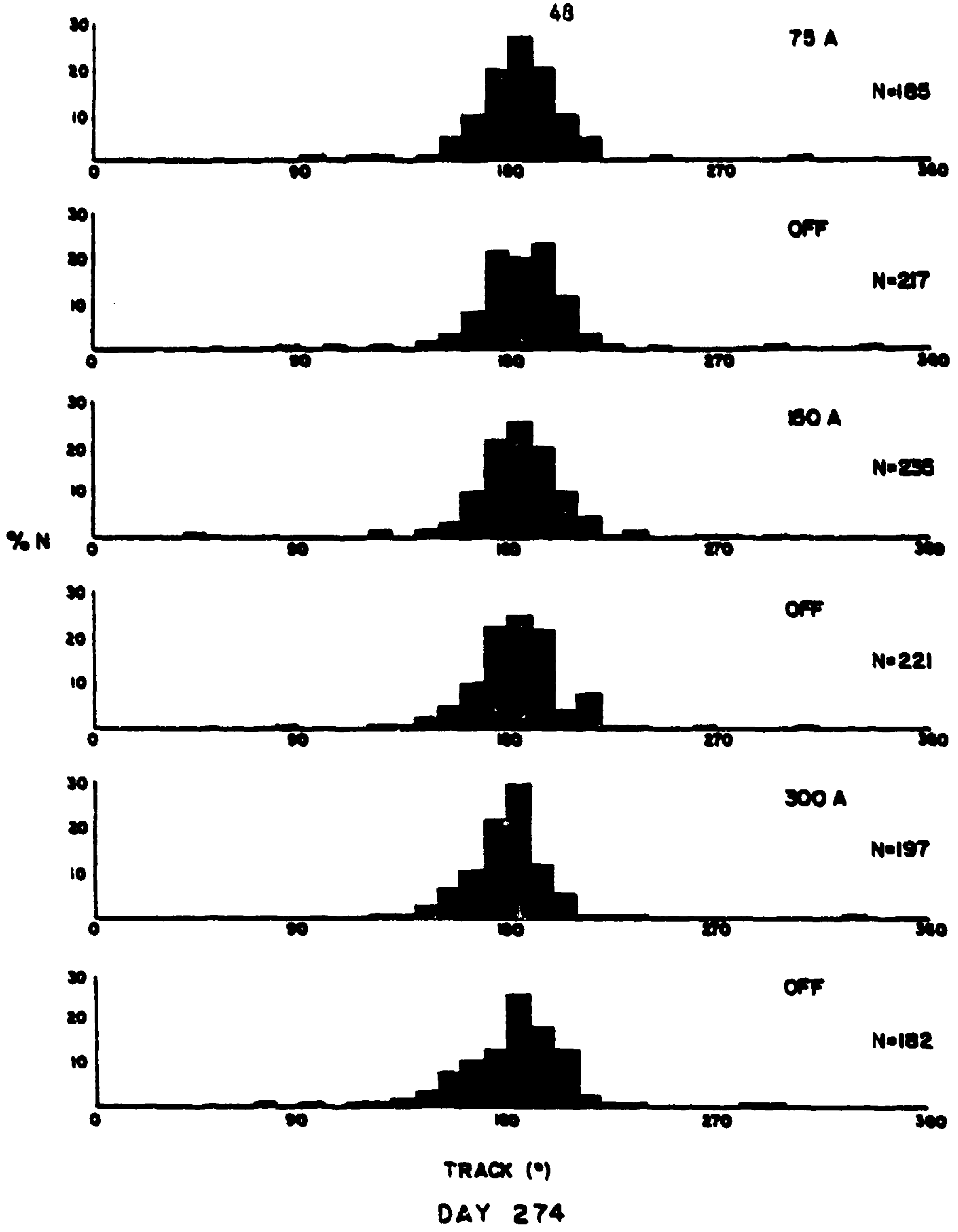


Figure 5.2

Distribution of direction of tracks for all birds on day 274, 1977 (changing power levels).

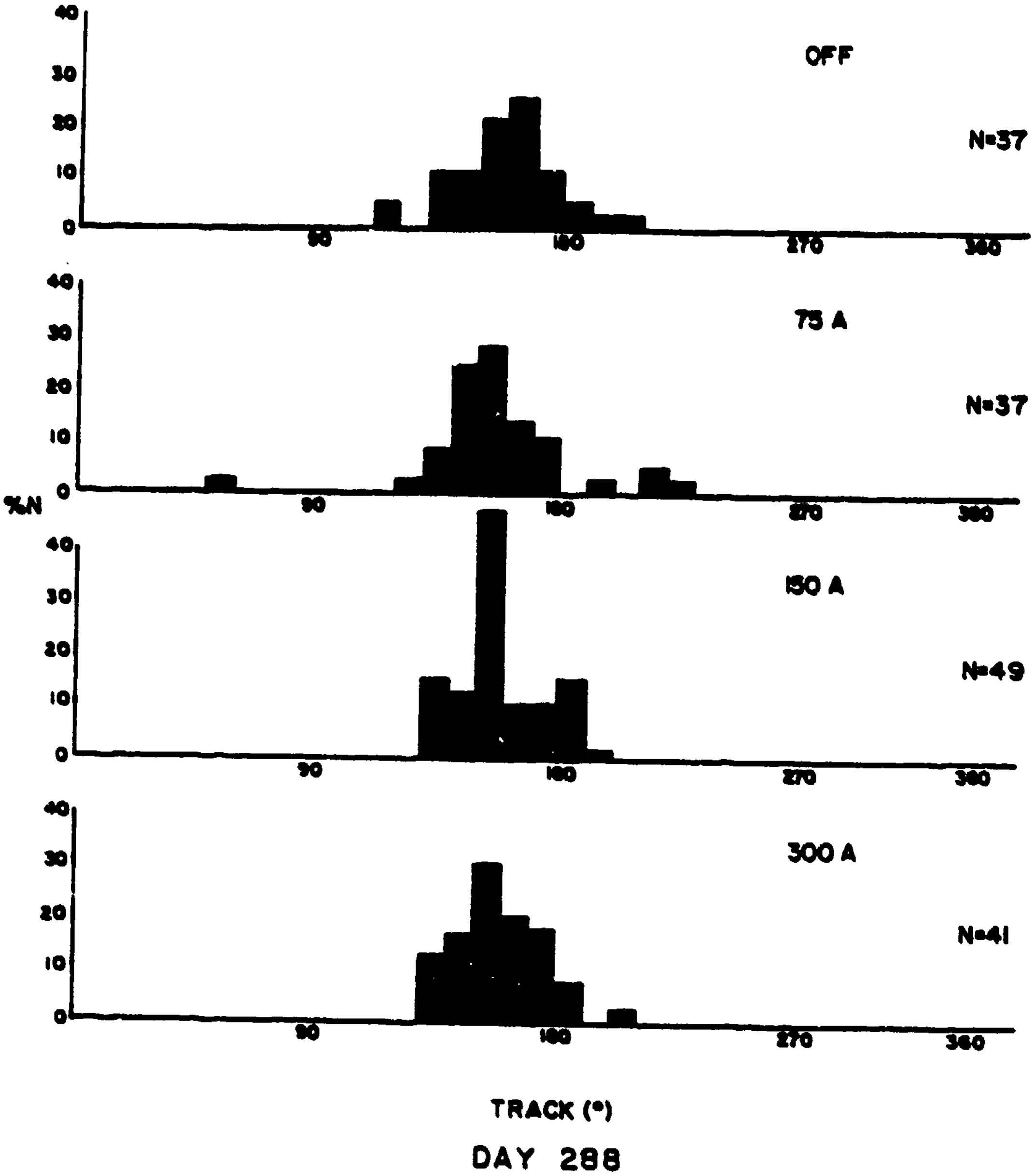


Figure 5.3

Distribution of direction of tracks for all birds on day 288, 1977 (changing power levels).

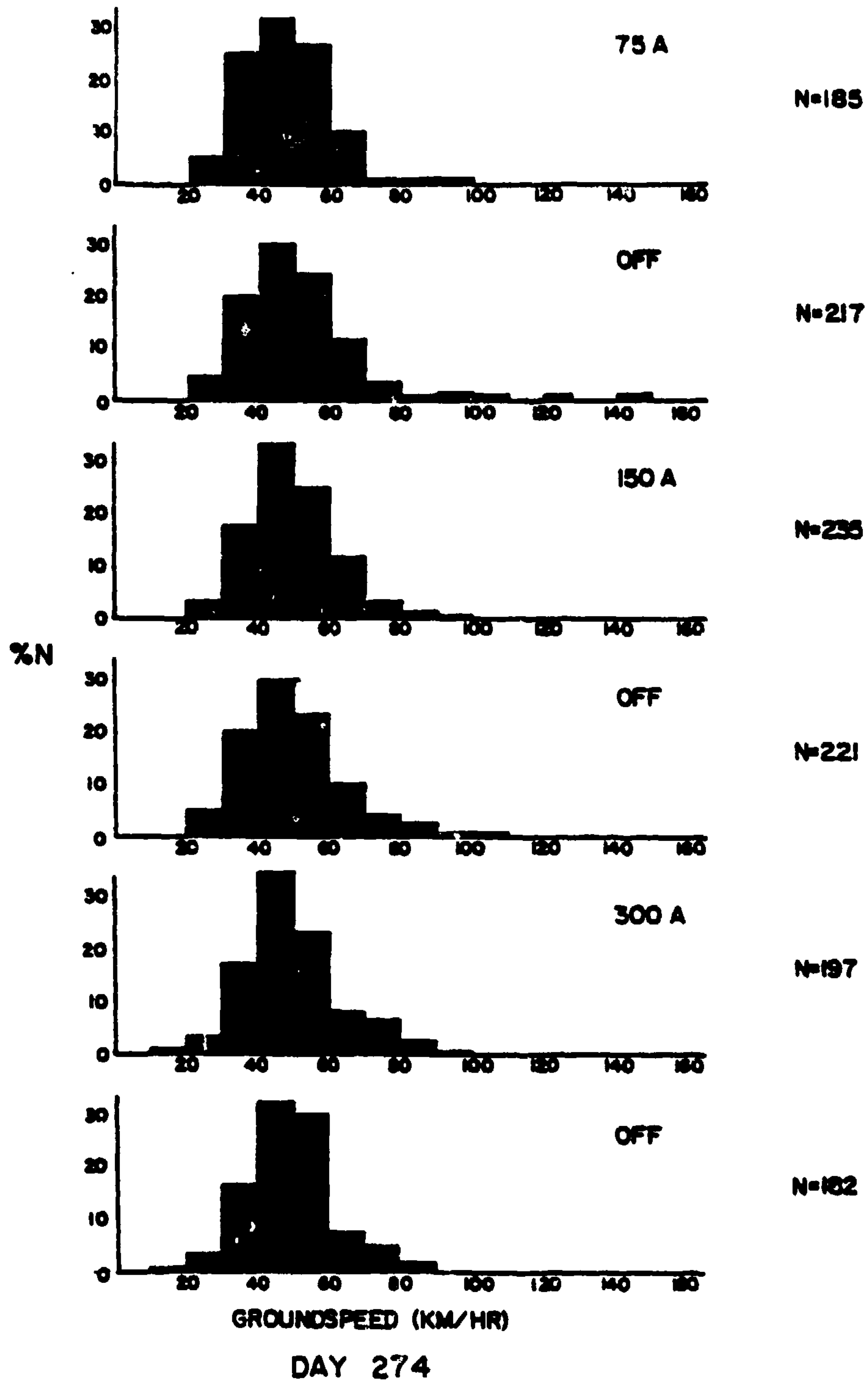


Figure 5.4

Distribution of groundspeed for all birds on day 274, 1977 (changing power levels)

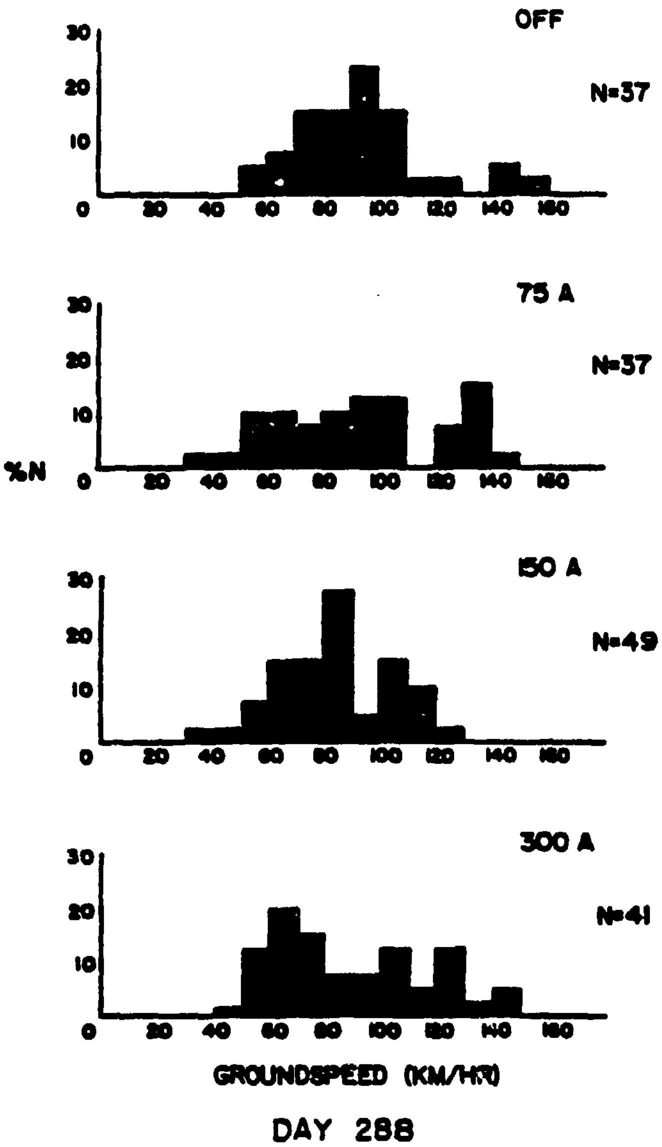


Figure 5.5

Distribution of groundspeed for all birds on day 288, 1977 (changing power levels).

A COMPUTER SIMULATION OF AVIAN MIGRATION OVER CENTRAL WISCONSIN

6.1 Introduction

In Section 3 we noted that on certain days there was a systematic deviation in the average direction of migrants flying over the WTF when the north-south antenna was activated. In this section of the report we investigate the possible effects of such a deviation. This is done by means of a computer simulation in which birds are flown through a measured wind field over the continental U.S. In general we attempted to create a worst case analysis by selecting the parameters of our simulation to maximize the possible effect of a temporary change in orientation of birds departing from or flying over the WTF. The assumptions upon which the simulation rests are as follows:

1. Avian migration is accomplished by maintenance of a constant heading in differing wind conditions. At the present time, there is little conclusive data on the orientation mechanisms used by birds during their migratory flights (see Emlen, 1975, and Schmidt-Koenig and Keeton, 1978). If migrant species are capable of true bicoordinate navigation (and there is considerable controversy on this point; see Baker, 1978), biologists are unable to offer any reasonable hypothesis supported by data to account for such navigation. A more plausible hypothesis at the present time is that birds utilize compass orientation to move between familiar areas or population specific goal sites (see Wiltschko and Wiltschko, 1978a). This conclusion is supported most clearly by our work on orientation of birds crossing the Atlantic from North America to South America and the Caribbean (see Williams and Williams, 1978 for a brief review), and by experimental studies reviewed by Wiltschko and Wiltschko (1978a).

2. The great majority of North American migrants move only at night. This finding is reported by almost all studies of migration over continental areas both in Europe and America, and appears to hold for both waterfowl and most song birds, although some waterfowl may also move during the day (see Eastwood, 1967 for a review). We assumed that birds would fly from 2000 hrs to 0600 hrs local time, based on the observations of Bellrose and Graber (1963). Shorter flight times would have been equally reasonable but would have reduced the observed effect of a change in orientation.

3. Birds maintain a constant heading for an entire night. The evidence for this assumption is based on experimental data reviewed by Wiltschko and Wiltschko (1978b). As above, this represents a worst case analysis. The Wiltschkos' data suggest that initial orientation for each night is determined from the magnetic field; birds then maintain heading without reference to that field, but by using a star compass for the rest of the night. A new orientation is determined at the beginning of each flight. As a worst case we are simulating the flights of birds which take off from the WTF area and fly for 10 hrs with a deviated heading.

6.2 Methods

The computer program used in this simulation was written by J. Ellen Marsden and Philip K. Stoddard. The heading and airspeed of the bird are specified variables; actual track and groundspeed are calculated by vector addition of heading and airspeed with wind velocity from a matrix of wind data. Wind velocity was determined for each 5° of latitude or longitude in the matrix by averaging measured winds on National Weather Service North American surface charts. Where great variation was suspected to be due to local effects, the geostrophic winds were calculated and combined to give an average value. For the first 5 hrs of flight each night, winds were taken from the 0000 Z weather charts and for the second 5 hrs from the 1600 Z charts. Every 2.5 hours of flight the position of the birds was calculated using new wind values if appropriate. Positions were corrected for curvature of the earth using the following equation:

$$x = x_o - x_o \frac{180}{\pi} \cdot RE \cdot \cos \frac{\pi}{180} \cdot y$$

where: x = corrected longitude of the bird
x_o = calculated longitude of the bird
y = calculated latitude of the bird
RE = radius of the earth (km)

The simulation was terminated after three nights of flight or when the bird flew south of latitude 30° N.

The resultant paths were plotted on a cartesian coordinate axis which was considered a sufficient approximation of a mercator projection over the area involved.

6.3 Results

Two nights (274 and 278, 1975) were selected for simulation as these gave the largest and most consistent observed deviations during our radar observations at the transmitter site in 1975. In each case, winds were measured for the three nights following these dates. Simulations were run using the average observed heading for each of these nights and for plus and minus one standard angular deviation in heading as observed at Wisconsin. These are shown as the solid lines in Figures 6.1 and 6.2 in which we used the average airspeed observed at Wisconsin for the simulation (see Table 6.1). These figures show that a difference in heading of only 35° on night 274 and only 22° on night 278 could result in differences of 500 km in position after three nights of flight. Thus the observed distribution of headings of birds migrating over Wisconsin on these two nights suggests that 68% of all migrants would be found within the shaded area of Figures 6.1 and 6.2 if their behavior followed the hypothesis used for the simulation. The relatively wide distribution of birds with only slightly differing headings is in part due to their encountering different wind conditions, but is primarily due to the hypothesis of constant heading orientation and the curvature of the earth; the base of an isosceles spherical triangle is necessarily greater than that of a similar planar triangle with the same length apical sides.

The broken lines in Figures 6.1 and 6.2 show the simulated track of a migrant with average airspeed, but whose heading has been deviated for the first night of flight by an amount equal to the average for all north-south antenna conditions on days 274 or 278. The second and third nights the bird's orientation did not differ from the average heading during control conditions, i.e., is equal to that of the simulated track just to their left. The principal effect of the deviation is a lateral displacement during the first night of migration. The continuing divergence of tracks after that time is due to the curvature of the earth.

Figure 6.3 illustrates the effect of alterations in airspeed on the simulation. The track of birds with average heading is simulated for the average airspeed and for plus or minus one standard deviation in airspeed. After three nights of flight the slower birds are of course less advanced upon the migratory route, but their tracks show little deviation from the route of the fastest birds.

6.4 Conclusions

We conclude from these simulations that deviations resulting from activation of the north-south antenna, even if these effects persisted for the remaining flight of that night, would produce insignificant deviations in the final dispersal of migrant species. The observed deviations in position are well within the lateral displacements to be expected from normal variations in wind velocity during migration. This conclusion does not pertain to birds which were raised within the WTF. Such birds might suffer a permanent change in their orientation systems which would not be covered by the hypotheses of this simulation; this effort only considered the effects upon birds which, either by stopping for a few nights or by flying over the WTF, had suffered a temporary change in orientation.

Table 6.1

Data used for migration simulations

DAY	MEAN HEAD	S.D.	N-S DEVIATION	MEAN SPEED (KM/HR)	S.D. (KM/HR)
274	187°	35°	-12°	35	18
278	160°	22°	-7°	60	28

N-S Deviation = mean deviation from control conditions during activation of the north-south antenna leg.

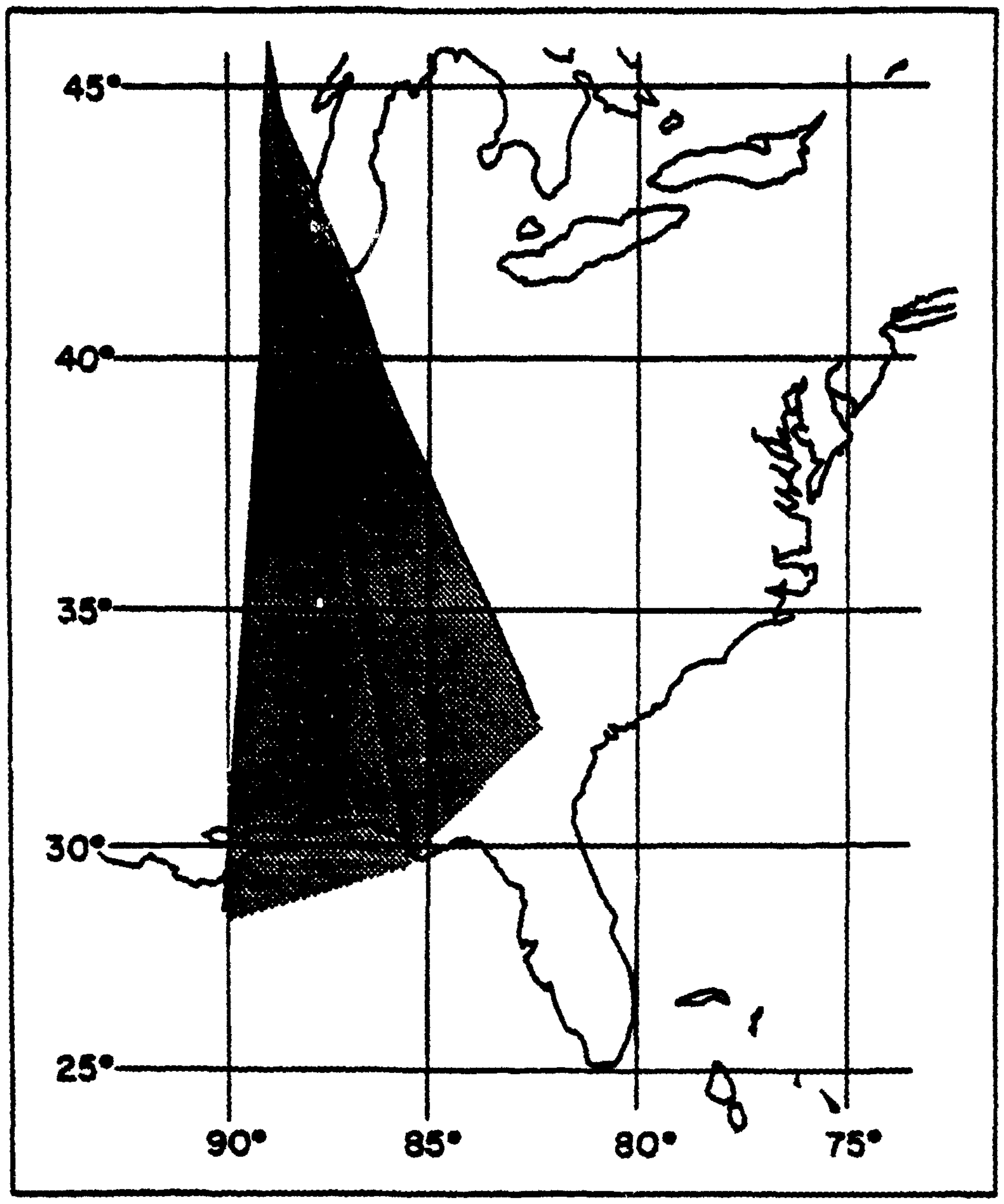


Figure 6.1

Computer simulation of the migratory pathways of fall migrants, showing birds flying with the average speed, and average heading plus and minus one standard deviation as observed at Wisconsin on day 274 (solid lines). The broken line indicates a bird with average speed and average heading, but with its heading deviated by the amount observed for the north-south antenna condition for the first night of flight.

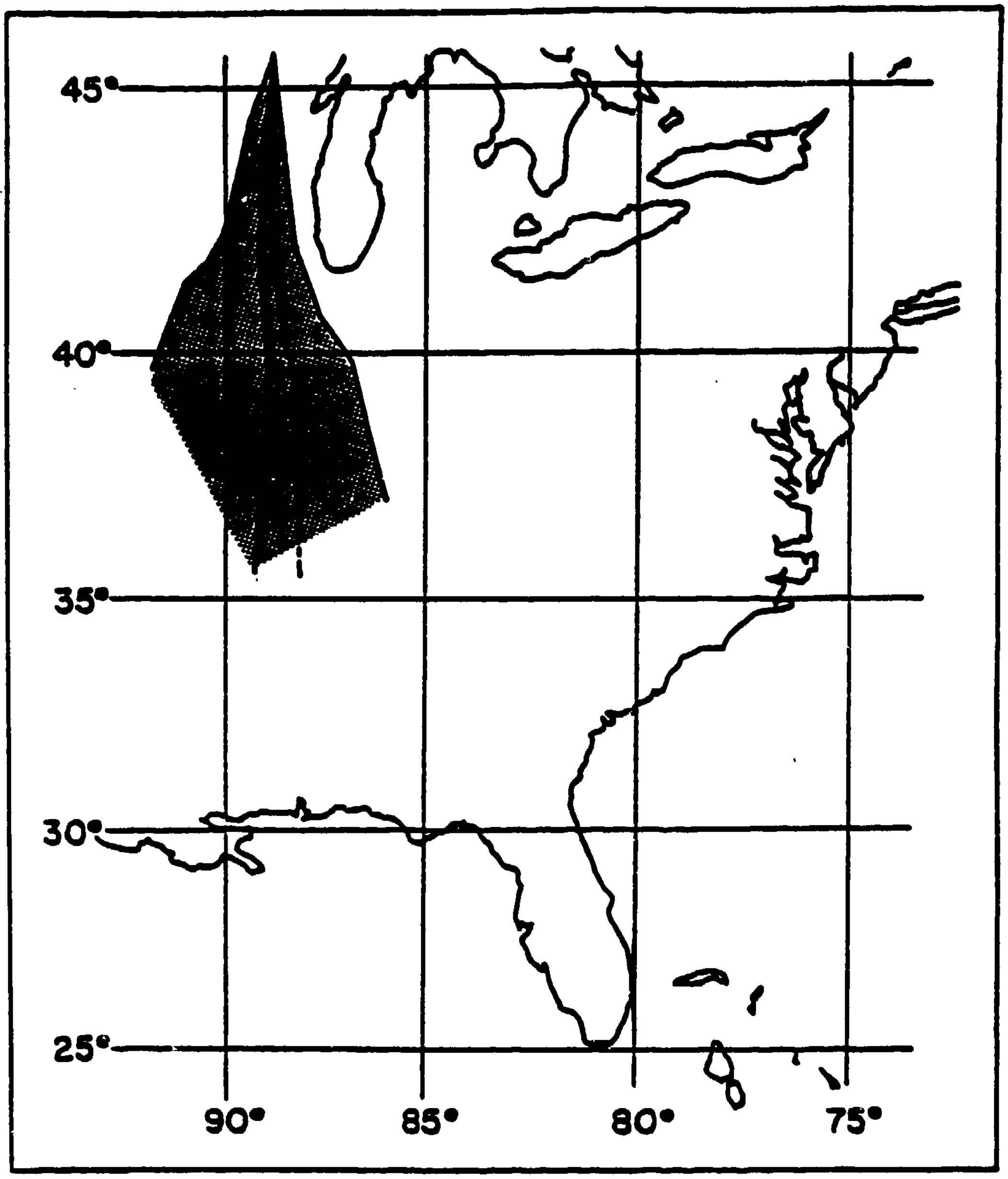


Figure 6.2

Computer simulation of the migratory pathways of fall migrants, showing data from day 278, plotted as in Figure 6.1.

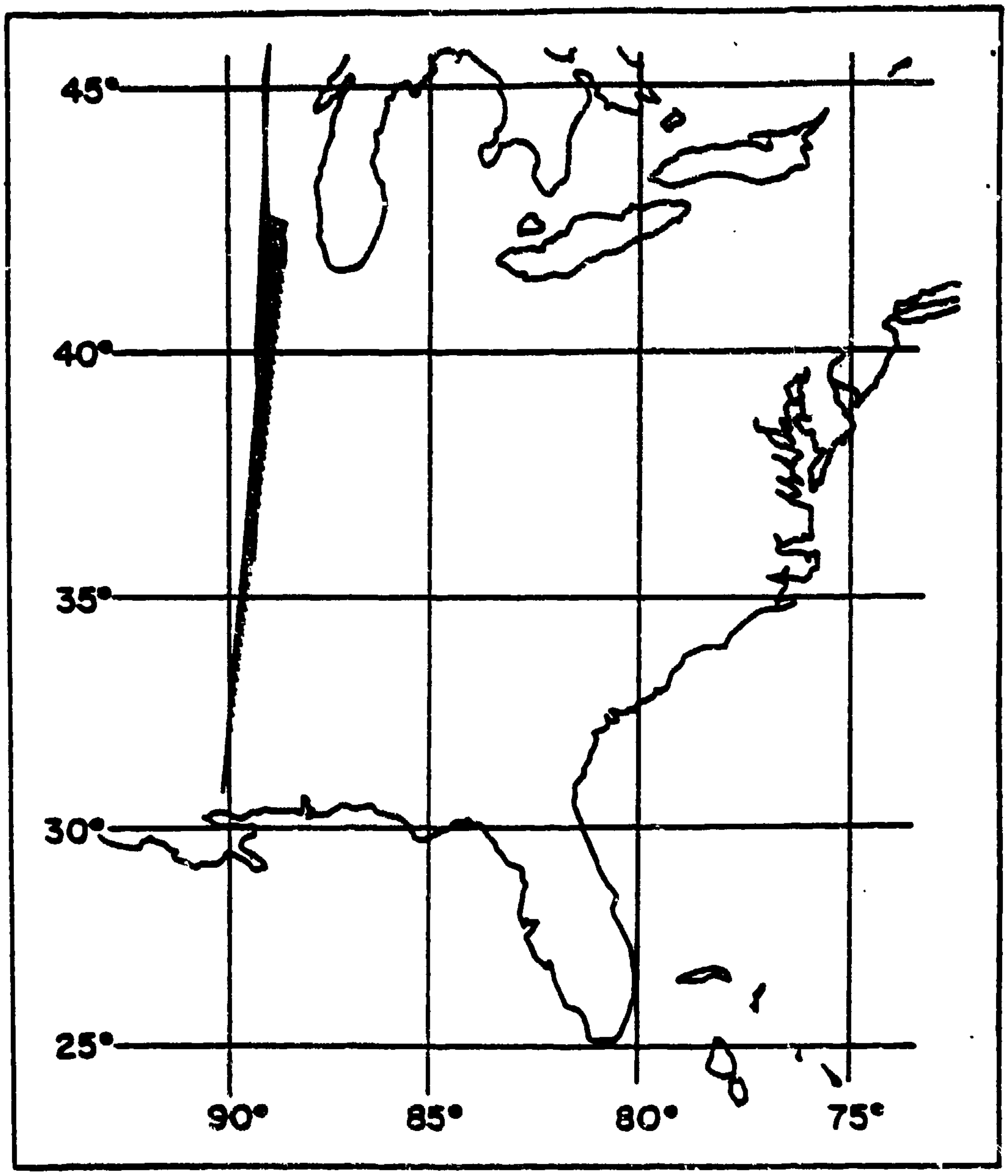


Figure 6.3

Computer simulation of the migratory pathways of fall migrants, showing birds with the average heading observed on day 274, and with average speed plus and minus one standard deviation.

OBSERVATIONS AT NATURAL MAGNETIC ANOMALIES

7.1 Introduction

Data from the changing sites experiment (Section 4) indicated that there are likely to be significant differences in the migratory patterns of birds flying within 100 m of the earth over relatively short geographical distances. It appeared reasonable to suspect that if deviations at the transmitter site (Section 3) were due to an imposed electric or magnetic field, natural anomalies in the earth's magnetic field at low altitudes might also have a disorienting effect on migrants.

7.2 Methods

In order to investigate the affect of natural magnetic disturbances on bird migration, three areas were chosen for radar observation: Iron Hill, Del., Franklin, Mass., and Mellen and Round Lake, Wisc. Observations were made in the spring and fall of 1978 in Iron Hill, in the fall of 1977 and 1978 in Franklin, and in the fall of 1977 in Round Lake. Magnetic anomalies to be investigated were selected from magnetic survey maps. The most useful maps were those produced by the U.S. Geological Survey from magnetic aerial surveys taken at an altitude of 150 m. These maps for Iron Hill and Franklin are shown in Figures 7.1 and 7.2 Unfortunately, the survey is not complete for the U.S., and several areas, including some especially intense anomalies in the Wisconsin iron ore areas, have not been covered; for these areas we relied upon maps made by the State of Wisconsin. The magnetic topography for Round Lake and Mellen is shown in Figures 7.3 and 7.4. In all cases we tried to use highly localized anomalies which were surrounded by areas of relatively little magnetic change. In two of the areas (Franklin and Mellen) the anomalies were accompanied by geographical changes such as ridges or hills. Such areas were undesirable not only because their rough topography made radar observations difficult, but because sharp topographical features might be expected to produce local variations in winds which could affect bird migration. The two anomalies in relatively flat country (Iron Hill and Round Lake) were considered superior sites for this reason.

In this section of the report we will at times use the term, relative magnetic intensity. Since magnetic survey maps are referenced to an arbitrary and not an absolute level, measurements within the area of a survey map may be compared, but may not be compared with other magnetic surveys. These surveys thus indicate only change in the local magnetic field, not the total strength of the earth's magnetic field at a given site on a survey map.

Local changes in the earth's magnetic field caused by these anomalies were considerably greater than any resulting from the antenna. For instance, at 150 m above ground level (about the lower limit that birds are detected by the ORNITHAR), the maximum change in the earth's field intensity produced by the intense anomalies was about two orders of magnitude greater than the maximum change produced by the antenna (see Table 7.2). Moreover, the anomaly field sources were spread out over a broad surface rather than a line. Therefore, nearly all the migrants flying over the anomalies were exposed to peak magnetic disturbance for a longer period of time than those flying over the antenna.

At each area, observations were made at one or two experimental sites (a magnetic low or high) and one control site which approached the "normal" magnetic intensity for the area. Selection of sites was influenced by problems with ground return; when it was not possible to find a site free of ground return, i.e., less than 20% of the screen obscured, a radar fence was used to reduce clutter (see below). The ORNITHAR radar was driven between the sites in sequence, with approximately ten minutes of observation at each site. The number and duration of replications, and prevalent weather conditions for each night, are given in Table 7.1. Alignment of the van, data recording, and scoring all followed the same procedure as in Section 4. The heading of the van was confirmed by using known landmarks, such as roads, on U.S. Geological Survey maps. The declination of the magnetic field was measured using the deviation of a transit compass from the pole star. At Iron Hill, the total intensity of the field at ground level was measured using a magnetometer.

7.3 Description of sites

FRANKLIN: Geomagnetic maps show a magnetically anomalous area ten km SSW of Franklin, Mass., just within Rhode Island. The experimental site was located at the center of this anomaly, 2.5 km east of Woonsocket, R.I., in a hilly, wooded area near electric power lines. The area covered by the radar was approximately divided in half by a line running SW-NE, such that the northern half of the screen was in a magentic high of relative intensity 5857 gamma, and the lower half was in a relative low of 2900 gamma. The control site was located six km NNW of the experimental site, five km NNE of Woonsocket. The topography was fairly flat and wooded, with Silver Lake 0.3 km to the NE. Observations were made on four nights in 1977 and 1978. On 29 Oct 1977, four replications of 10 minutes were taken at each site from 2012-0121. In 1978, three nights of data were taken, on 28 and 30 Sept and 2 Oct, from which two, 28 and 30 Sept, were selected for analysis on the basis of weather conditions and the presence of the radar fence, which was used on 30 Sept.

IRON HILL: Radar observations were made on four nights in the spring and fall of 1978 at Iron Hill, Del., approximately three km south of Newark. Geological maps show that Iron Hill and nearby Chestnut Hill are composed of outcroppings of gabbro, a weakly magnetic iron ore. U.S. Geological Survey geomagnetic maps confirm the presence of a large magnetic anomaly centered around the area of Iron Hill. On the basis of these maps, three areas were chosen for observation, two located in magnetic highs, and one in a magnetic low. The first site was located approximately 100 m from a toll station on Route I-95, on the side of a 107 m hill (Iron Hill); in the fall the radar was moved approximately 300 m to a cleared lot which provided a better radar horizon. The relative magnetic intensity was 7400 gamma, declination averaged 11°; total intensity as measured at the site with a magnetometer was 52,500 gamma (.525 gauss). The second site was located five km SW of the first, on the side of a wooded rise with a maximum elevation of 89 m, in a magnetic low of relative intensity 7120 gamma, declination 13°. The third site was located three km ESE of the first site, in a fairly flat area, with a magnetic high of relative intensity of 7800 gamma, declination 12°. This site was only used on one day in the spring; another nearby site with similar topography was used in the fall. At both sites, most of the inner half of the screen was obscured by ground return, and therefore very few birds were detected. Magnetic intensities and declinations for each site are given in Table 7.2.

The radar fence, used on one day at Franklin and two days at Iron Hill (see Table 7.1), consisted of 3 m long wooden poles driven into the ground in a semicircle, 4 m from the van and with 2 m between each pole. A 95 cm wide aluminum mesh screen was attached to the upper portion of the poles, creating an "artificial horizon" approximately 5° high. The height of the poles was adjusted so that the ground return of the screen only just disappeared, insuring that not many birds were lost by the obscuration of the fence. At both Franklin and Iron Hill the ground return was localized on the screen, so that it was only necessary to erect a partial fence (90°

around the van) in order to reduce the ground return by 50%.

ROUND LAKE and MELLEN: Two anomalies near the WTF were chosen on the basis of the availability of detailed magnetic surveys of the area, kindly provided by Dr. Frank Mudrey of the U.S.G.S., and the strength and geographical extent of the disturbance. One of the anomalies was located approximately 2.5 km south of Mellen, Wis., and formed a long thin band (2-3 km wide in the area of interest) running E-W through the Gogebic Range. The other was located at Round Lake near Hayward, Wis. It was irregularly shaped and extended 5-6 km along its SW-NE axis and 1-2 km along its SE-NW axis. The average intensity of the earth's field in northern Wisconsin is about 0.6 gauss and the average declination of magnetic north is 0°. At the crest of the Mellen anomaly, magnetic field strength was increased by about 10% and the declination of the field was rotated by 150°E. A compass needle would point southeast at this point. At the crest of the Round Lake anomaly, field strength was reduced by 50% and the declination was rotated by 35°E. These values should not be taken as representative of declinations within the range of the radar at the anomaly sites. Both the declination and inclination of the field can vary considerably over a very short distance at the crest of the anomaly.

Sites were selected to allow observation of migrants before, during, and after passing over the anomaly. Four sites were used at Mellen (see Figure 7.4): two control sites, one (site 5) approximately 5 km north of the anomaly and the other (8) 3.5 km south of it, and two anomaly sites, one (6) at its crest and the other (7) at its southern edge. Three sites were used at Round Lake: two controls, one (9) 1.5 km northwest of the anomaly and the other (11) 3.25 km southeast of it, and one anomaly site (10) within the smaller of its two crests. Observations began at nautical twilight (2000 C.S.T.) and continued until 0100 or 0200 of the next day. Two nights were spent at Mellen, 12 and 16 Oct, and two at Round Lake, 14 and 18 Oct. Two sampling procedures were tried. For both nights at Mellen and the first night at Round Lake, the van was driven back and forth between the northernmost and southernmost sites with fifteen minute observation stops at each site. For example, the schedule of site stops on the first night at Mellen was as follows:

REPLICATION	ORDER OF OBSERVATIONS BY SITE
I	5, 6, 7, 8,
II	8, 7, 6, 5,
III	5, 6, 7, 8.

This design minimized traveling time between sites but had the disadvantage of making stops at the anomaly more evenly spaced in time than stops at the controls. Therefore, a partial latin square design was adopted on the second day at Round Lake. This design increased the traveling time between sites, but avoided consistent differences in temporal spacing between the anomaly and control site stops.

7.4 Results

IRON HILL and FRANKLIN: Figures 7.1 and 7.2 present magnetic surveys of the two areas tested. Distribution of directions observed at Iron Hill and Franklin frequently departed from a normal distribution. Therefore, to test for differences in the distribution of directions of observed migration at the sites, we employed the chi-square test suggested in Batschelet (1965). The values for this test are presented in Table 7.3. All days at Iron Hill showed significant differences, but only one day at Franklin showed a difference. Figure 7.5 gives the distribution of directions and groundspeeds at Iron Hill on day 100 (winds were light and variable).

Table 7.4 gives the significance levels attained in repeated one-way analyses of variance for each day for each of 10 variables. As with the directional data, major differences were detected at Iron Hill and the data at Franklin did not show any clear differences.

For a closer examination of possible effects of the magnetic disturbances in the experimental site at Franklin, we compared tracks observed on either side of a line running 40° E through the center of the PPI display. According to the magnetic survey maps (see Figure 7.2), this places the tracks into a region of low magnetic intensity, from 2900-3400 gamma, and a magnetic high of 5857 gamma. A chi-square test performed on these two distributions was not significant for any of the days analyzed; even within the magnetic disturbance at Franklin there was no clear separation of behavior with magnetic field strength.

MELLEN and ROUND LAKE: Three out of the four nights had sufficient sample sizes for statistical analysis. Only nine birds were detected on the second night at Mellen (16 Oct). Light to moderate southeast migration was observed on the remaining three nights. There was only one short period of total overcast during these nights, lasting throughout the first replication of site stops on 18 Oct; otherwise the sky was completely clear. The summed K-index (measured at Fredericksburg, Va.) for the period from noon to midnight of each day is shown in Table 7.1. All filmed data from 12-18 Oct were scored but only every other minute from 14 Oct, since migration density was much higher on that night.

Analysis of mean track direction revealed significant differences between sites at Mellen, but this difference cannot be attributed to the magnetic properties of the sites. Results of a circular one-way analysis of variance (Mardia, 1972) of track by site for each night is shown in Table 7.4. Neither day at Round Lake showed significant differences in tracks between sites. Inspection of tracks for Mellen reveals that the major difference is between the site groups of 5 and 7 and 6 and 8. There is no obvious explanation for this difference based on the magnetic properties of the sites. We assume that local wind conditions were a factor in the observed differences in migratory direction.

On the first night at Round Lake (14 Oct), migrant tracks were more dispersed at the anomaly (10) than at the control sites (9 and 11). Examination of data for all three nights shows a trend for the variance in track direction to be lowest at the anomaly only on 14 Oct. To test the significance of this trend, the variance was computed for each minute sampled on this night. This was possible since all minute samples contained at least two birds. The variances were then ranked and a Kruskal-Wallace one-way analysis of variance showed a significant difference in median site ranks (df = 2, X^2 = 27.35, P = 0.01). The <u>mean</u> site ranks were as follows:

Site		Mean Rank
9	control	44.40
10	anomaly	28.50
11	control	44.65

Linear one-way analyses of variance (ANOVA) were done for each night on the remaining eleven migration variables monitored. A $\log_e$ transformation of the data was used to stabilize sample variance. The data for 14 Oct at Round Lake contain the greatest number of significant differences between site means. The $\log_e$ transformed data show significant results from ANOVA's of LIMIT, NC, SUMLEN, SPD, and RES at the 0.05 level or better. However, <u>a posteriori</u> comparisons (Least Significant Difference) reveal that the anomaly mean is different from both control sites in the case of LIMIT and NC only. The table of transformed data for 18 Oct shows significant results from ANOVA's of LIMIT, NC, and RMAX. Again, LIMIT and NC are significantly lower at the anomaly than both controls, but RMAX does not show a similar trend. The tables for 14 Oct show no significant differences between means, although LIMIT and NC are lowest at the anomaly sites as on the other nights.

Migration density was consistently lower at the anomaly than at the control sites on 12 and 14 Oct, but not on 18 Oct.

7.5 Conclusions

Observations of bird migration in the vicinity of natural magnetic anomalies and at nearby areas without major magnetic disturbances reveal that at least at some sites there are major differences in the patterns of bird migration over magnetic anomlaies. At the present time it is not possible to assert that it is magnetic disturbances rather than differences in landmarks or topography that cause the observed deviations in migratory behavior. These experiments do show, however, that avian migrants flying within 100 m of the ground are normally subject to alterations in migratory behavior at least as great as those reported during activation of the ELF field at the transmitter site at the WTF.

TABLE 7-1

Observations at Magnetic Anomalies

SITE	YEAR	DAY	TIME	#REPS.	REP. LENGTH (MIN)	TEMP. °F	% CLOUD COVER	K (12 HR)	RADAR FENCE
FRANKLIN	77	301	8:00- 1:21	4	20	32-38°	0-20	7	None
	78	271	7:20-11:14	4	10	51-45°	0	13	Site 1
	78	273	7:03-12:03	4	10	54-53°	0-95	5	None
IRON HILL	78	100	7:16-9:48	2	10	50-42°	0	14	None
	78	114	7:42-10:19	2-3	10	56-50°		13	None
	78	296	7:29-12:12	2	10	68-51°	100	5	Site 1
	78	303	7:28-11:44	3	10	46-47°	90	13	Site 1
MELLEN	77	285	8:40- 1:58	3	15	28-35°	0	10	None
ROUND LAKE	77	287	8:00-12:28	4	15	38-41°	0	13	None
	77	291	8:42-12:34	3	15	35-43°	0-100	18	None

Table 7.2

Intensity and declination of the earth's magnetic field for observation sites, intensity taken from U.S. Geological Survey geomagnetic maps (see text fo further explanation), declination taken relative to Polaris with a transit.

SITE	RELATIVE MAGNETIC INTENSITY (gamma)	MAGNETIC DECLINATION
1	2900 to 5857	22° E
2	3080	14° E
1	7450	11° E
2	7140	13° E
3	7800	12° E
5	59,700 to 59,900	4° E
6	58,500 to 65,700	10° E
7	60,500 to 65,700	9° E
8	60,000 to 59,900	1° E
9	0 to -5,000	0°
10	0 to-30,000	21° E
11	0	3° E

Table 7.3

Chi-square tests for differences in distribution of tracks at anomalous and control sites.

SITE	DAY	N	X^2	d.f.	p
FRANKLIN	302	109	3.712	3	.2943
	271	640	13.228	3	.0042
	273	159	3.485	3	.3227
IRON HILL	100	185	13.529	3	.0036
	114	180	21.815	6	.0013
	296	320	10.062	3	.0181
	302	150	12.688	6	.0483

Circular one-way analyses of variance (Mardia, 1972) of track by site.

SITE	DAY	N	F	d.f.	p
MELLEN	285	365	4.160	3.361	$<.01$
ROUND LAKE	287	627	1.702	2.624	$>.05$
	291	256	1.576	2.253	$>.05$

Table 7.4

Levels of significance of ten variables from an analysis of variance by observation site for the natural anomalies, 1977 and 1978.

	DAY	LIMIT	NC	LENGTH	SUMLEN	SPD	COEFVAR	RES	RMAX	DEVIAT	H	N
FRANKLIN												
	302											109
	271						*					640
	273											259
IRON HILL												
	100		*	**	**	***	**		***			185
	114	**	***	***	***	***	*	*	***			180
	296	***	*									320
	302						**					150
MELLEN												
	285											365
ROUND LAKE												
	287	*	**	*	*	***		*				627
	291	**	**	*	*							256

* $p < .05$ ** $p < .01$ *** $p < .001$

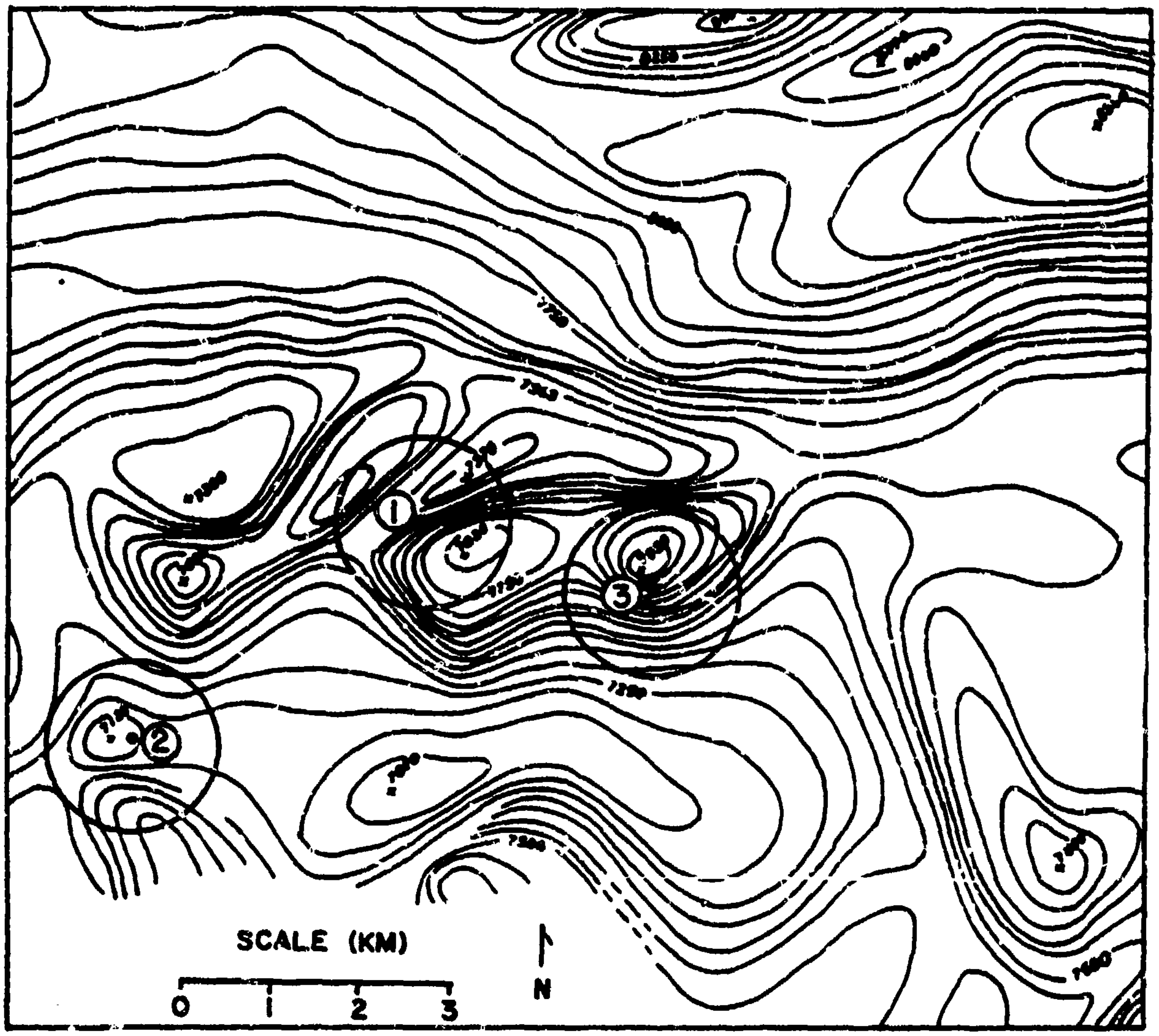


Figure 7.1

U.S. Geological Survey geomagnetic map of Iron Hill, Del. showing magnetic intensities ralative to an arbitrary mean. Sites are located with a dot; one nautical mile diameter circles around each site indicate the range of radar observation.

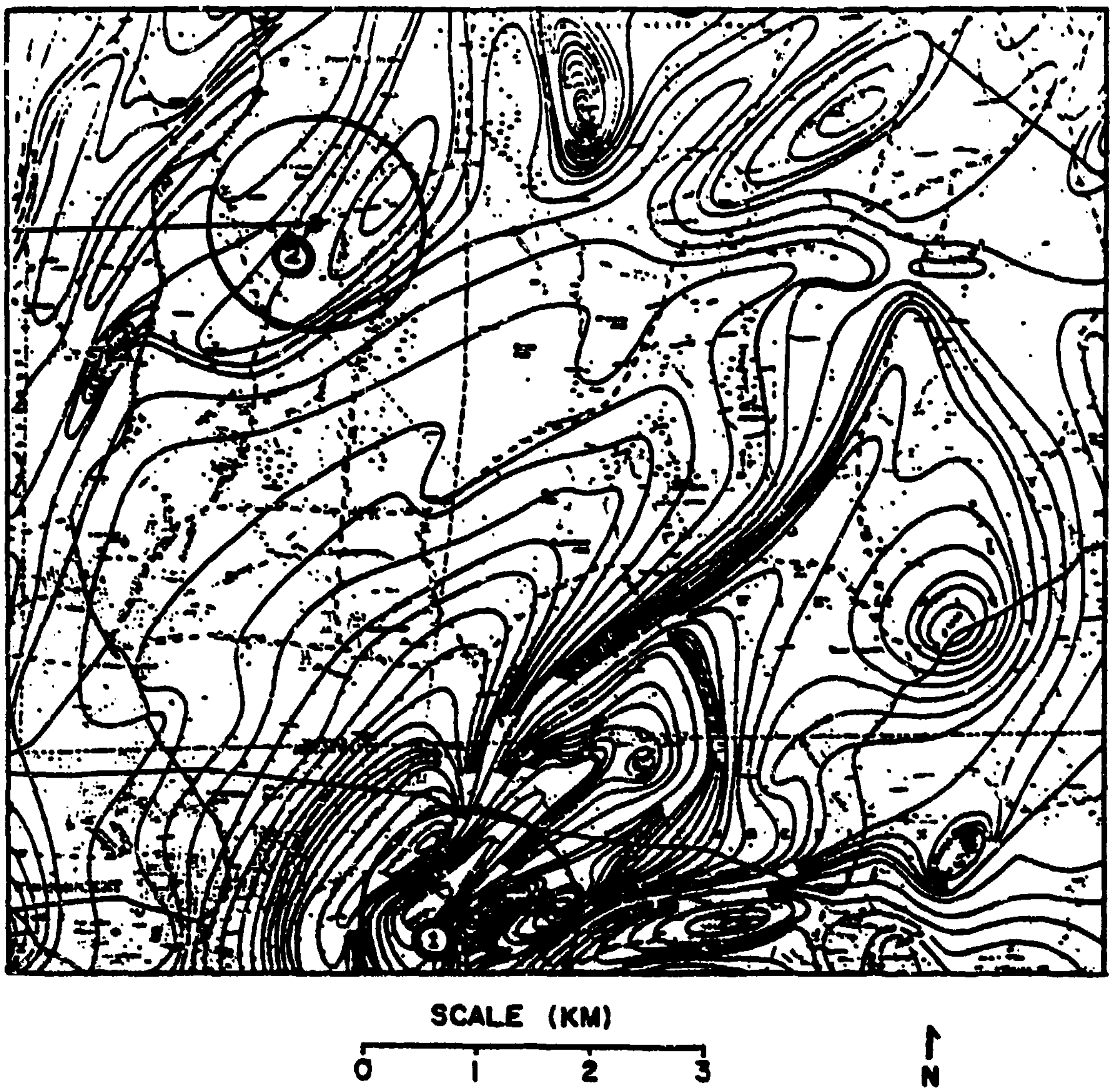


Figure 7.2

U.S. Geological Survey geomagnetic map of Franklin, Mass. showing magnetic intensities relative to an arbitrary mean. Sites are located with a dot; one nautical mile diameter circles around each site indicate the range of radar observation.

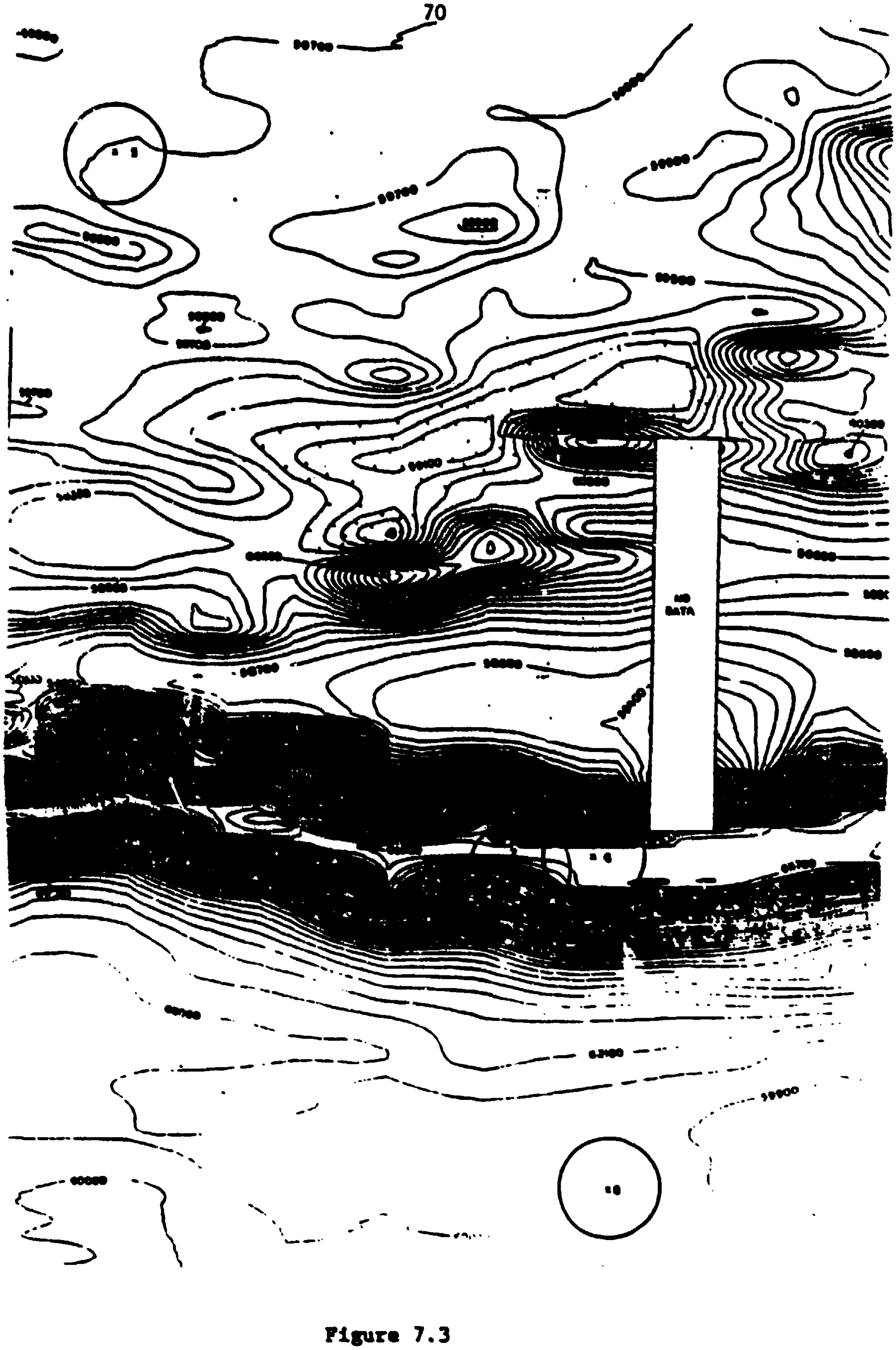


Figure 7.3

Geomagnetic map of the Mellen anomaly based on aerial geomagnetic survey maps of the University of Wisconsin Geological and Natural History Survey. 100 gamma intervals relative to an arbitrary level. Observation sites indicated with an X; circles indicate the approximate range of the radar.

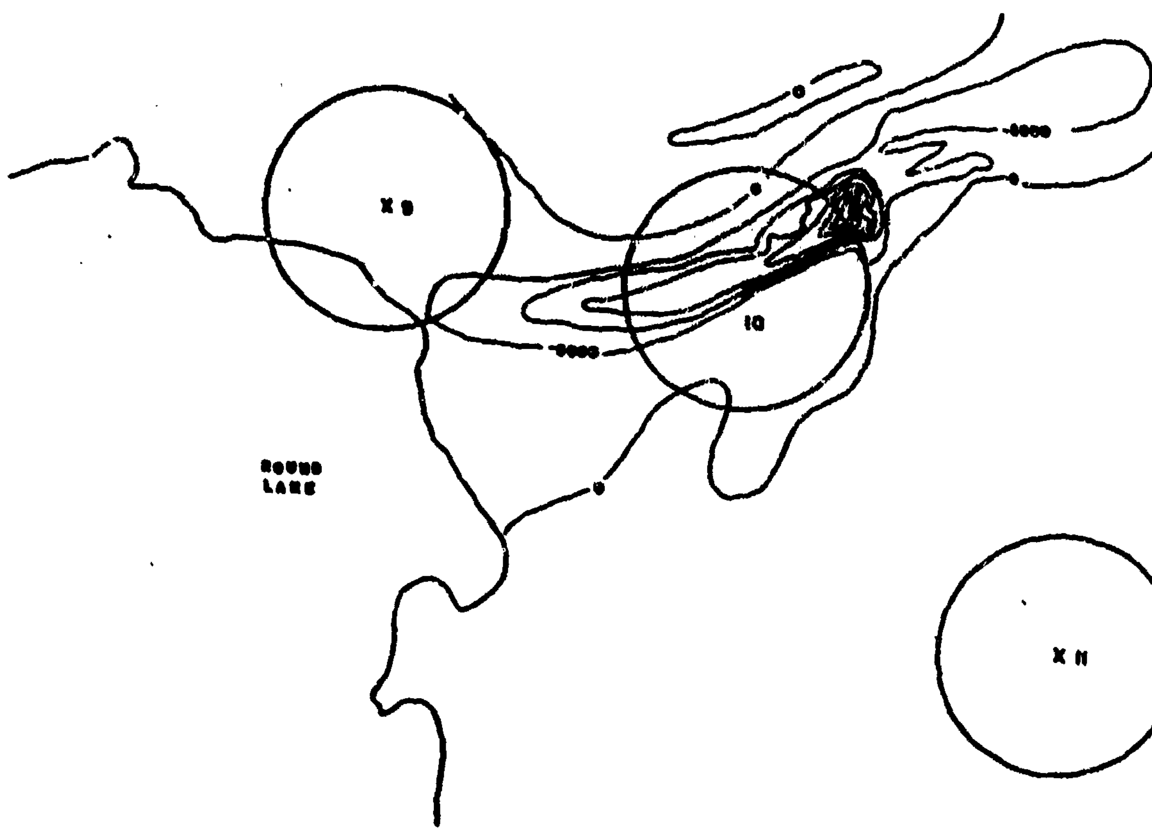


Figure 7.4

Geomagnetic map of the Round Lake anomaly, magnetic intensities measured at ground level , 5000 gamma intervals relative to an arbitrary level. Sites are located with a cross; circles show approximate range of radar.

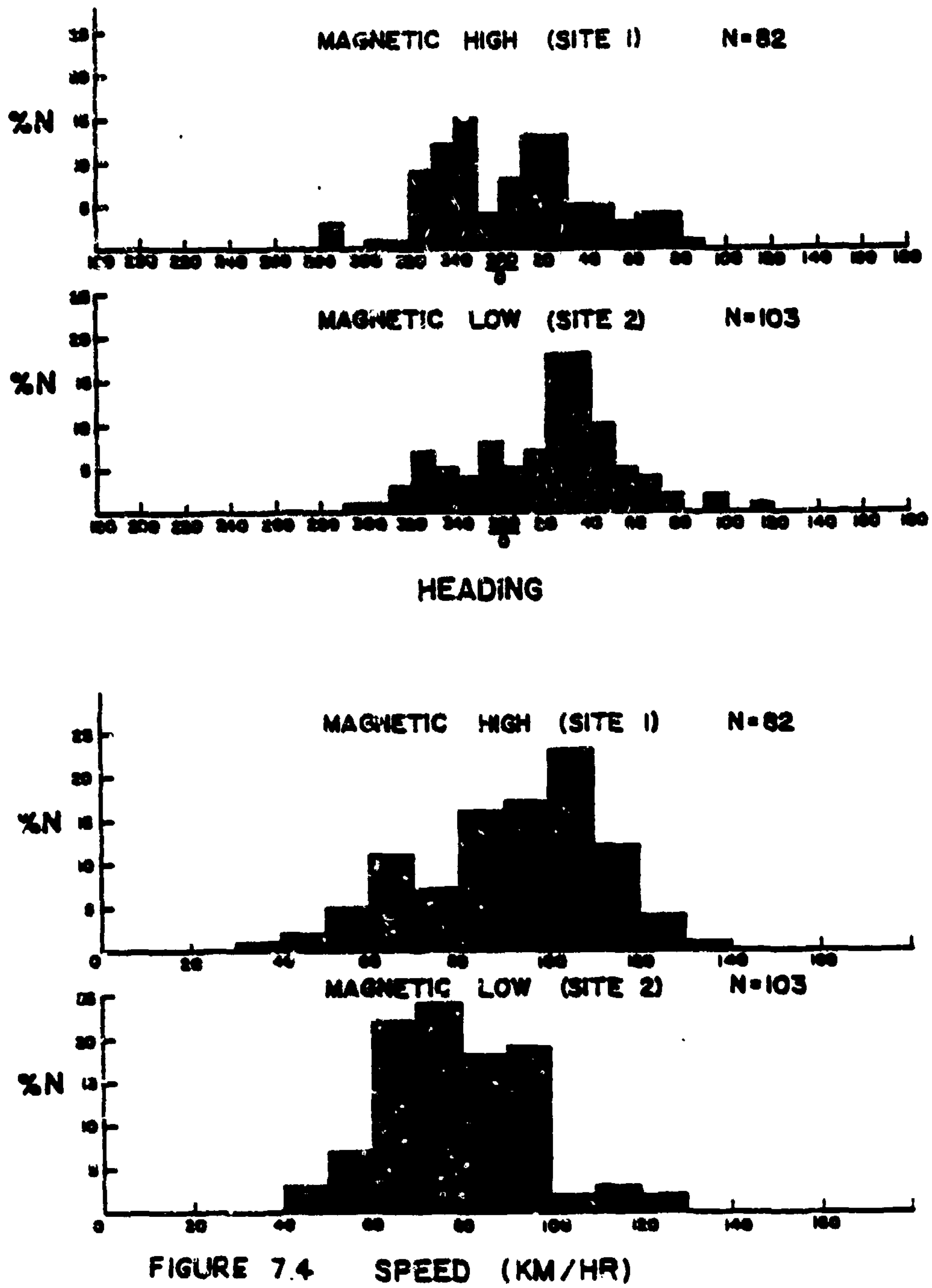


Figure 7.5

Distribution of track and groundspeeds at each site at Iron Hill on day 100, 1978.

SUMMARY OF RESULTS

1. Between 1974 and 1979 we have studied the effect of an ELF field on free flying migrant birds over the Wisconsin Test Facility. The technique has been to observe bird migration with short range, low power radars while the antennas of the WTF were activated in sequence. Results from our first two years of observations were reported in the final report of our previous contract. These observations showed that when the radar(s) were positioned near the transmitter building, several changes in the migratory behavior of birds were associated with activation of the antennas, particularly the north-south antenna leg. None of the changes were major and none occurred on all nights of observation.

2. Identification of migrants from radar data alone is not possible at present and thus extensive ground observations were used to estimate what species were those most likely to be moving through the study area during our observations. These observations suggest strongly that we observed the major portion of waterfowl migrations during both 1975 and 1977 and that we also observed migrations of large numbers of song birds, especially during the earlier periods of fall migration. The correlation between change in the number of birds seen on the ground and intensity of migration detected with radar was good.

3. Further analysis of the extensive (over 9,000 tracks) data collected during the fall of 1975 confirmed the general conclusions of our previous report but failed to reveal any more consistent pattern of effect or the ability to predict the magnitude of the effect based on either weather parameters or the direction or magnitude of bird migration itself.

4. Observations at sites remote from the transmitter building failed to show any consistent association with antenna state. This conclusion resulted from both the observations made at various distances from the north-south antenna leg and from observations made at the north-south antenna leg with varying peak antenna currents. In no case of ten nights of observation were regular changes seen remote from the transmitter in 1977, while three of nine nights at the transmitter in 1975 showed such effects. We therefore conclude that the effects noted at the transmitter site were not due to ELF fields generated by a linear antenna segment, but may have been due to the much more complex fields induced at the transmitter site or to some factor other than electric or magnetic fields at the transmitter site.

5. A computer simulation was devised to test the possible effects of a deviation in migratory orientation such as that observed at the WTF. In choosing parameters for the simulation we consistently assumed a worst case hypothesis consistent with current knowledge of avian orientational capabilities. The simulation indicated that the effect on final migratory goals of birds wintering in the continental U.S. would be minimal. This conclusion does not pertain to birds raised within the field of the WTF, only to migrants flying over the site.

6. We also briefly investigated those natural phenomena which might be expected to exert an effect similar to that observed at the WTF transmitter site. Observations at several sites within the area of the WTF revealed that low altitude avian migrants observed by our radar are normally subject to slight but regular changes in migratory behavior as they move over apparently flat areas located several kilometers apart. Observations at four areas

known to be magnetically anomalous also revealed systematic differences in flight behavior of birds over areas with different magnetic topography. Thus it appears that if the transmitter site induces a temporary, highly localized change in migratory behavior, this may be a normal occurrence in the migration of birds.

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