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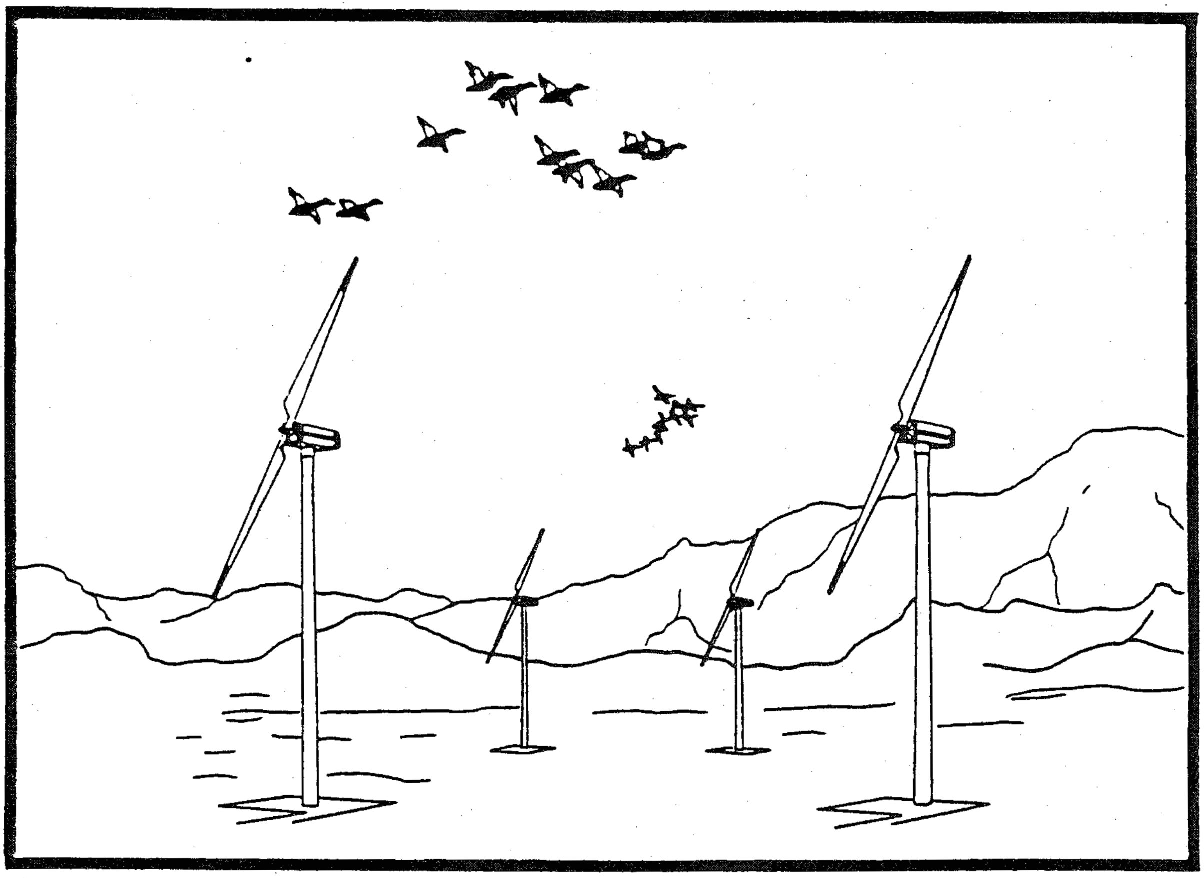
NOCTURNAL AVIAN MIGRATION ASSESSMENT OF THE SAN GORGONIO WIND RESOURCE STUDY AREA, SPRING 1982



Michael D. McCrary, Robert L. McKernan, Ross E. Landry,
William D. Wagner, and Ralph W. Schreiber

Report Prepared for Research and Development, Southern California Edison Company, Rosemead, California Through the Los Angeles County Natural History Museum Foundation , Section of Ornithology, Los Angeles, California.

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Section of Ornithology
Natural History Museum Foundation, Los Angeles County
Los Angeles, CA 90007

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Research and Development
Southern California Edison Company
Rosemead, CA

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SEAWEST

1455 FRAZEE ROAD
NINTH FLOOR
SAN DIEGO, CA 92108-4310
TEL (619) 293-3340
FAX (619) 293-3347

TRANSMITTAL

TO:	Mike Green	**DATE:**	November 9, 2001
COMPANY:	**FWS-MBHP**		
ADDRESS:	911 N.E. 11th Ave. Portland Oregon 97232		
PHONE:	(503) 872-2707	**FAX:**	
FROM:	Mike Azeka	**EMAIL:**	mazeka@seawestwindpower.com
PHONE:	(619) 908-3418		
FAX:	(619) 293-3347	**COPY:**	

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ACKNOWLEDGMENTS

Several people deserve special mention for their assistance in this study. Jack Mardesich of Jay-Mar Engineering Services constructed, modified, and/or installed much of the complex electronic components used. Ellen Adelman at Southern California Edison assisted in all data processing and Robert W. Smith of Ecological Data Analysis performed all multivariate statistical analyses. We thank Robert Yinger at SCE for providing engineering specifications on wind turbine designs, Larry Bregman at SCE for providing information on the weather of southern California, John Kelly and the personnel of the SCE Devers Substation for the use of their facilities, and Terry Sciarrotta (SCE Project Manager, Bird Migration) for providing valuable support and assistance throughtout. Finally, we wish to especially thank Sidney A. Gauthreaux for his expert technical assistance, guidance, and enthusiasm which greatly contributed to the completion of this project.

INTRODUCTION

As part of Southern California Edison's (SCE) goal to develop alternate and renewable energy resources, wind energy development is planned for the San Gorgonio Pass Wind Resource Area (Figure 1). This development may encompass as much as 186 km^2 and involve the installation of over 32,000 wind turbines (Wagstaff and Brady 1982). The utilization of wind to produce electrical power, although not new, has never been carried out on such a large scale. As a result the environmental hazards of wind turbine generators (WTG's) and the supportive transmission network are relatively unknown.

Two major environmental concerns of wind energy utilization are whether WTG's will affect seasonal movements or other behavior of migratory birds, and whether collisions will result in significant avian mortality. Although the probability of avian collisions with wind turbines is unknown, high levels of mortality from collisions with numerous other man-made structures (TV towers, smoke stacks, light houses, transmission and distribution lines, etc.) have been documented (for a review see Banks 1979). Estimates of avian mortality from collisions with radio and TV towers alone range from 1 to 1.25 million birds per year (Banks 1979, Mayfield 1967).

Few studies are available for developing effective environmental criteria for the San Gorgonio WTG park. Information on the

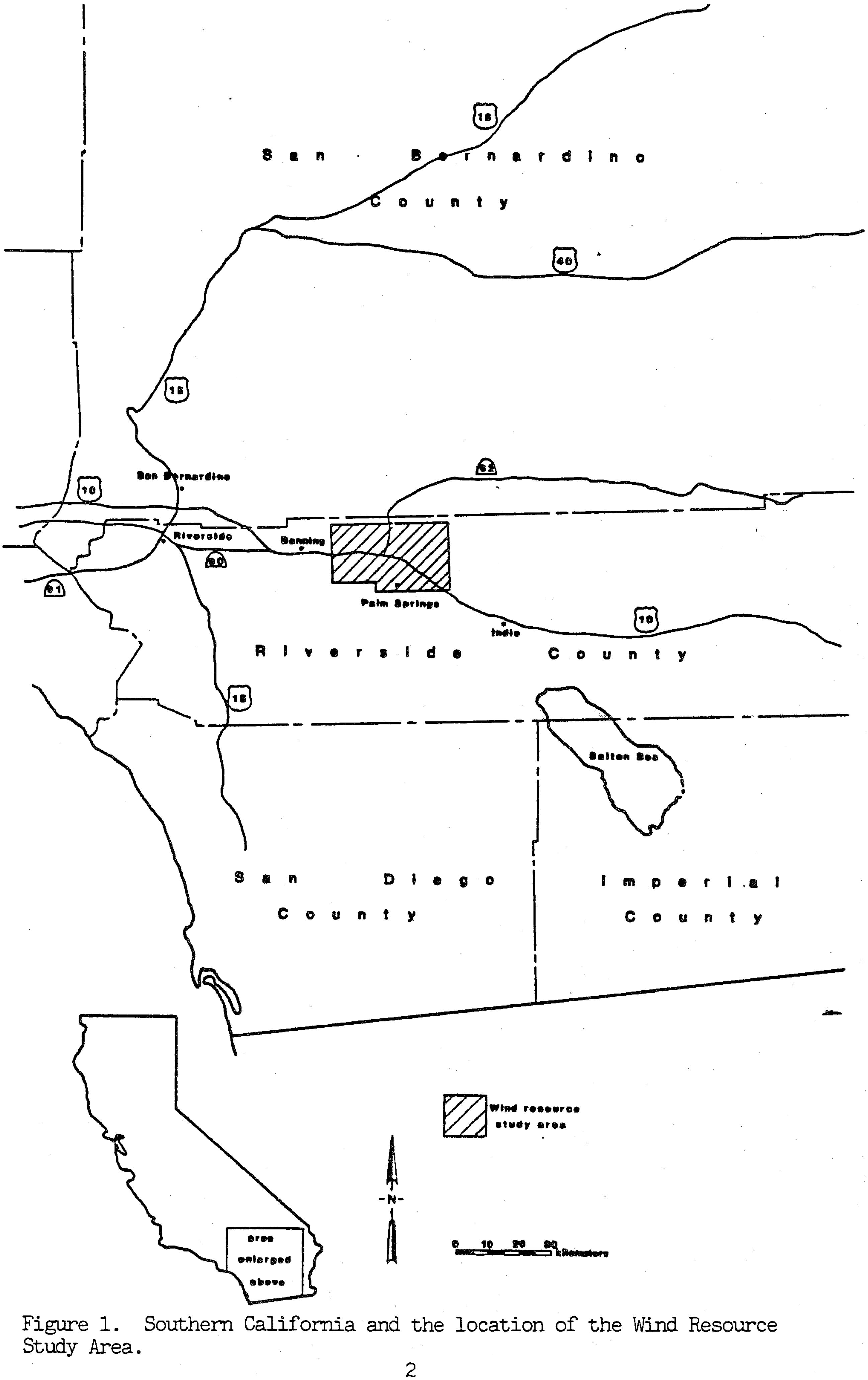

Figure 1. Southern California and the location of the Wind Resource Study Area.

distribution of nocturnal migrants at the lowest altitudes is not currently available and nocturnal migration has not been examined under the unique physical conditions characteristic of the Wind Resource Study Area (WRSA). A further hinderance is a general lack of information on nocturnal bird migration in southern California.

In accordance with its policy to protect the environment while generating and distributing electrical power, SCE has funded a number of studies on birds in the Coachella Valley and surrounding areas since 1979. Prior to spring 1981 these studies concentrated on densities and utilization patterns of diurnal resident and migratory birds. However, as most birds migrate at night (Able 1973, Emlen 1975), the emphasis of research in the WRSA was shifted to nocturnal studies of migratory birds. This research is intended to: 1) gain a thorough understanding of the dynamics of bird migration in the Coachella Valley, 2) provide information necessary for predicting the potential impact to avifauna resulting from wind turbine construction and operation in the WRSA, and 3) develop generic information on bird interactions with WTG's. These studies are only a portion of SCE's long term commitment to environmental research in regards to alternate energy development.

Research on nocturnal migration was initiated in April 1981 and has continued during four migratory periods (spring and fall 1981, spring and fall 1982). Our initial observations were confined to visual sightings on low altitude nocturnal migration. These data provided preliminary estimates of migration magnitude, flight direction, and the influence of wind on migration (McCrary et al. 1981). With the equipment employed during this period (spring and fall 1981), the altitude of nocturnal avian flights could not be determined, an obviously important aspect in evaluating the potential impact of the WTG park on birds. In spring 1982 we incorporated a modified vertical beam radar (see methods) in the nocturnal research which provided essential data on the altitudinal distribution of nocturnal bird migration. In this report we summarize spring 1982 bird migration in the WRSA.

Our principal research objectives were to:

1) Measure the magnitude of nocturnal migration in the Wind Resource Study Area (WRSA).

2) Measure the altitude of nocturnal migration.

3) Obtain data on weather conditions (wind speed and direction, temperature, cloud cover, barometric pressure) and determine how these factors influence nocturnal bird migration in the WRSA.

4) Evaluate the effects of topography (change in relief, elevation, etc.) on nocturnal bird migration (altitude, flight direction, magnitude, etc.).

5) Conduct experiments on methods for determining the effect of tall structures on bird behavior and mortality.

6) Develop a baseline data set (eg. altitude) necessary to predict the influence, if any, of the proposed WTG park on migratory birds.

7) Develop recommendations for mitigating the potential effects of the proposed WTG park on migratory birds.

STUDY AREA

Location and General Description

The San Gorgonio Pass and northwest end of the Coachella Valley where we conducted this study, are located in northern Riverside County in the Colorado Desert of southern California. This area of approximately 453 km^2 is north of Palm Springs and east of Banning (Figure 1).

The east-west lying San Gorgonio Pass is bounded by the San Bernardino Mountains (3,350 m) to the north and the San Jacinto Mountains (3,050 m) to the south (Figure 2). The elevation of the floor of the pass is approximately 365 m, decreasing from west to east. The pass is about 5 km in width and its borders are dramatically abrupt, rising in places to over 3,000 m in less than 8 km.

The northwest to southeast lying Coachella Valley is located to the east of the San Gorgonio Pass, between the Little San Bernardino Mountains (1,220 m) to the northeast and the San Jacinto and Santa Rosa Mountains (1,980 m) to the southwest. The valley floor varies from approximately 300 m in elevation at its northwest end to 70 m below sea level at the Salton Sea (Figure 3).

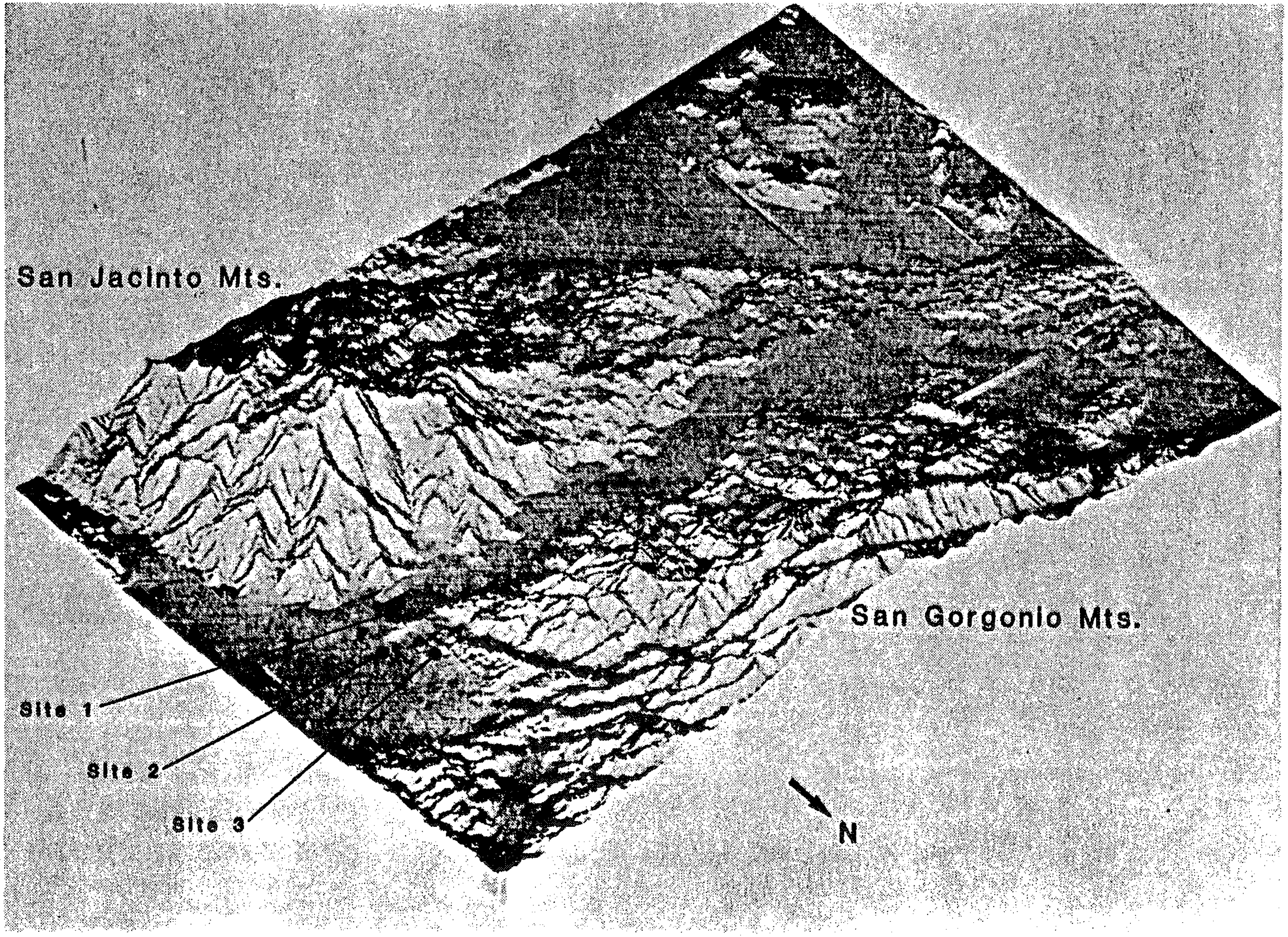

Figure 2. Computer simulated aerial view of the San Gorgonio Pass showing 3 of the 7 nocturnal study sites.

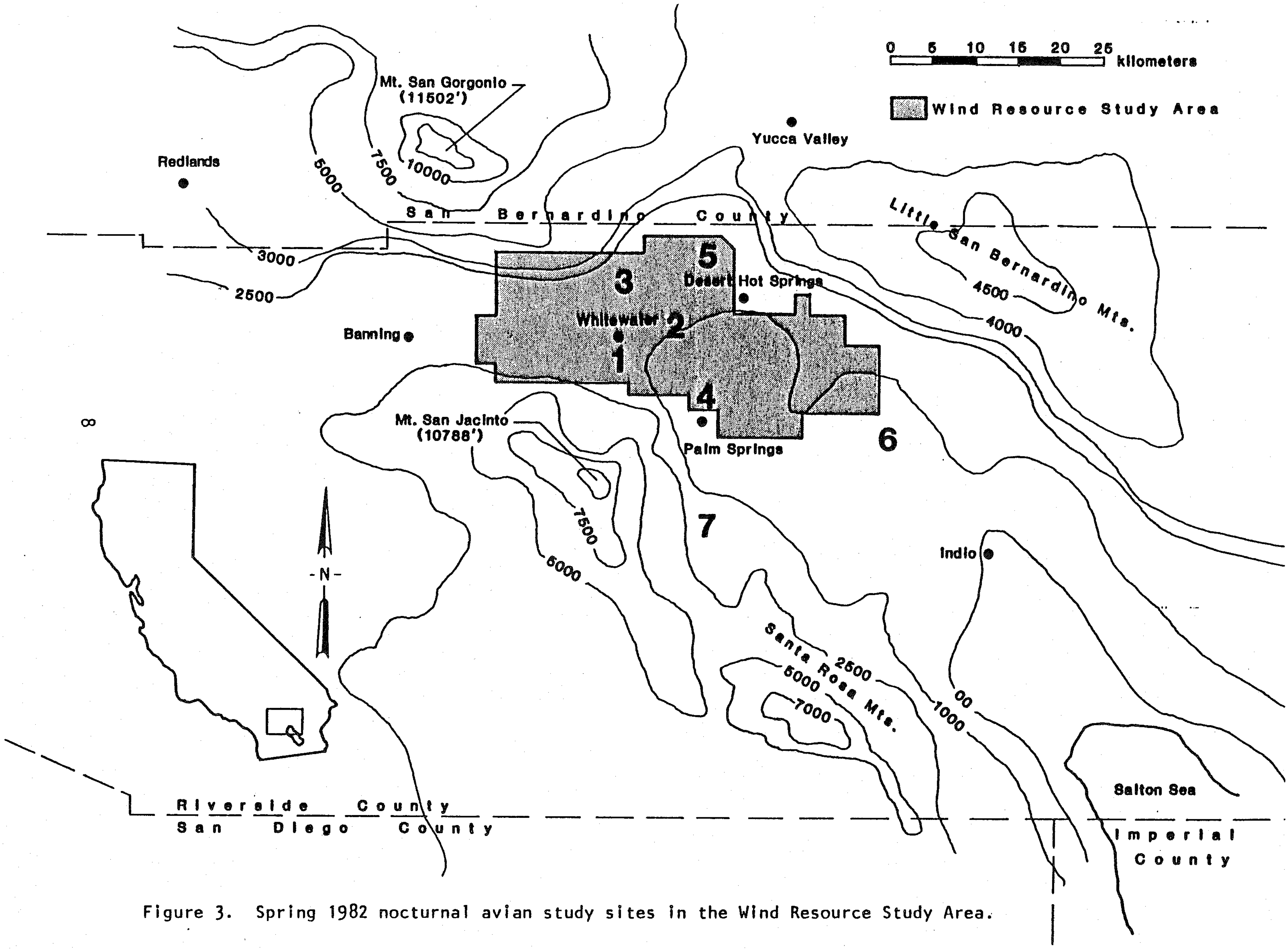

Figure 3. Spring 1982 nocturnal avian study sites in the Wind Resource Study Area.

Climate

The climate of the WRSA is characterized by moderate winters and hot, dry summers. Temperatures at Palm Springs range from a mean winter low of 4.4 C° (40 F°) (January) to a mean summer high of 42.2 C° (108 F°) (July) (Aldrich and Meadows 1966). Average annual rainfall in Palm Springs is 16 cm (6.3 in) (N.O.A.A. 1974) indicating the xeric nature of this area. Most rainfall occurs from December through March at Palm Springs, with February averaging the highest (Aldrich and Meadows 1966).

During spring, daytime temperatures in the WRSA average from 25°-34°C with nighttime temperatures averaging from 10° - 15°C (Aldrich and Meadows 1966). Storms originating to the northwest of the study area, during March and early April can be quite extensive, covering most of the Coachella Valley, but generally dissipate near the pass. Usually, however, during most of the year low clouds and fog are uncommon in the area of the WRSA. A northwest - southeast gradient in temperature and rainfall in spring occurs through the WRSA resulting from the rainshadow effect of the San Jacinto - San Bernardino Mts. and a NW-SE decrease in elevation through the Coachella Valley.

The most prominent climatic feature of the study area is the consistent high westerly winds which are especially strong at night during spring and summer (Zambrano and Arcemont 1981). Generated by the differential between cool coastal conditions and the characteristically higher temperatures of the Colorado Desert, this wind flow pattern averages 20 mph (8.9 m/s) on the floor of the pass during spring and more than 24 mph (10.7 m/s) on well exposed ridges (Zambrano and Arcemont 1981). Daily averages can occasionally exceed 45 mph (20.0 m/s), with gusts of more than 60 mph (26.8 m/s) not unusual when storm fronts pass through southern California. The drop in elevation from the west end of the pass (700 m) to the east end (183 m) produces a west-east increase in wind speed with wind velocity peaking near Whitewater (Figure 3). Winds are especially strong along the southern edge of the pass east of Whitewater, resulting from a further drop in elevation from north to south (Zambrano and Arcemont 1981).

Although we were unable to measure winds aloft during this study, data collected in previous years indicate that, up to at least 600 m, the direction of winds aloft is highly correlated with surface winds but may occur at even greater velocities (Zambrano and Arcemont 1981).

Vegetation

The vegetation of the study area is dominated by species characteristic of the Upper Colorado Desert, although several plant communities are present (see Thorne 1982). These are a result of extremes in rainfall, temperature, soil conditions, and topographic relief which occur in the area. By far the most extensive habitat is creosote bush scrub which occurs throughout most of the WRSA on desert slopes, alluvial fans, and valley floors below 1,200 m. This habitat is overwelmingly dominated by creosote bush (Larrea divaricata) and also includes important components of bursage (Ambrosia dumosa) and brittle bush (Encelia farinosa). This vegetation is typically low, windswept, and sparse over most of the area.

Other habitat types include dry wash, [creosote bush, palo verde (Cercidium floridum), and ironwood (Olneya tesota)], sand dunes [creosote bush, saltbush (Atriplex canescens), and mesquite (Prosopis glandulosa)], and small but important components of mountain and riparian vegetation.

Nocturnal Study Sites

We studied nocturnal bird migration for 38 nights (368 hours) at 7 sites within or near the perimeter of the WRSA from 15 March - 24 May 1982 (Figure 3). On most nights observations began approximately 45 minutes after sunset and continued until 2315 (PST). We then moved to another site where we resumed observations at 0030 and continued until 45 minutes before sunrise. Appendix A lists the schedule of observations for this study.

The 7 nocturnal study sites were:

Site 1. Approximately 0.5 km west of the meteorological tower on the floor of the pass, 1 km SE of Whitewater, elevation 366 m (9 nights, 48 hours). The pass at this site is approximately 5 km wide.

Site 2. Approximately 0.5 km east of the Bendix wind turbine near Devers Substation, 7.5 km west of Desert Hot Springs, elevation 335 m (13 nights, 90 hours). This site is at the NW end of the Coachella Valley, approximately 4 km from the entrance to the pass. The terrain is relatively open and flat and the valley at this site is approximately 13 km wide.

Site 3. Painted Hill, approximately 2 km NW of the intersection of Interstate Highway 10 and State Highway 62 (4.5 km NE of Whitewater), elevation 518 m (9 nights, 38 hours). This site is on the slope of a north-south lying ridge that extends partially into the east end of the San Gorgonio Pass. The slope of this site increases approximately 100 m/km.

Site 4. Approximately 0.5 km east of Indian Avenue in the Whitewater River wash, 6 km north of Palm Springs, elevation 183 m (9 nights, 51 hours). This site is in the dry floodplain of the river, approximately 8 km from the east entrance to the pass.

Site 5. Approximately 0.5 km north of Indian Avenue, 5 km NW of Desert Hot Springs, elevation 434 m (8 nights, 39 hours). This site is on the valley floor along the southern edge of the Little San Bernardino Mountains. Although the terrain of the site itself is relatively flat, the foothills of these mountains arise abruptly just north of the site.

Site 6. Approximately 1 km north of Ramon Rd. near Thousand Palms, 13 km east of Palm Springs, elevation 91 m (8 nights, 79 hours). This site is located near the center of the valley on the eastern edge of the WRSA.

Site 7. Palm Canyon, 7 km south of Palm Springs, elevation 213 m (6 nights, 30 hours). This site is on the floor of a narrow (2 km), north-south lying canyon draining the NE slope of the San Jacinto Mountains. Although outside the WRSA, this site was selected to test hypotheses on migration densities across the valley.

We selected these study sites based on their location in relation to proposed wind turbine developments and/or to test hypotheses on how nocturnal bird migration in the WRSA is related to topographic features and air flow patterns. Although data were collected at these specific sites, this information applies to most other areas in the WRSA and is probably representative of spring migration throughout much of the Coachella Valley.

METHODS

Equipment

We employed a combination of electronic visual and radar technologies (Figure 4) to obtain data on the altitude, magnitude, and direction of nocturnal bird movement. A high resolution X band (3 cm), 10 kW marine radar (Decca 150) was used to determine the altitude and magnitude of bird flights above 19 m (see below). We modified this radar by replacing the standard rotating T-bar antenna normally used for marine application with a 76 cm parabolic antenna positioned in a vertical, fixed beam mode (Gauthreaux pers. comm.). The antenna and transceiver were mounted in a small trailer, while the radar display console was mounted in a utility van positioned about 20 m from the trailer (Figure 5). A closed circuit television camera centered over the radar display screen was used to store data on video tape (Figures 4 and 6). The radar field of view was 5.56°, and the range of observed altitudes was 19 - 1,483 m (0.01 - 0.80 n.m.), in increments of 19 m (0.01 n.m.). We selected this range scale over others, as it is difficult to separate bird echoes with longer ranges, and based on occasional use of higher settings, very little migration (less than 0.5%) occurred above 1,483 m.

In conjunction with the marine radar, we used a vertically directed image intensifier (an electronic 155 mm telescope which

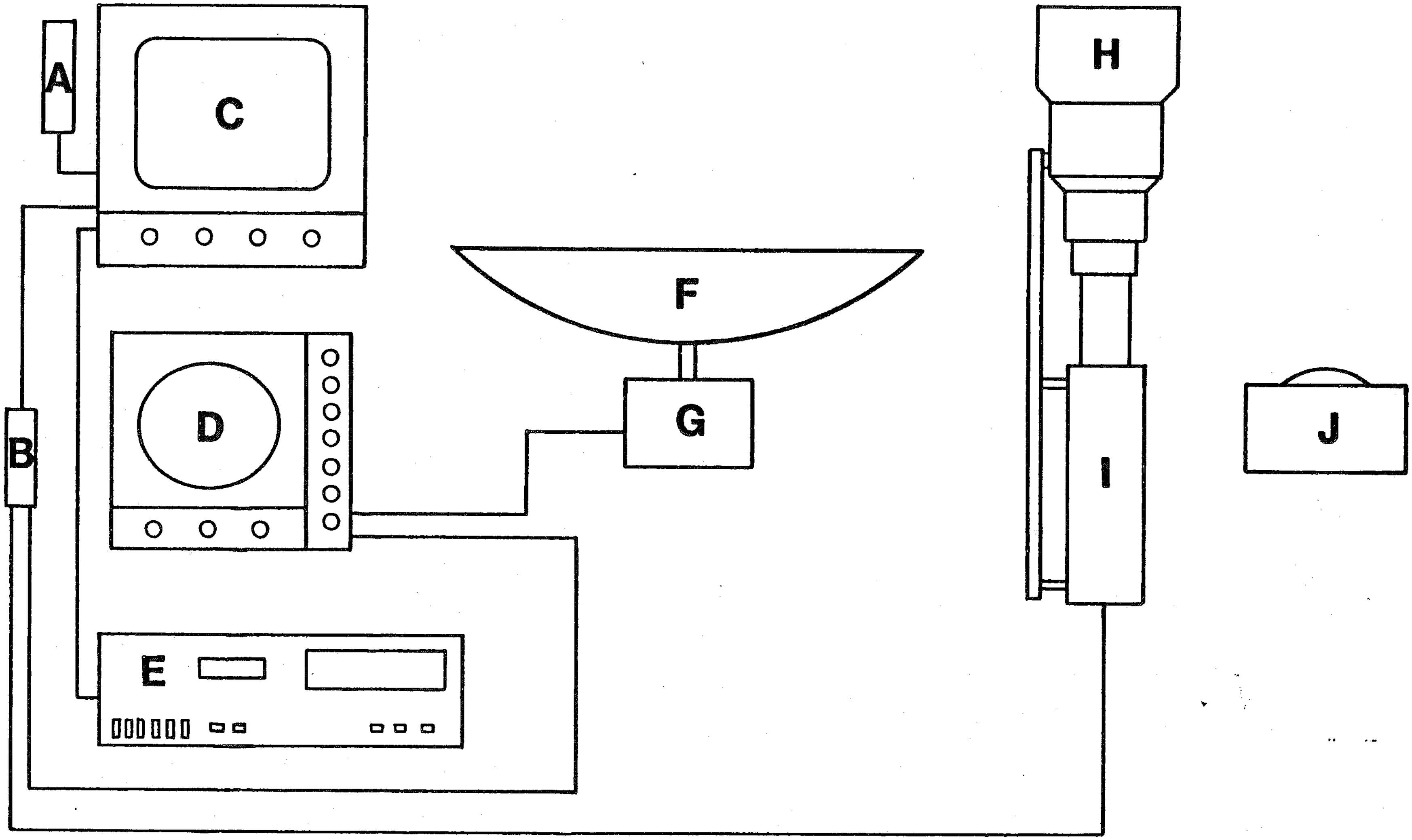

Figure 4. Image Enhacement and Radar System. A) Time-date generator, B) video spliter, C) video monitor, D) radar PPI (screen), E) video cassette recorder (VHS), F) radar parabola G) radar transceiver, H) AN/TVS image intensifier, I) video camera, J) narrow beam high candle power spotlight.

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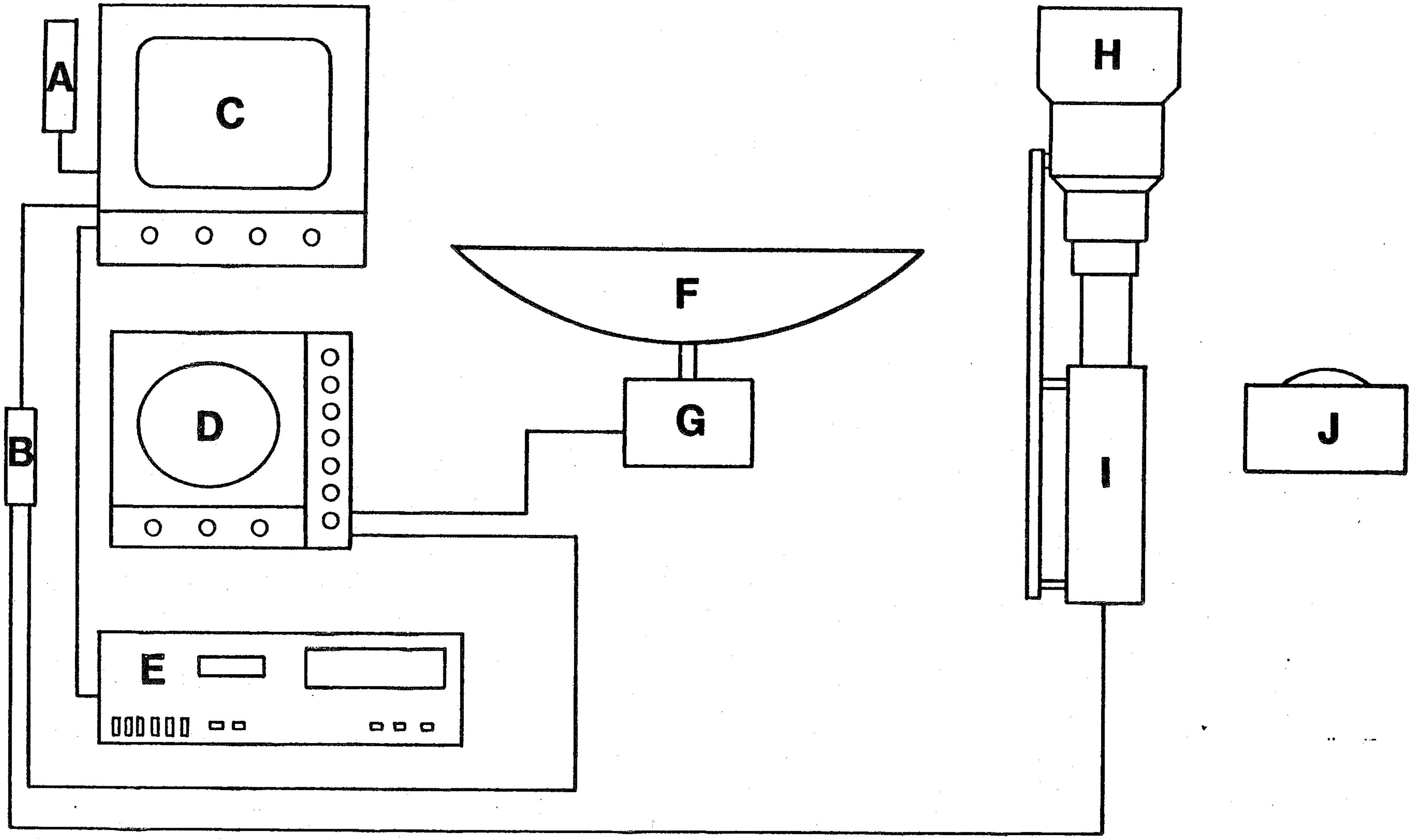

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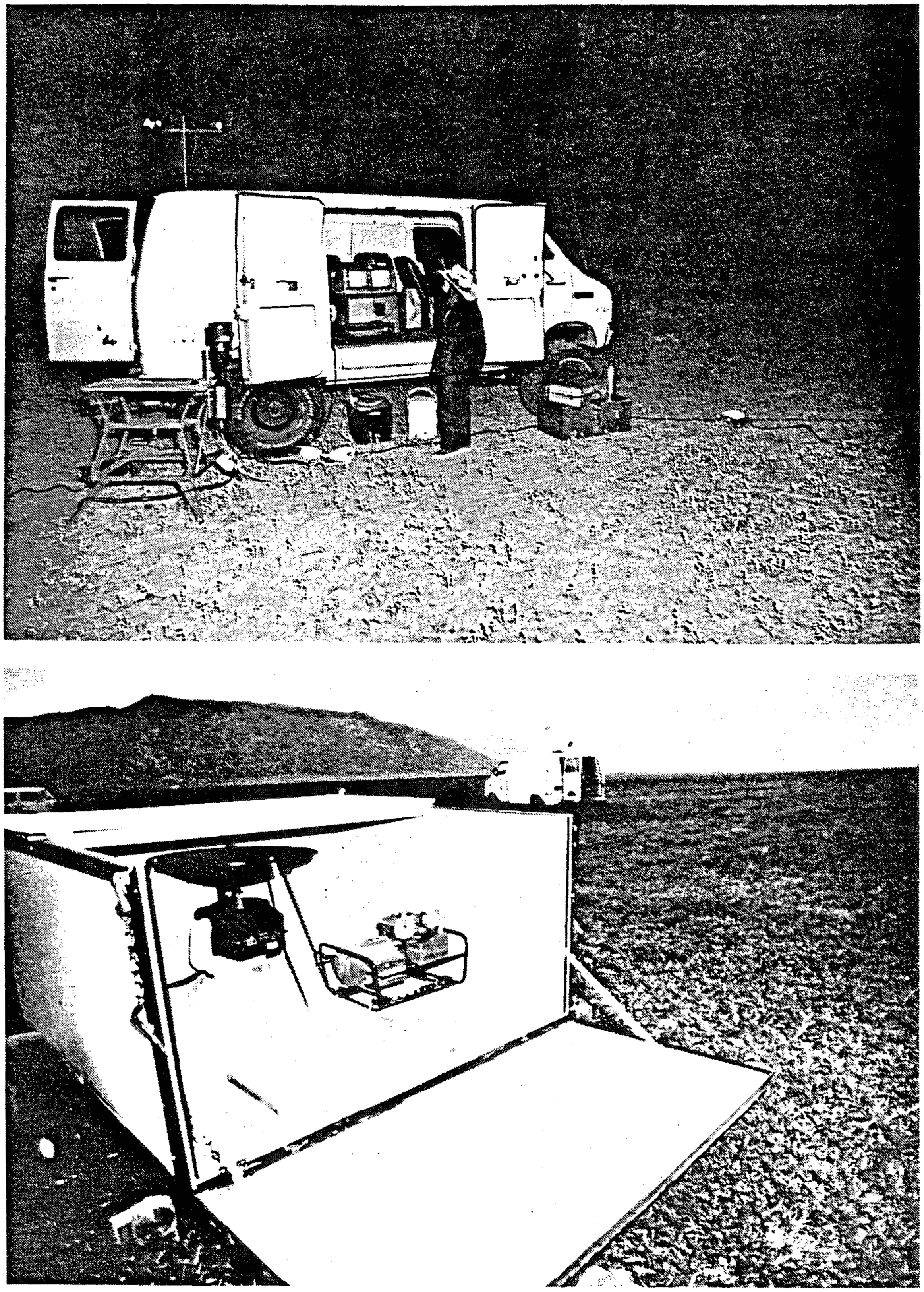


Figure 5. Utility van used for observing nocturnal bird migration (upper). Trailer with radar transceiver, parabolic antenna, and generator (lower).

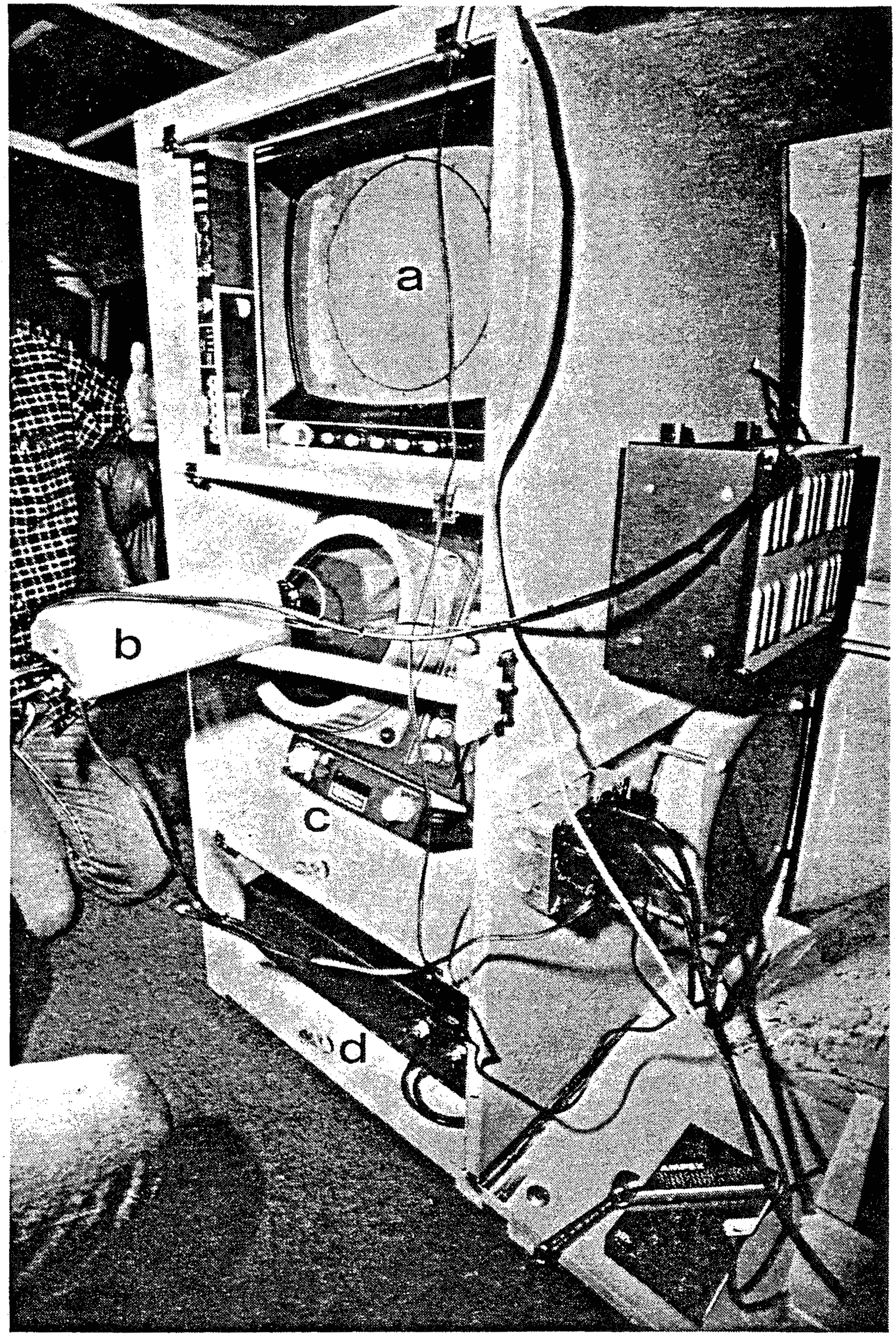


Figure 6. Interior of utility van showing monitoring equipment:
a) video monitor, b) TV camera, c) radar (PPI) screen, d) video recorder.

amplifies ambient light up to 30,000 times) to visually observe nocturnal migrants. This telescope was attached to a closed circuit television camera connected to a video monitor located in the van (Figure 4 and 6) (Gauthreaux 1980). A vertically directed narrow beam ceilometer (500 watt) illuminated birds passing overhead (Gauthreaux 1969). The image intensifier and camera were mounted on the trailer and aligned with the field of view of the radar, with the ceilometer positioned about 20 m away. The average maximum altitude at which most passerines are visible with the image intensifier/ceilometer system is about 300 m, while larger birds and flocks are visible to over 1,000 m. For ease of observation and data storage, the output of both the radar and image intensifier cameras were simultaneously displayed on the same monitor using a video screen splitter (Figure 7). A video recorder connected to the monitor provided storage of all data for later review when necessary.

During 1981 research, we relied entirely on the image intensifier/ceilometer system to determine both the magnitude and direction of migration (Gauthreaux 1980). In spring 1982, however, we determined the magnitude of migration from the combined radar-image intensifier system. Because of the sensitivity of the marine radar to a variety of flying insects, we recorded only those radar echoes in the band of flying insects (19 - 185 m) for which there were corresponding visual sightings. We used a cutoff of 185 m for the image intensifier, as most insects were observed flying below this altitude and the detectability of small passerines with the image intensifier

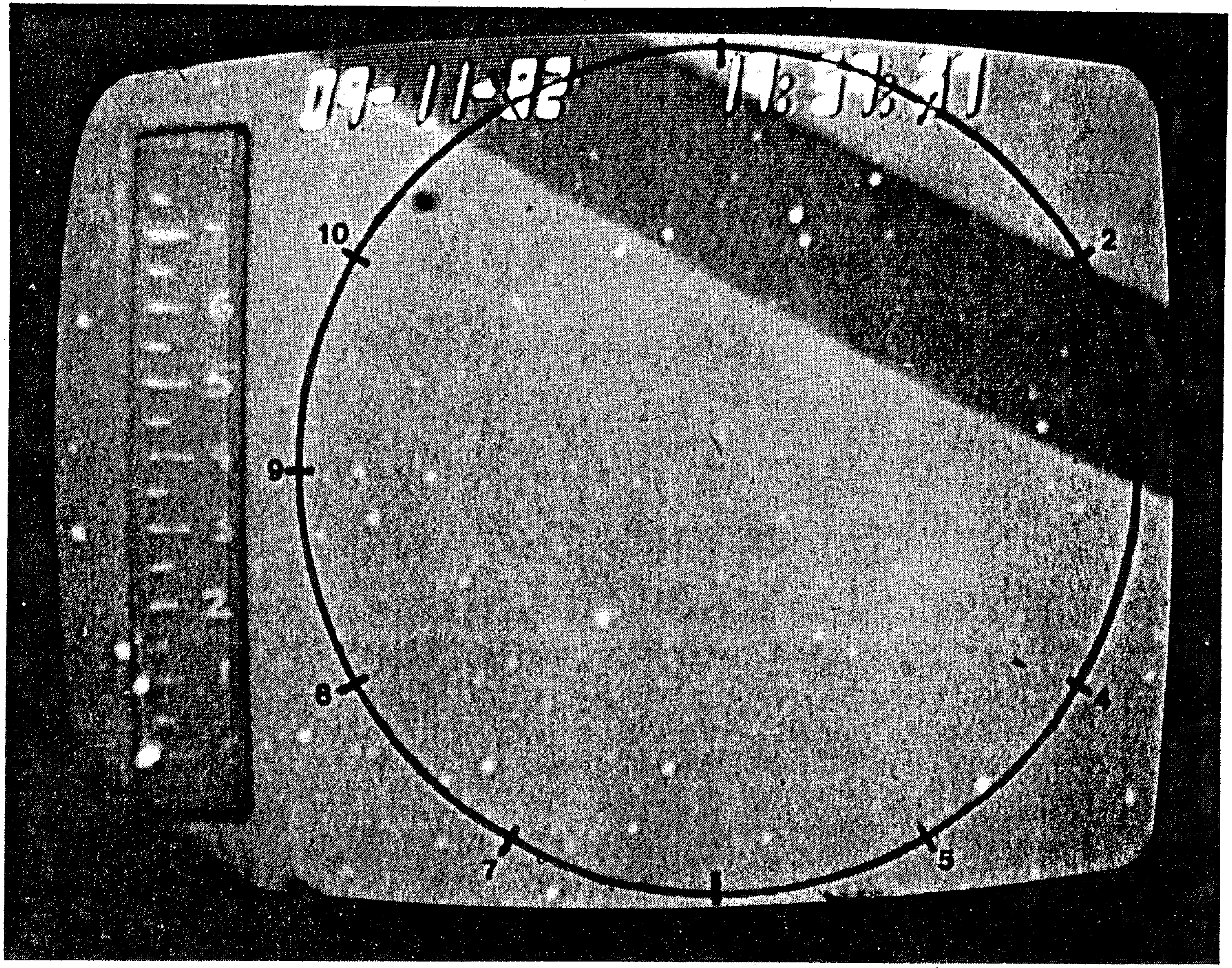


Figure 7. TV monitor inside utility van showing simultaneous view of night sky with the image intensifier (large circle) and radar (narrow rectangle). Numbers around circle represent clockface directions. Radar scale calibrated in 0.05 n.m. increments. A radar bird echo is shown at 0.1 n.m.

declines above 185 m. All radar echos above 185 m were recorded regardless of whether corresponding visual sightings were observed. Most insects appeared out of focus or exhibited erratic flight behavior and were easily distinguishable from birds. We also used cues related to the relatively greater speed and brightness of birds and the frequent presence of wingbeats to differentiate birds from insects. However, insects occasionally occurred at altitudes above 185 m, and on these nights all radar entries below 300 m have been excluded. Additionally, the image intensifier malfunctioned on 1 May and with the lack of visual confirmation, we have not included any radar entries below 300 m recorded during May. (All mean traffic rates and altitudes given in this report are based on only those nights when all equipment was functioning properly and there were no insects above 185 m unless otherwise stated.)

Observations were conducted by two field biologists experienced at operating this type of equipment. They viewed the video monitor and recorded the exact time (PST) a bird(s) was sighted, the number of individuals, and the altitude(s) of birds. All information was recorded on portable micro-cassette tape recorders.

The behavior of birds flying near a high tension transmission tower at site 2 was observed with the image intensifier and ceilometer directed horizontally at the top of the tower. The behavior of each bird was recorded as no reaction (no apparent change in the bird's flight path or behavior), moderate reaction (single change in flight path as if to avoid striking the structure), or high reaction (a change near a structure from normal to erratic flight, including circling of the structure). We also used binoculars and 20X spotting scopes in place of the image intensifier to observe birds at this tower.

Analysis

We use the concept of Migration Traffic Rate (MTR) (Lowery 1951) - the number of birds crossing a line 1 km long in 1 hour - to express the magnitude of migration. MTR's are calculated from birds/hr by multiplying correction factors (see below) based on the dimensions of the conal area sampled with the radar/image intensifier system (Figure 8). To determine altitudes of migrants, the vertical range of the radar beam as observed on the radar screen was divided into 80 increments of 19 m (0.01 n.m.) each. In order to determine MTR's, we calculated correction factors for each of these 80 altitudinal increments. Below 185 m we used correction factors based on the field of view of the image intensifier (4.41°), while above 185 m correction factors were based on the width of the radar beam (5.56°).

We calculated correction factors by a complex method involving simultaneously recorded observations on both the radar and image intensifier. The first step in this process was to video tape the full moon with the image intensifier. The width, in degrees, of the image intensifier field of view was measured from the known width of the moon (0.5°). We then reviewed video tapes of single birds and flocks

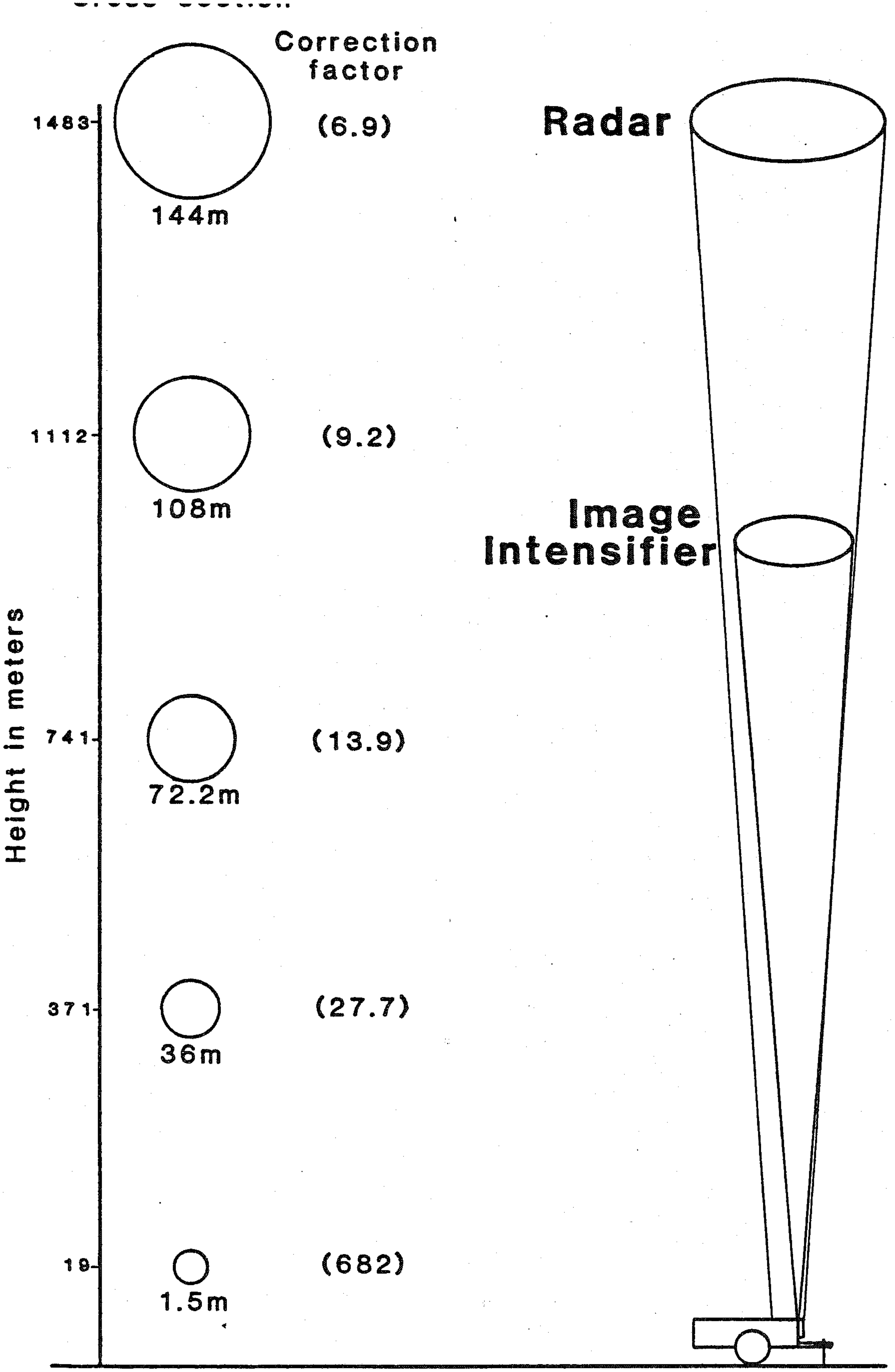


Figure 8. Radar and image intensifier fields of view with selected MTR correction factors.

the center of the aligned field of view of the radar and image intensifier at several different altitudes. By measuring the elapsed flight time across the image intensifier and the corresponding flight time across the radar, the width of the radar beam was calculated. From these measurements the average beam width of the radar was determined (5.56° ± 0.32 SE, n = 29). The actual diameter of the radar was calculated for each altitudinal increment by the trigonometric function (diameter = height x tangent of angle) and correction factors are equal to the number of diameters of the sample area in 1 km; correction factors range from 682 at 19 m to 7 at 1,483 m. Thus, MTR's are calculated by summing the corrected number of birds at each height increment in an hour. A further correction accounted for periods of less than 1 hour.

Azimuth flight directions (expressed as directions birds were flying to in degrees from true N) were calculated from clockface directions with information provided by Gauthreaux (1980). With this method, flight directions are grouped in 7.5° intervals.

We determined mean flight directions and dispersions by vector analysis (Batschelet 1965). The statistic (r) represents the length of the sample mean vector. This is a unitless measure of concentration around the mean ranging in value from 0 (undefined mean angle) to 1 (all data concentrated in the same direction). The significance of all average flight directions was determined with the Rayleigh test, which tests the null hypothesis of a random distribution of flight directions.

All nocturnal bird data were compiled and segregated on an IBM 3033 computer using Statistical Analytical Systems (SAS) software. We used several multivariate techniques to analyze the data on migration density, site, and weather. Analyses of variance were used to determine if differences occurred between sites in migration magnitude. This was performed on residuals determined from smooth curves which removed the effect of date on MTR's. A similar analysis of variance was performed on migration magnitude, altitude, and synoptic weather patterns. Stepwise multiple regression was used to examine the relationship between migration density, altitude, and 15 specific weather variables.

PART 1. BIOLOGICAL ASPECTS OF NOCTURNAL BIRD MIGRATION IN THE COACHELLA VALLEY

RESULTS

During 38 nights of study, we recorded over 30,000 entries on radar and 2,134 birds visually. Based on behavior, visual observations were separated into 2 groups: single birds or birds in very loose associations and flocks. Single nocturnal migrants are considered as mainly songbirds (order Passeriformes), while flocks are either shorebirds (order Charadriiformes) or waterfowl (order Anseriformes) (Able 1974), although birds in these orders may also fly singly. This classification is supported by our observations on the flight directions of single migrants vs flocks under high winds (>7 mph) (see below). A list of nocturnal migrants observed during diurnal observations in the WRSA and surrounding areas is shown in Appendix B.

Single migrants were the most common during this study (88%), as in spring 1981 (McCrary et al. 1981). Since the migratory flight behavior of waterfowl and shorebirds is known to be dissimilar, single migrants and flocks have been considered separately. It should be noted, however, that we were unable to differentiate flocks from single migrants with radar only, but visual observations with the image intensifier indicate that the vast majority of radar echoes were single birds.

As in other studies of nocturnal migration, (Able 1972, Gauthreaux

1971, Lowery 1951, McCrary et al. 1981, Moorhouse 1980), we found considerable variation in the number of migrants observed from hour-to-hour and night-to-night. The mean MTR for single migrants, all hours and sites combined, was 4,006 ± 562 SE (range 42 - 24,477). As indicated by the range of MTR's, at least some migration occurred during all hours of observation, with substantial variation frequently occurring within a single night. For example, on 15-16 April 1982 at site 6, MTR's varied from 8,127 at 1900 to 612 at 0300. The range of MTR's in this study was greater than that observed in spring 1981 (62 - 14,136) (McCrary et al. 1981). Much of the observed variation in MTR's can be explained through an analysis of hourly, seasonal, and topographic patterns of migration, as well as by the influence of weather.

Nightly Pattern of Migration

Although tremendous differences in the amount of migration frequently occurred during a night, the nightly pattern of change in migration magnitude was highly consistent from night-to-night and site-to-site (Figure 9). A strong negative correlation exists between mean MTR's and hour of the night ($r = -0.950$, $n = 10$, $p < 0.001$) with most migration occurring during the first 4 hours (1900 - 2200) of the night (61%); over 20% occurring during the first hour, and the lowest level of migration occurred at 0300 (4.2%). Mean MTR's for hours before midnight were greater than those after midnight at all sites (Table 1), and the mean MTR before midnight, all sites combined, was significantly greater than the mean MTR after midnight ($p < 0.01$). Although not

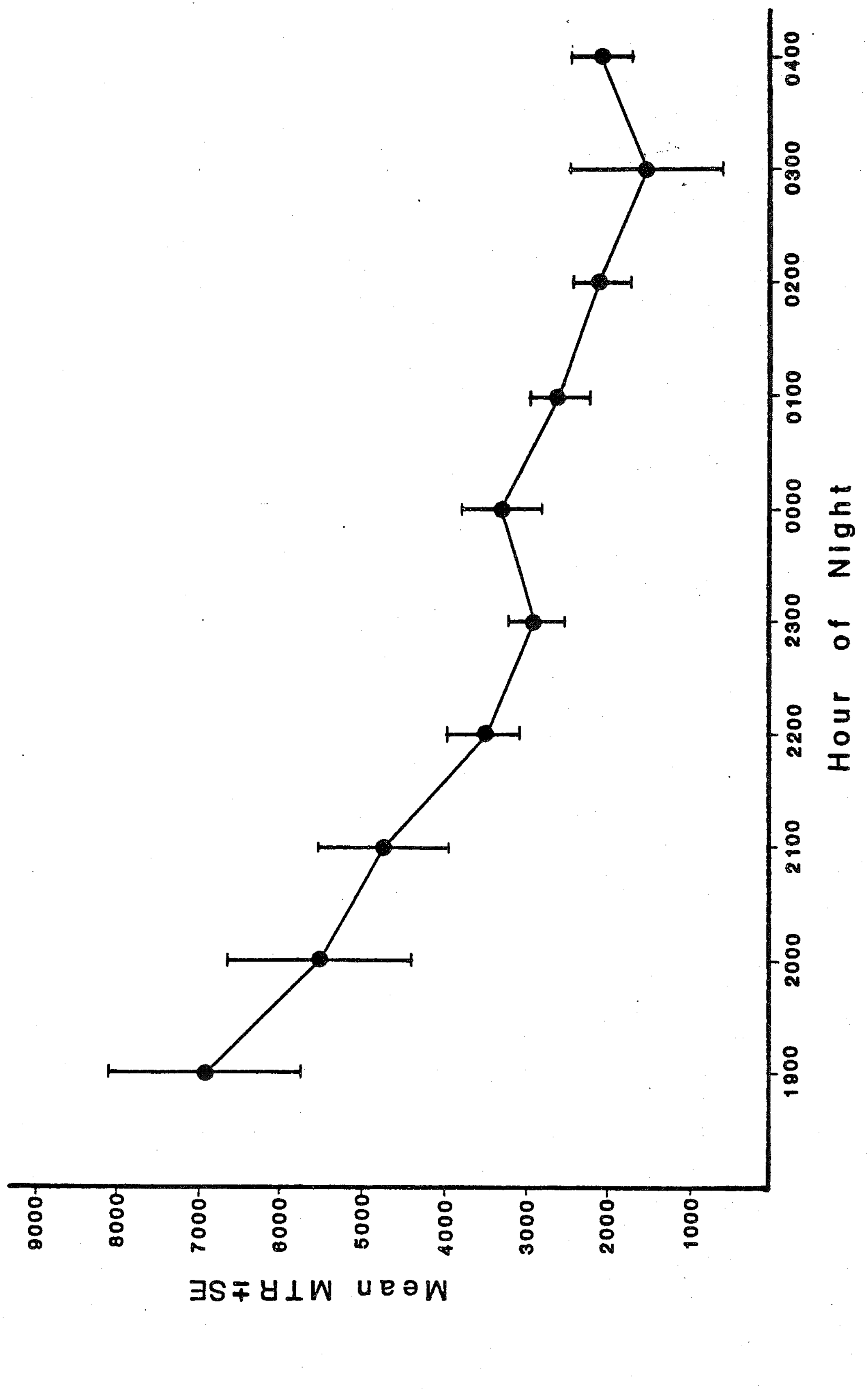


Figure 9. Nightly pattern of nocturnal passerine migration, all sites combined.

Table 1. Mean passerine MTR's observed in the Wind Resource Study Area during spring 1982.

Site	Mean MTR ± SE before midnight (1900 - 2300)	n	Mean MTR ± SE after midnight (0000 - 0400)	n	Mean MTR ± SE all hours
1	4,309 ± 1,076	8	1,808 ± 356	10	2,919 ± 583
2	6,017 ± 1,257	9	1,096 ± 318	10	3,427 ± 833
3	5,793 ± 723	9	1,572 ± 272	10	3,571 ± 614
4	3,753 ± 545	19	2,736 ± 371	15	3,304 ± 352
5	3,282 ± 413	9	3,059 ± 427	10	3,165 ± 291
6	5,360 ± 1,244	25	2,833 ± 425	25	4,082 ± 676
7	5,568 ± 839	10	2,202 ± 377	10	3,885 ± 591
All	4,846 ± 423	89	2,317 ± 170	90	4,006 ± 562

entirely consistent, 1900 was usually the peak hour of migration (47% of nights), with the peak on other nights distributed evenly through most of the remaining hours (2000 - 0400) (Table 2). Migration activity usually decreased sharply after 1900, with a more gradual decline through the remainder of the night. As indicated earlier, the actual change in magnitude during the night was sometimes dramatic.

Seasonality

Although migration was recorded during all nights in this study, the actual degree of migration varied considerably through the season. Figure 10 shows mean nightly MTR's for hours before midnight. Mean nightly MTR's before midnight were significantly correlated with Julian date ($r = 0.534$, $p < 0.01$). Both mean and peak (Table 2) MTR's were low to moderate in late March and early April, increasing after 9 April to a peak mean MTR (14,204) and highest single MTR (24,477) on 22 April at site 6. This peak coincides precisely with the peak night observed in the WRSA during spring 1981 (peak MTR = 22,800 at site 6 on 22 April 1981) (McCrary et al. 1981).

Because of equipment failures and insect clutter, in Figure 10 we show only a portion of the nights actually covered in this study. Observations during the remaining nights of study are limited to only altitudes above 300 m (Figure 11). Although the nightly mean MTR's above 300 m are not representative of the actual mean rates of migration during the study, the seasonal pattern of migration is very

Table 2. Nightly peak passerine MTR's observed in the Wind Resource Study Area during spring 1982.

Date	Site	Hour	Peak MTR
24 March	5	1900	6,259
27 March	5	1900	4,125
31 March	4	2200	6,055
3 April	6	0400	3,658
4 April	1	1900	3,631
6 April	7	0000	3,539
8 April	6	2100	4,889
12 April	3	1900	8,063
13 April	2	1900	9,376
14 April	7	2100	5,982
15 April	6	1900	8,127
17 April	1	2000	8,336
21 April	7	0000	4,305
22 April	6	1900	24,477
24 April	3	2200	9,142
25 April	2	1900	11,586
28 April	7	1900	11,129
29 April	6	0100	5,732
30 April	4	2000	8,654

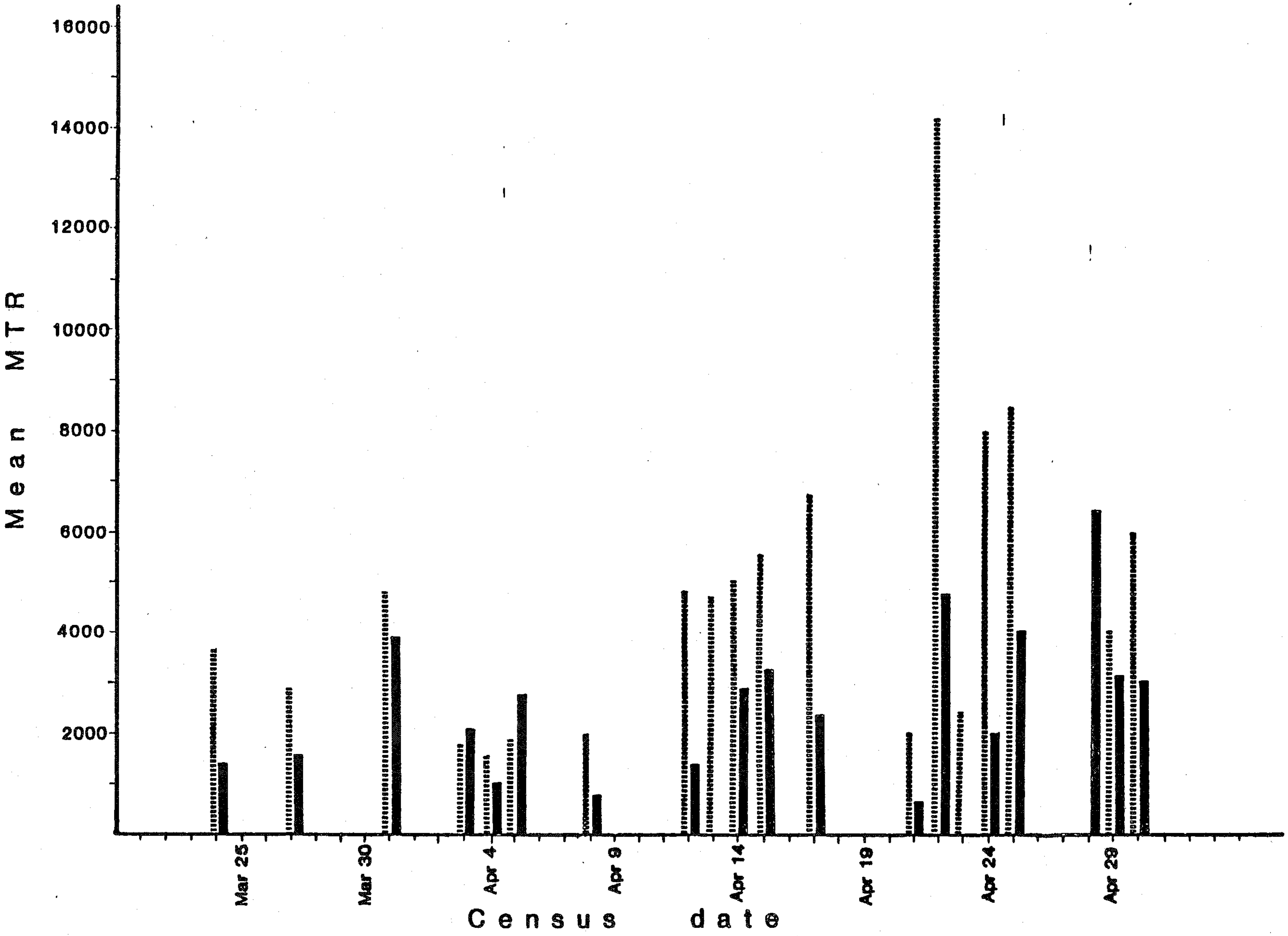


Figure 10. Variation in nightly mean passerine MTR's by date, all sites combined. Migration occurred on all nights of observation. (Broken line = before midnight, solid line = after midnight).

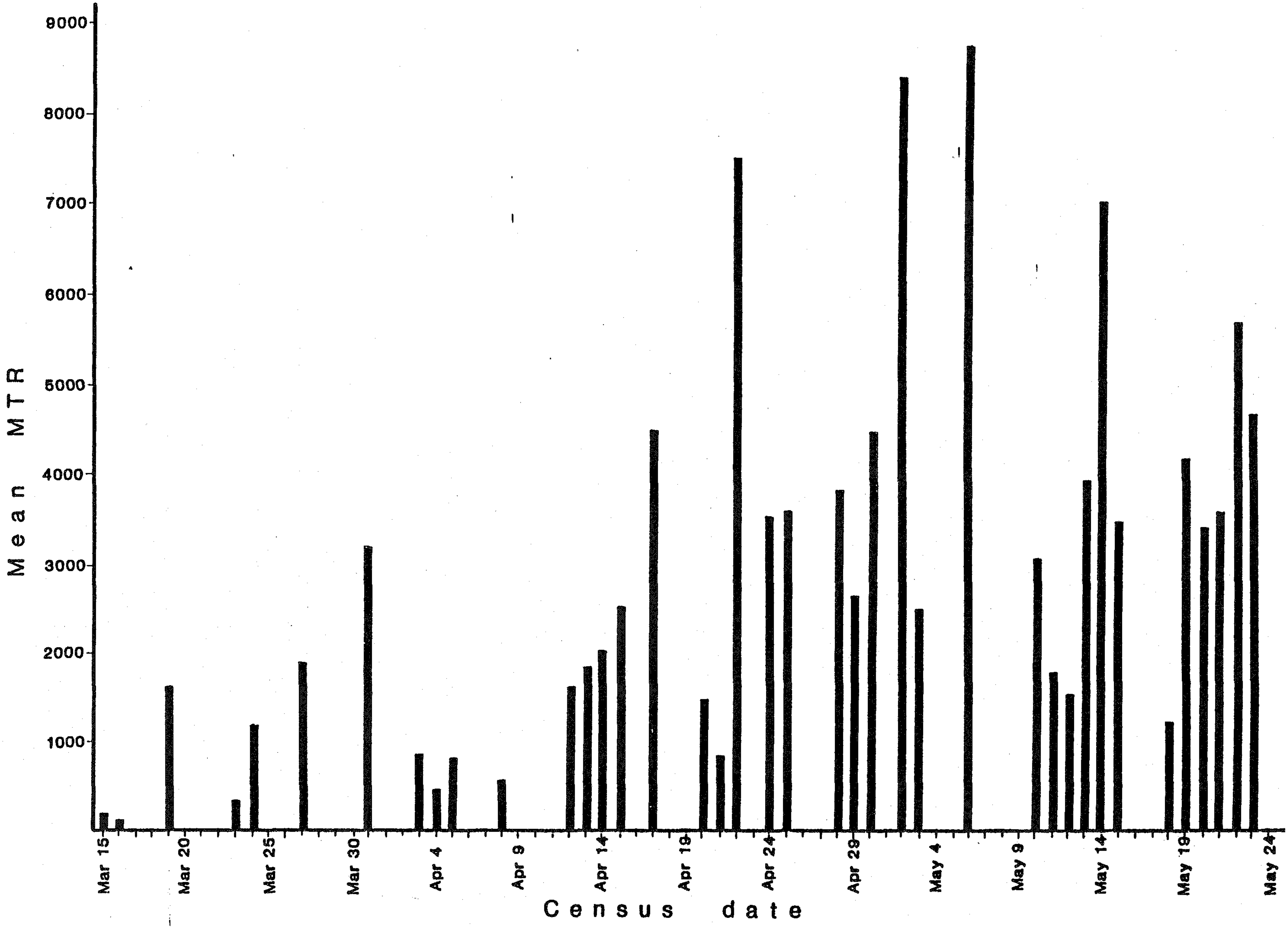


Figure 11. Variations in nightly mean passerine MTR's observed above 300 m for hours before midnight, all sites combined. Migration occurred on all nights of observation.

similar to that shown in Figure 10 and includes the period from 15 March - 25 March and from 1 May through the end of the study (23 May). Only low levels of migration occurred in mid-March, and the peak period of migration actually continued through the end of the study (Figure 11).

Results of diurnal studies in the WRSA and surrounding areas during spring 1979 and 1980 show a similar seasonal pattern of migration (McKernan et al., in prep.). These data indicate that moderate numbers of spring migrants occur in the study area through 1 June, with abundance dropping sharply thereafter. From both nocturnal and diurnal observations, spring migration in the WRSA appears to begin for some species in early March but occurs at only low to moderate levels through mid-April. High levels of migration begin from about mid-April and may continue through the end of May, with migration dropping off rapidly during the first week of June.

Geographical Variation in Migration Magnitude

The sites selected for study during spring 1982, although quite different in topography, showed only slight variation in mean MTR's, which ranged from 2,919 ± 583 SE at site 1 to 4,082 ± 676 SE at site 6 (Table 1). Problems in comparing sites in this fashion arise, however, because of the dynamic nature of bird migration. Although we attempted to equally distribute sampling periods among sites through the season, we were not totally successful. Because of equipment failures and insect clutter, some sites were covered more during April when greater numbers of migrants were aloft than in March when less migration occurred. This tends to skew the mean MTR's at these sites toward the high end, while sites covered more in March would have lower means. Figure 10 shows a clustering of some sites when samples were collected under similar conditions within a few days of each other. Mean nightly MTR's before midnight on 3, 4, and 8 April indicate a high degree of similarity between sites 1, 4, and 6 respectively. The same is true for sites 2, 3, 6, and 7 during the period from 12-15 April. The similarity between sites is statistically verified through an analysis of variance on mean nightly MTR residuals determined from smooth curves which remove the effect of date. No significant difference between sites exists either before midnight ($F = 0.79$, $p > 0.5$) or after midnight ($F = 1.09$, $p > 0.4$) for those nights when MTR's were determined for all altitudes (19 - 1,483) (Figure 10). Nor were there differences between sites before midnight ($F = 1.26$, $p > 0.3$) or after midnight ($F = 0.34$, $p > 0.9$) for all nights of observation above 300 m (Figure 11). This indicates that passerine migration in the WRSA occurs in a broad front rather than in specific pathways. However, it is difficult to account for the extreme difference in migration observed between sites 4 and 6 on the nights of 21 and 22 April despite the occurrence of very low winds on both nights (Figure 10). Apparently, a wave-like movement of migrants occurs in the Coachella Valley during spring, similar to that observed in the eastern United States; this is especially noticeable during May (Figure 11).

Influence of Weather on Migration Magnitude

Bird migration in the eastern United States has been shown to be heavily influenced by synoptic weather patterns (for a review see Richardson 1978); however, this phenomenon has received little attention in the western U.S. (see Moorhouse 1980). In general, unlike the east, synoptic weather patterns in southern California seem to have only marginal influence on migration (McKernan, unpubl. data). We examined the relationship between migration magnitude and synoptic weather in the WRSA by classifying each night of observation into 1 of 4 synoptic weather categories (A = Pacific high pressure, B = low pressure cold front over southern California, C = low pressure front east of southern California over Nevada, D = complex weather pattern; see Appendix C for a more detailed description). The most frequent patterns during spring 1982 (11 March - 26 May) were Pacific high (32.5%) and low pressure cold front (34.9%) with complex weather occurring only infrequently (4.8%). Low pressure cold fronts in the area of the WRSA are usually not associated with precipitation and extreme temperature changes as tend to occur in other geographical areas; thus, cold fronts may not impede bird migration in the WRSA to the same degree as occurs in the eastern U.S. Little difference in mean MTR's occurred between synoptic patterns (Table 3) and an analysis of variance on MTR residuals shows no significant relationship between MTR's and synoptic weather either for all altitudes ($F = 0.05$, $p > 0.9$) or above 300 m ($F = 0.64$, $p > 0.60$).

Table 3. Mean passerine MTR's before midnight in relation to synoptic weather.

Synoptic category (Appendix C)	19 - 1,483 m Mean MTR ± SE	n
A	5,117 ± 712	34
B	5,097 ± 979	34
C	5,394 ± 643	17
	>300 m	
A	2,437 ± 270	68
B	3,813 ± 592	43
C	2,676 ± 223	38
D	3,917 ± 1,415	4

Although synoptic weather patterns seem to have little or no influence on migration, relationships between MTR's and weather do exist for individual weather variables (Table 4). For those nights when all altitudes were surveyed, only night date ($r = 0.568$, $p < 0.01$, $n = 20$) and temperature ($r = 0.602$, $p < 0.01$, $n = 20$) were significantly correlated with nightly mean MTR's, with wind direction north-south closely approaching significance ($r = -0.478$, $p = 0.053$, $n = 17$). Since date and temperature are highly correlated in the WRSA during spring ($r = 0.830$, $p < 0.0001$, $n = 20$), it is difficult to determine which is the more important factor in bird migration. The results of a stepwise multiple regression analysis (Table 5) indicate that, for those nights when all altitudes were surveyed, date is the more important factor in explaining the variance observed in mean nightly MTR's, while for flights above 300 m, temperature is the more overriding influence. This analysis also points to a slight relationship between wind direction and migration magnitude in the WRSA.

The results of this study indicate that migration magnitude is significantly correlated with increasing temperature, date, and a reduction in north-south wind direction components. Thus, higher migration magnitudes may be expected to occur on warmer nights in April and May when the wind is blowing from the west. Surprisingly, almost no correlation exists between mean MTR's and wind speed in the WRSA during spring 1982 as compared to the significant correlation with wind speed determined for spring 1981 migration (McCrary et al. 1981). In

Table 4. Product-moment correlation coefficients (r) between mean MTR's before midnight and weather variables. The variables are defined in Appendix D.

	19 - 1,483 m			>300 m		
Variable	r	p	n	r	p	n
nitedate	0.568	0.009	20	0.540	0.0005	37
cloudcover	-0.315	0.176	20	-0.230	0.171	37
cloudheight1 (1st layer)	-0.035	0.924	10	0.030	0.898	20
cloudheight2 (2nd layer)	———	———	———	0.611	0.582	3
sitecldcov	-0.383	0.096	10	-0.376	0.022	37
precip	-0.130	0.584	20	-0.026	0.880	37
pressure	-0.084	0.725	20	-0.297	0.074	37
presschange	-0.224	0.342	20	-0.158	0.349	37
temp	0.602	0.005	20	0.592	0.0001	37
tempchange	0.273	0.245	20	0.197	0.242	37
visib	0.087	0.714	20	-0.208	0.217	37
winddirec(E-W)	-0.304	0.235	17	-0.376	0.034	32
winddirec(N-S)	-0.478	0.053	17	-0.456	0.0087	32
windvector(E-W)	0.020	0.933	20	-0.070	0.681	37
windvector(N-S)	-0.330	0.155	20	-0.272	0.104	37
windspeed	-0.086	0.719	20	0.001	0.998	37

Table 5. Stepwise multiple regression analysis for mean passerine MTR's before midnight observed in the Wind Resource Study Area during spring 1982. The variables are defined in Appendix D.

variable	B	F	P
19 - 1,483 m			
tempchange	527	6.36	0.024
nitedate	162	11.44	0.004
ABwinddirec(N-S)	-3050	2.73	0.119
ABwindvector(N-S)	-252	3.73	0.073

overall R = 0.669
F = 7.57
p = 0.002

variable	B	F	P
>300 m			
temp	253	20.9	0.0001
tempchange	171	3.12	0.0862

overall R = 0.24
F = 5.37
p = 0.0094

spring 1981 highest single MTR's and mean MTR's occurred on calm nights at sites 1, 2, and 6 during late April and early May, resulting in negative correlations between wind speed and MTR's at these sites. However, during spring 1982, no calm nights occurred at sites 1 and 2 during that period. But, as mentioned earlier, the greatest nightly mean MTR and single MTR occurred on a calm night at site 6 (22 April). Thus, although high MTR's occurred in both spring 1981 and 1982 at sites 1 and 2 even under high westerly winds, peak migratory movements are apparently more likely to occur on calm nights, which may occasionally occur in the WRSA during mid to late spring.

Altitude of Spring Migration

At least some migration occurred at all altitudes observed during this study (19 m - 1,483 m) (Figure 12). The slightly lower amount of migration from 100 - 200 m probably resulted from the reduced efficiency of the image intensifier in detecting small passerines above 100 m. Most migration was below 400 m (65%) and 12.9% was below 100 m; only 0.3% of migration occurred above 1,300 m. However, there was considerable variation in the altitudinal distribution of migrants from hour-to-hour, night-to-night, and site-to-site.

The mean altitude above ground level of all passerine migratory flights was 351 m ± 1.9 SE with means at most sites in the range of 300 - 400 m (Table 6). A highly significant positive correlation exists between mean flight altitude above sea level and site elevation

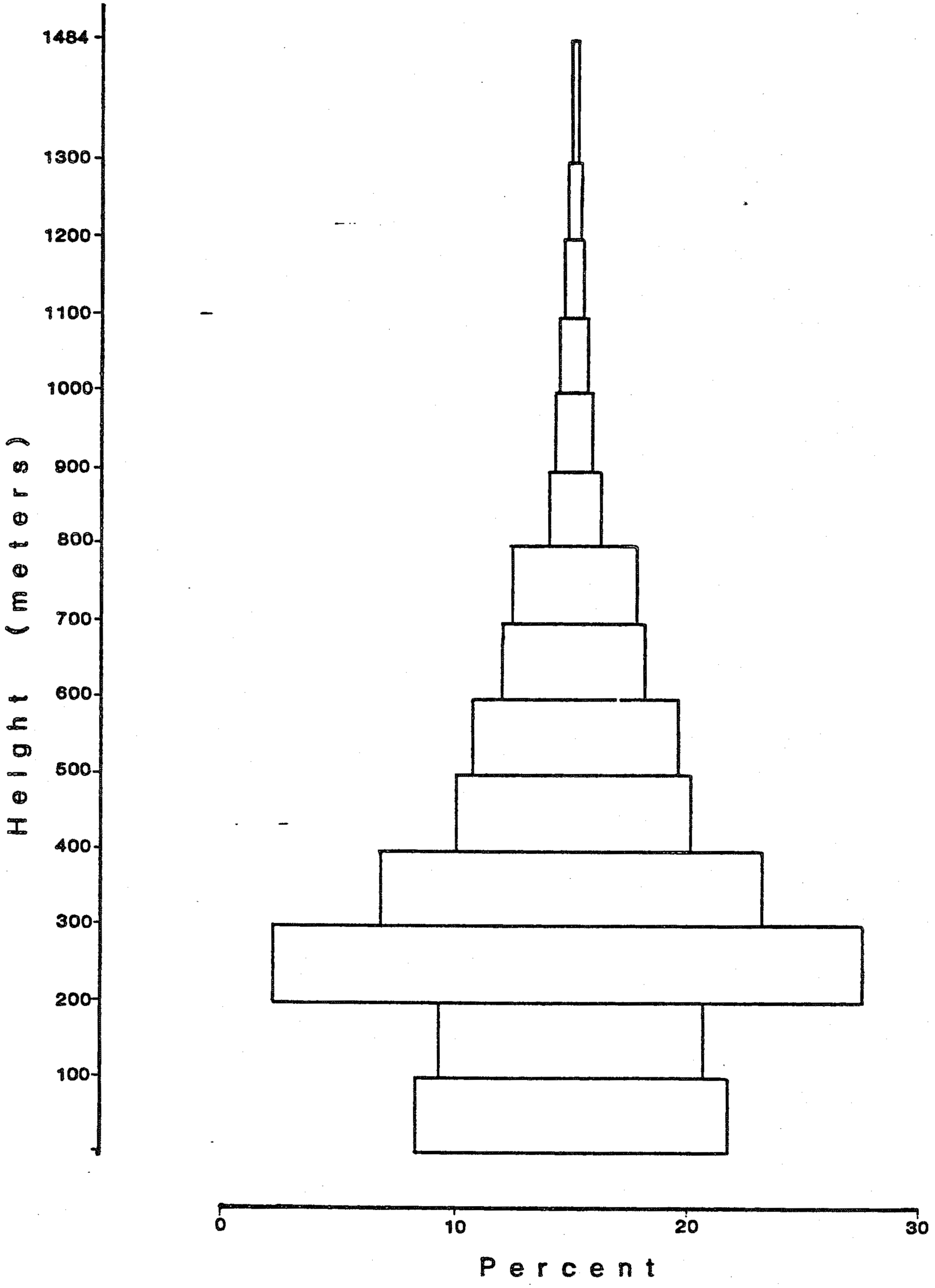


Figure 12. Altitudinal distribution of passerine birds in the Wind Resources Study Area during spring 1982, all sites combined.

Table 6. Mean nocturnal flight altitudes of passerine birds during spring 1982 migration in the Wind Resource Study Area.

Site	Mean Altitude ± SE (meters)	Elevation of site	Mean altitude above sea level
1	380 ± 6.1	366	746
2	315 ± 6.2	335	650
3	263 ± 5.1	518	781
4	408 ± 4.6	183	591
5	329 ± 5.7	434	763
6	371 ± 3.1	91	462
7	322 ± 5.4	213	535
ALL	351 ± 1.9		647

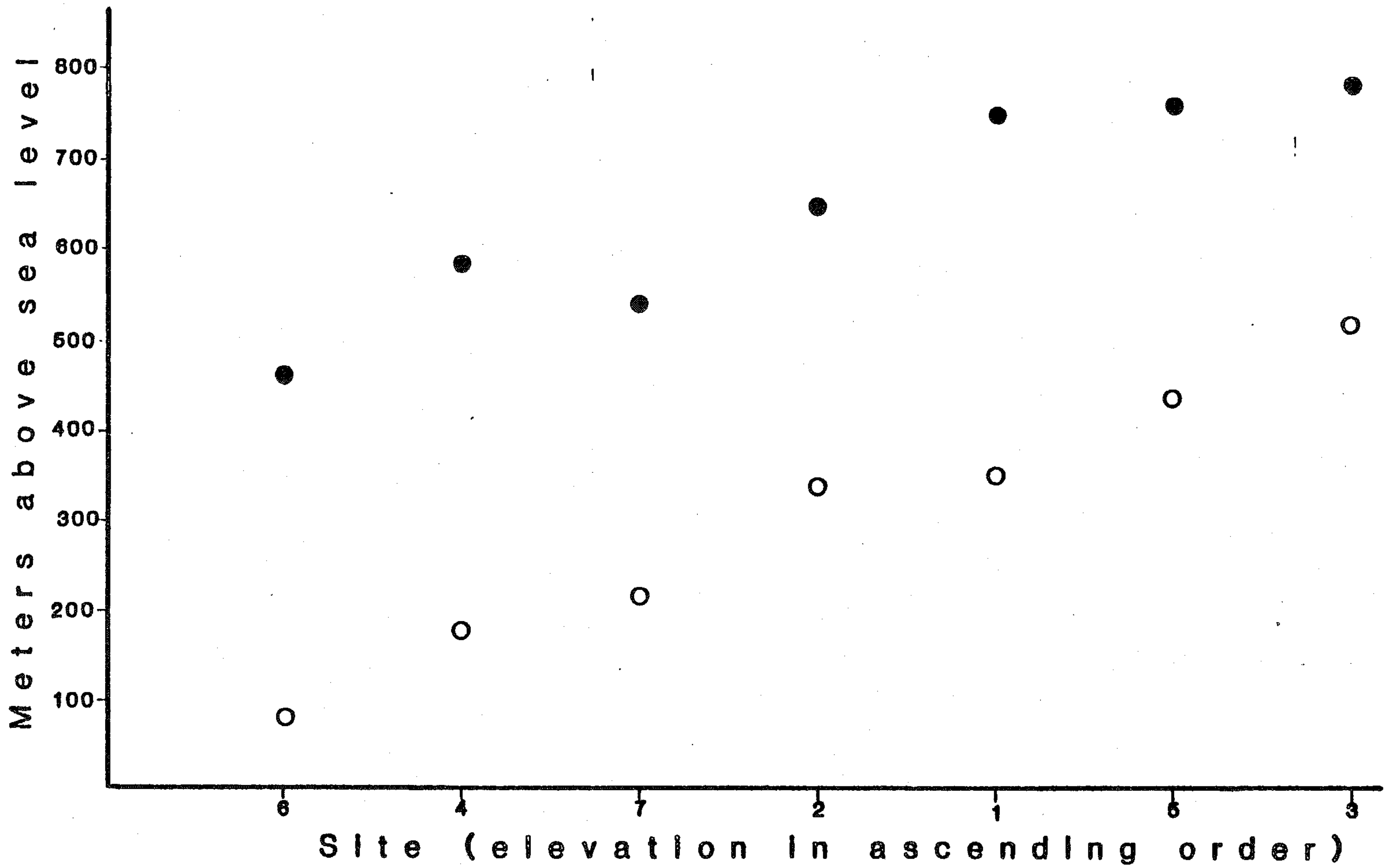


Figure 13. Plot of mean flight altitudes above sea level (●) in relation to site elevation (○).

(Figure 13; $r = 0.956$, $p < 0.001$, $n = 7$) indicating that birds maintain a relatively constant altitude above ground. This pattern may be disrupted, however, by abrupt changes in topography, as indicated by the lower mean altitude above ground level at site 3 (Table 6). This site is located on the side of a north-south lying, steep ridge which bisects the W-E flight paths characteristic of most spring passerine migrants in the WRSA (see Flight Directions). Apparently, birds flying over this 740 m ridge increase their flight altitudes only enough to safely avoid the obstacle.

A general increase in altitude occurred during the early evening as migrants climbed in height (Figure 14). This was especially apparent during the first hour (1900) when a sharp increase in altitude occurred indicating a rapid ascent of migrants after the initiation of flight. This is similar to the nightly pattern of migration observed by Able (1970) in the eastern United States. The highest hourly mean altitude (389 m) occurred at 2300 followed by a steady decline in altitude until 0400.

This pattern was reversed at the lower altitudes, especially below 100 m. In Figure 15 we illustrate the change in quantity of nocturnal migration from 19 - 100 m. The decrease in percentage of passerine birds below 100 m indicates an ascent after initiating flight. The decline in numbers in this altitude range continued until 2300 when the lowest (6.9%) level occurred. This was followed by an increase in numbers until 0400 when 22.7% of migration was concentrated below

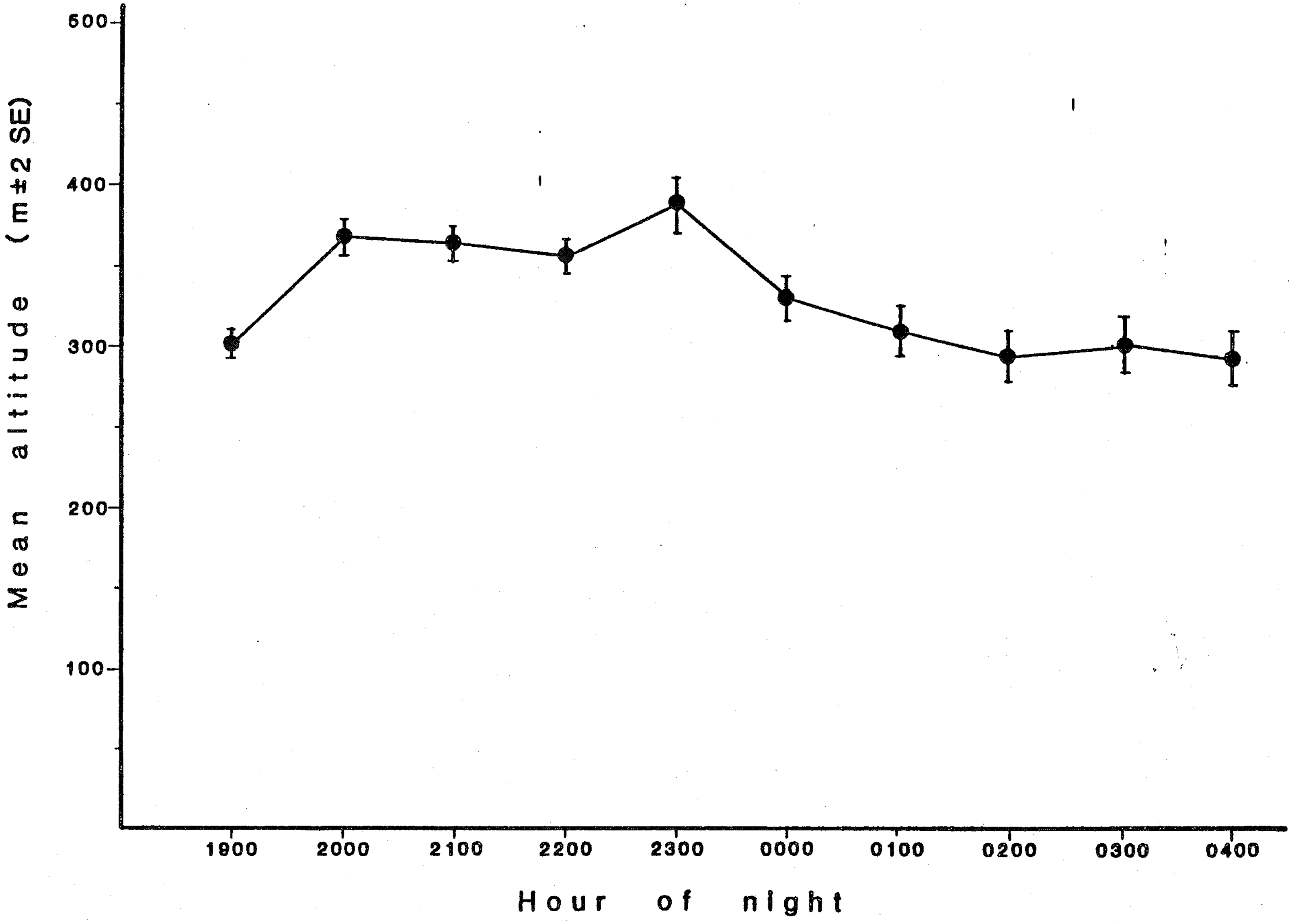


Figure 14. Nightly pattern of single migrant mean altitudes observed in the Wind Resource Study Area during spring 1982, all sites combined.

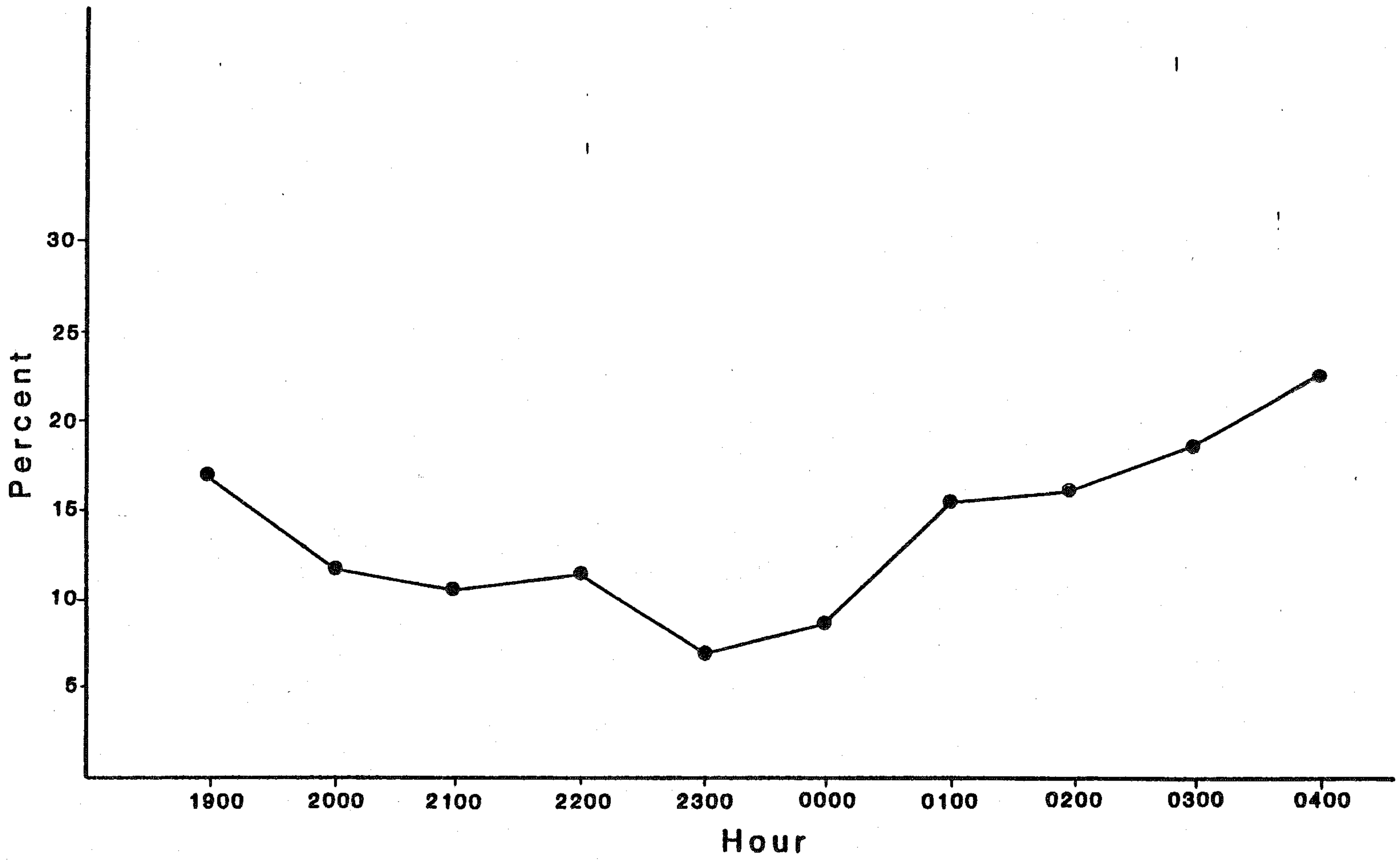


Figure 15. Nightly distribution of birds below 100 m.

100 m. As expected, the reverse of this pattern occurred at higher altitudes

Although the nightly pattern of altitudinal change was generally true for most nights and sites, differences in the altitudinal distributions occurred between sites, especially below 100 m (Figure 16). The major differences between sites were in the 0-100 m range with Site 2 (19%) and Site 3 (20.4%) showing the greatest amount of migration below 100 m; other sites ranged from 11.2 - 13% of migration below 100 m.

Influence of Weather on Altitude

We examined the relationship between nightly mean passerine altitude before midnight and synoptic weather (Appendix A) and between mean altitudes and 15 weather variables (Appendix B) in the same manner as MTR's were analysed. As with MTR's, an analysis of variance on mean altitude residuals shows no significant relationship between altitude and synoptic weather ($F = 2.47$, $p = 0.114$). However, significant relationships do exist between mean altitude and specific weather variables. A univariate analysis of mean altitude indicates that only cloud cover was significantly (negative) correlated with altitude (Table 7). This may be somewhat spurious, as a stepwise multiple regression analysis does not point to a strong relationship between altitude and cloud cover (Table 8). Instead, this multivariate analysis indicates that a complex association of weather variables

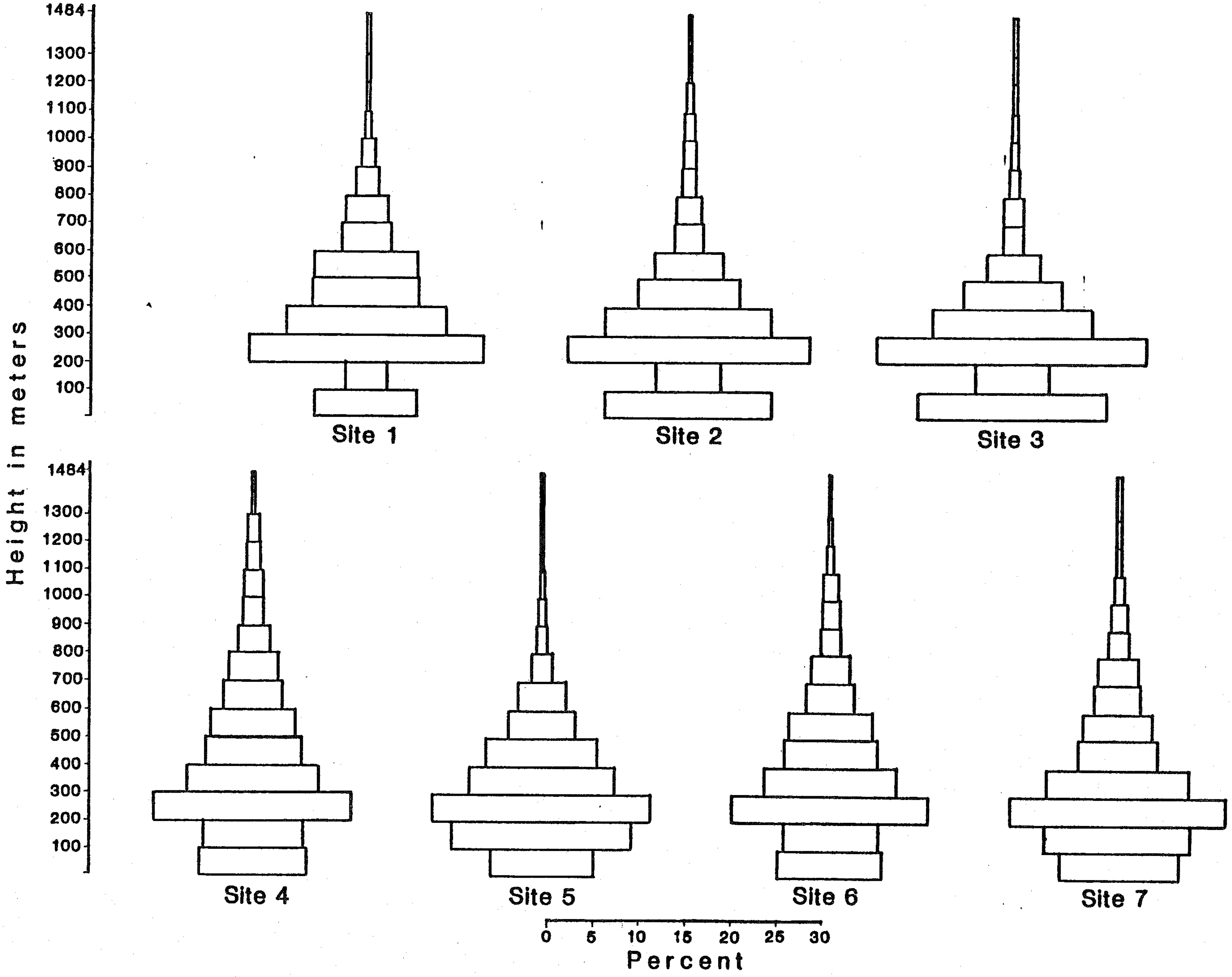


Figure 16. Altitudinal distribution of nocturnal passerine migrants at 7 sites in the Wind Resource Study Area during spring 1982.

Table 7. Product-moment correlation coefficients (r) between mean passerine altitudes before midnight and weather variables. Variables are defined in Appendix B.

Variable	r	prob	Number of nights
nitedate	0.333	0.151	20
cloudcov	-0.541	0.014	10
cloudheight1 (1st layer)	0.377	0.283	20
sitecloudcov	-0.342	0.140	20
precip	0.401	0.080	20
pressure	-0.243	0.303	20
presschange	0.195	0.411	20
temp	0.274	0.242	20
tempchange	0.038	0.874	20
visib	-0.084	0.726	20
winddirec(E-W)	-0.262	0.310	17
winddirec(N-S)	-0.161	0.537	17
windvector(E-W)	-0.019	0.937	20
windvector(N-S)	0.185	0.435	20
windspeed	0.049	0.839	20

Table 8. Stepwise multiple regression analysis for mean passerine altitudes before midnight observed in the Wind Resource Study Area during spring 1982

variable	slope	F	prob
precip	253	28.2	0.0002
presschange	332	23.6	0.0005
temp	10	12.5	0.0047
windvector(E-W)	6	16.6	0.0018
windvector(N-S)	447	28.7	0.0002
ABpresschange	226	3.9	0.0738

Overall R = 0.871
F = 9.24
p = 0.0006

influences the altitude of nocturnal passerine migration in the WRSA with the strongest factors being precipitation, pressure change, temperature, and wind. Thus, mean altitudes tend to be higher: 1) with the occurrence of rain, 2) under large pressure changes, 3) with higher temperatures, and 4) with high north - south wind vector components.

Flock Migration

Unlike passerine birds, flocks of shorebirds and waterfowl occurred only sporadically through the study, and on several nights we recorded no flock movement (Table 9). We visually recorded 44 flocks during the study, most of which were small (mean number of individuals = 6, range = 3 - 30). The mean MTR for flocks was only 44.4 ± 25 SE birds (range 0 - 2,004), although considerable variation occurred between sites (Table 10). Apparently, flock movement concentrated along the northeastern edge of the WRSA (sites 3 and 5, Tables 9 and 10), skirting the foothills of the Little San Bernardino and San Bernardino Mountains. Of the 44 flocks observed, 25 were recorded at sites 3 and 5, while only 10 were recorded at sites 1, 2, 4, and 7, combined. Another area of moderate flock movement was site 6 (9 flocks). Similarly, mean MTR's at sites 3 and 5 were higher than other sites (Table 10).

The occurrence of flocks through the night (Figure 17) was different from passerines (Figure 9). The nightly distribution pattern of flocks was bimodal with peaks occurring at 2000 and 0100 and

Table 9. Timing, location, size and altitude of flocks observed in the Wind Resource Study Area during spring 1982.

Date	Site	Hour	Number of individuals	Altitude (m)	MTR[a]
19 March	1	1900	3	945	292
19 March	1	1900	10	371	
24 March	5	2000	3	519	150
24 March	5	2100	7	630	124
24 March	5	2200	10	704	110
31 March	4	2000	10	815	95
31 March	4	2300	30	908	86
8 April	6	2200	5	852	91
12 April	3	2100	3	315	247
13 April	2	2200	3	463	168
14 April	5	0100	3	111	2,004
14 April	5	0100	3	93	
14 April	5	0100	3	167	
14 April	5	0200	3	297	833
14 April	5	0200	3	352	
14 April	5	0200	6	222	
14 April	5	0400	6	537	145
14 April	7	2000	3	389	200
17 April	1	2000	5	371	210
18 April	3	0000	6	575	255
18 April	3	0000	7	649	
18 April	3	0100	4	352	221
21 April	4	2100	3	649	120
22 April	6	2000	11	389	608
22 April	6	2000	9	834	
22 April	6	2000	8	1464	
22 April	6	2000	9	297	
22 April	6	2100	5	686	113
22 April	6	0000	4	723	107
24 April	3	2100	8	148	631
24 April	3	2100	4	741	
25 April	1	0000	3	204	382
25 April	2	2000	4	556	140
26 April	5	0000	3	445	365
26 April	5	0000	8	408	
26 April	5	0100	4	204	863
26 April	5	0100	12	482	
26 April	5	0100	5	389	
26 April	5	0100	3	649	
26 April	5	0200	3	93	701
26 April	5	0300	4	167	568
26 April	5	0300	6	760	
29 April	6	2200	6	834	93
30 April	6	0100	6	1001	78

[a] based on mean flock size for all flocks

Table 10. Mean MTR's and altitudes of flocks during spring in the WRSA.

Site	Mean MTR ± SE	n	Mean Altitue ± SE (meters)	n
1	32.7 ± 18.7	27	352 ± 119	4
2	10.6 ± 7.4	29	505 ± 46	2
3	54.2 ± 28.9	25	345 ± 90	6
4	6.8 ± 3.9	44	775 ± 77	3
5	244.3 ± 95.6	24	246 ± 43	19
6	21.8 ± 12.7	50	642 ± 108	9
7	10.0 ± 10	20	389	1
ALL	44.4 ± 25	219	362 ± 43	44

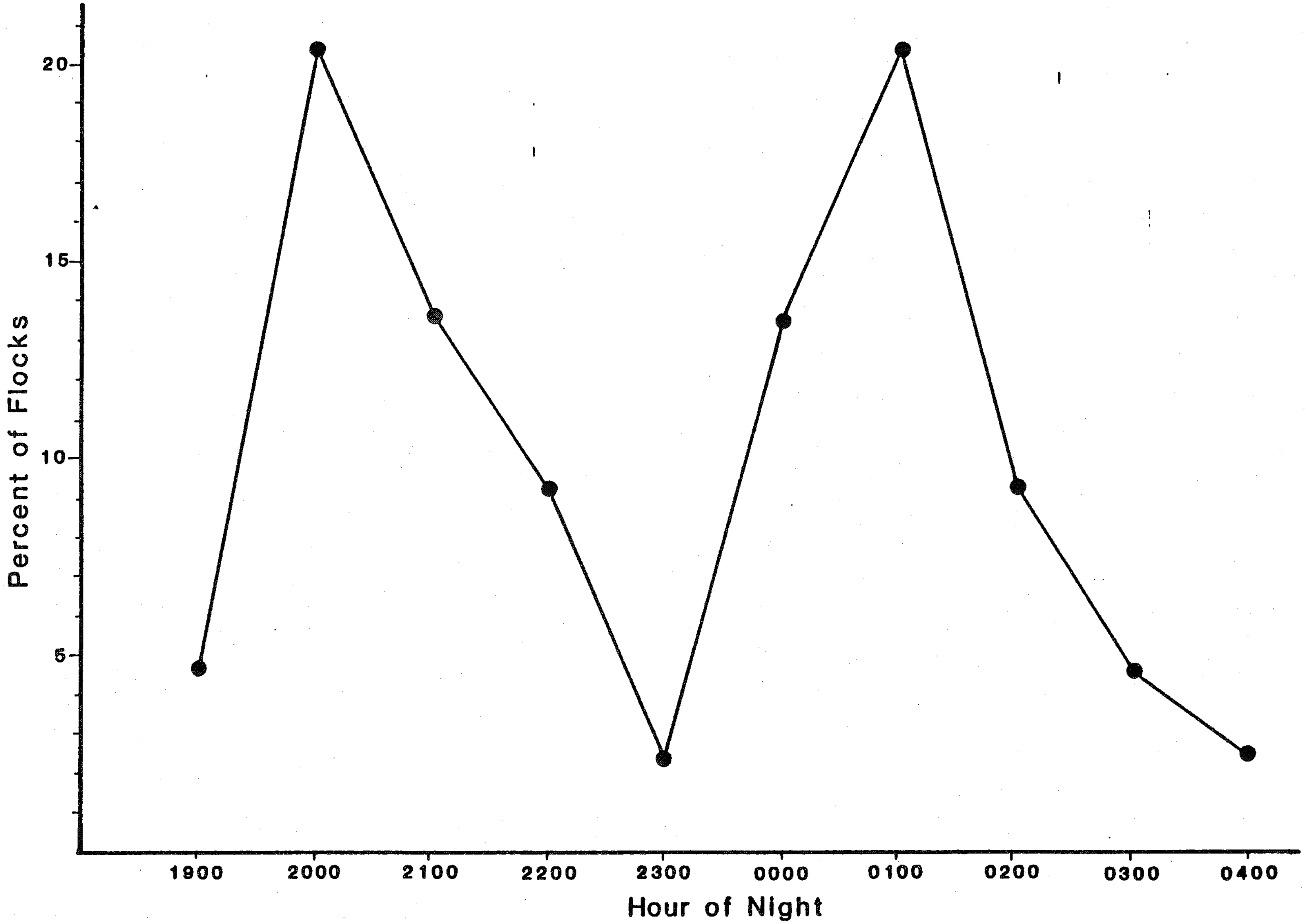


Figure 17. Nightly pattern of nocturnal flock migration in the Wind Resource Study Area during spring 1982.

lulls at 2300 and 0400, and there was no difference between the number of flocks observed before (22) and after midnight (22). This pattern may be explained from the points of origin of the observed flocks. The closest loafing area for waterbirds to the south of the WRSA is the Salton Sea where flocking migrants occur in large numbers. Flocks leaving the Salton Sea in the early evening would not appear in the WRSA until sometime after we began our observations, thus producing a peak flock movement at 2000. Similarly, the peak at 0100 may have been composed of flocks that initiated migration from the Sea of Cortez which is the next area south of the Salton Sea where large concentrations of flocks occur.

As with single migrants (Figure 10), most flock movement occurred after 12 April (Figure 18). Peak flock movements occurred at sites 2 and 5 on the night of 13 April (mean MTR = 315) and 25 April (mean MTR = 264).

The altitudinal distribution of flocks (Figure 19) was similar in many respects to passerine birds (Figure 12). Most flocks (70.8%) were below 400 m, with the greatest amount of migration from 100 - 200 m (21.3%). Little flock movement occurred above 1,100 m (0.5%), although this may be an underestimation to some degree because of the possible inefficiency of the image intensifier in detecting small flocks at the higher altitudes. The mean altitude of all flocks was 362 m ± 43.4 SE, with the range of means varying from 246 m at site 5 to 775 m at site 4 (Table 10). No flocks were observed below 93 m (Table 9).

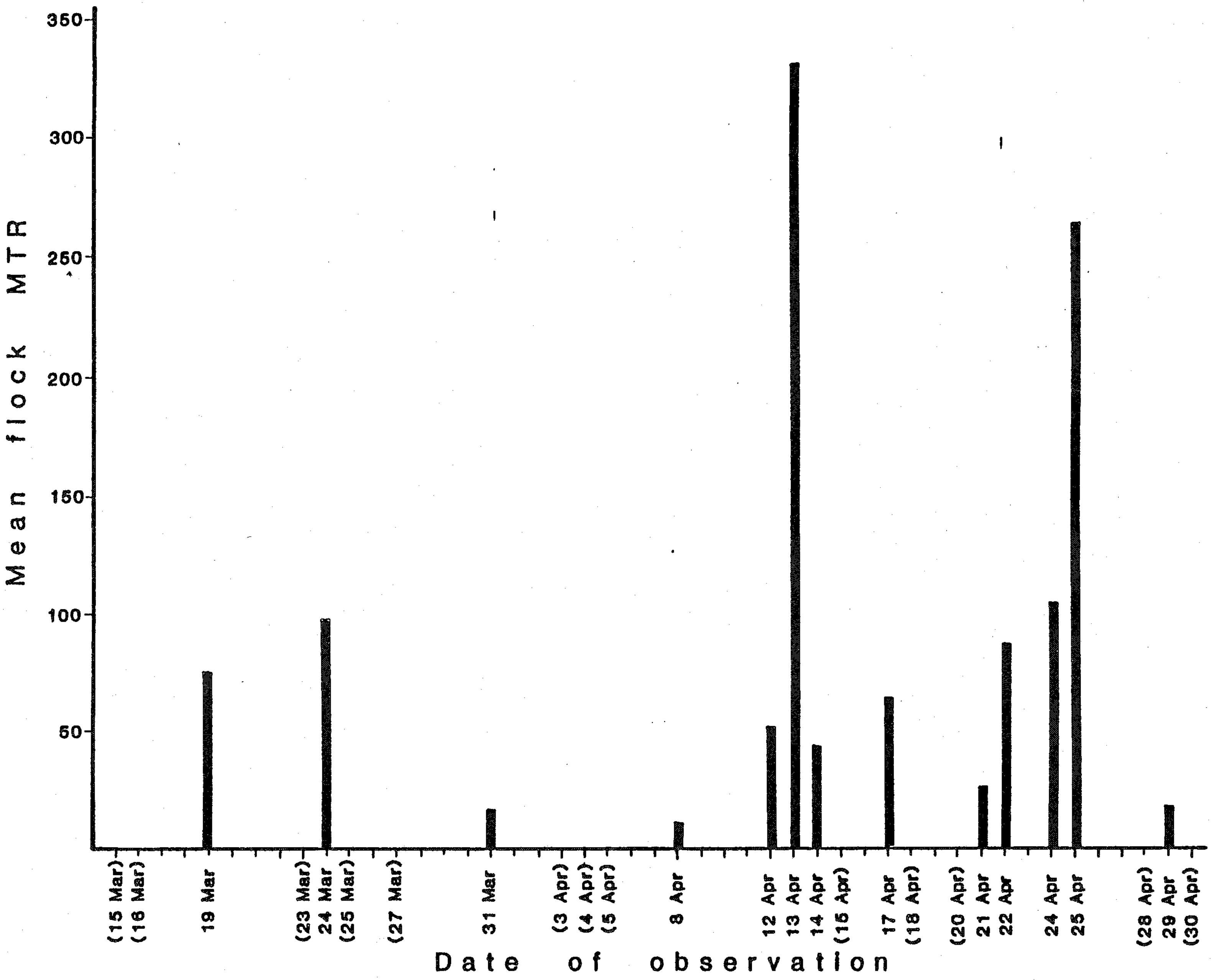


Figure 18. Nightly mean flock MTR's observed in the Wind Resource Study Area during spring 1982 (parentheses around date indicates no flocks observed).

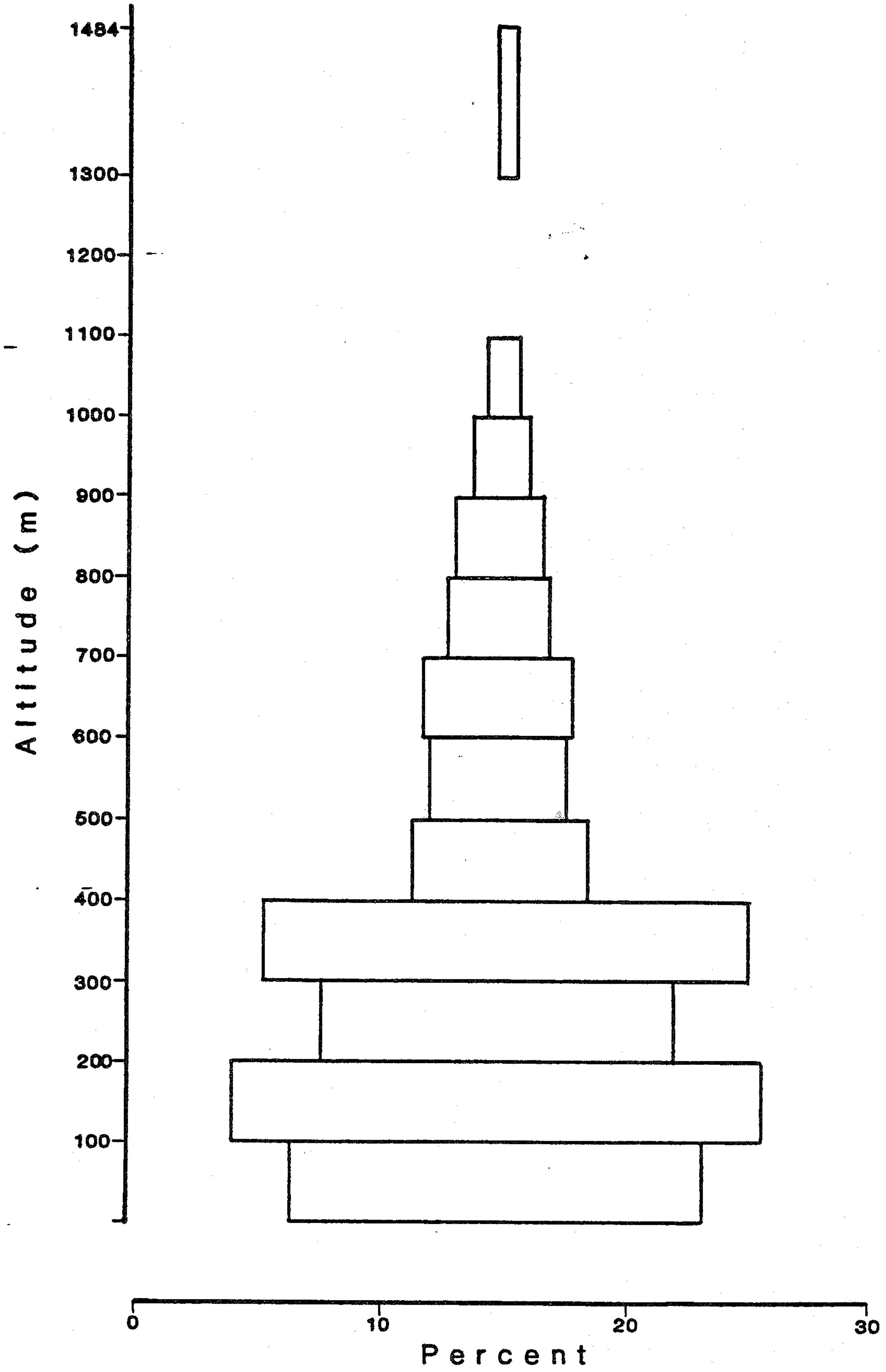


Figure 19. Altitudinal distribution of flocks as observed by vertical radar and image intensifier during spring 1982 in the Wind Resource Study Area.

Flight Directions

Most passerine bird flight tracks (76%) observed in the WRSA during spring 1982 were not in the appropriate northerly (315° - 45°) direction for spring migration (Table 11, Figure 20). The mean of all pooled individual tracks was 68.2° ($r = 0.108$; $p < 0.001$, Rayleigh test; $n = 2,134$), and the mean of the nightly means was 82.2° ($r = 0.392$; $p < 0.002$, Rayleigh test; $n = 39$). Although both means are significantly grouped, considerable flight dispersion is evident from the low r values. Most of this dispersion can be explained by an analysis of winds (presence or absence, direction, and speed).

The eastward movement of most single migrants (68.2°) roughly corresponds to the strong westerly winds (291°), ($r = 0.981$, mean wind speed = 11.0 mph ± 0.5 SE) observed in the WRSA during this study. A closer relationship exists between wind speed and direction and flight tracks when the mean nightly flight tracks are plotted in relation to downwind (0°) (Figure 21). Under high winds (>7 mph), grouping of mean nightly flight tracks is highly significant, and the mean of the nightly means closely approximates the downwind direction (mean of means = 351.1°; $r = 0.972$, $p < 0.0001$, Rayleigh test; $n = 19$). Under moderate winds (4 - 7 mph) mean nightly flight tracks are still significantly grouped near the downwind direction but dispersion is greater (mean of means = 352.5°; $r = 0.732$; $p < 0.05$, Rayleigh test;

Table 11. Nocturnal flight tracks of passerine migrants in the Wind Resource Study Area during spring 1982.

		Wind		Mean track	
Date	n	(degrees	mph)	(degrees)	r
		Site 1			
15 March	21	284 (104)[a]	23.4	77	0.751
19 March	39	293 (113)	6.6	122	0.571
4 April	28	293 (113)	26.8	110	0.625
13 April	20	300 (120)	25.0	112	0.805
17 April	24	282 (102)	15.3	80	0.757
25 April	20	278 (98)	13.6	67	0.733
		Site 2			
18 March	11	293 (113)	6.3	25	0.589
23 March	82	293 (113)	3.8	43	0.309
28 March	16	255 (75)	25.0	55	0.662
13 April	63	278 (98)	22.2	87	0.906
21 April	23	36 (216)	9.6	231	0.577
25 April	67	287 (107)	19.3	73	0.872
		Site 3			
20 March	19	337 (157)	2	124	0.185
5 April	18	279 (99)	24.8	79	0.879
12 April	61	282 (102)	20	96	0.826
18 April	45	276 (96)	4	95	0.610
24 April	60	281 (101)	19	101	0.829
		Site 4			
16 March	15	298 (118)	2.7	80	0.282
25 March	45	310 (130)	5.2	80	0.675
31 March	178	292 (112)	16.2	122	0.309
5 April	26	302 (122)	30.0	129	0.790
15 April	44	290 (110)	37.2	100	0.731
21 April	37	315 (135)	1.4	9	0.302
29 April	30	290 (110)	25.6	106	0.360
30 April	15	290 (110)	20.6	101	0.419
		Site 5			
24 March	89	23 (203)	0.2	288	0.462
27 March	23	260 (80)	1.8	85	0.238
14 April	78		0	314	0.647
20 April	50	15 (195)	6.0	224	0.708
26 April	60		0	306	0.723

Table 11. continued

Date	n	Wind (degrees	mph)	Mean track (degrees)	r
Site 6					
3 April	34	322 (142)	17.0	146	0.818
8 April	60	326 (146)	0.7	286	0.312
15 April	76	322 (142)	11.8	145	0.904
22 April	319		0	294	0.573
25 April	84	328 (148)	6.3	184	0.269
Site 7					
6 April	42		0	269	0.392
14 April	109		0	332	0.385
22 April	50	192 (12)	2.0	336	0.790
28 April	50		0	353	0.248

[a] direction toward which wind was blowing

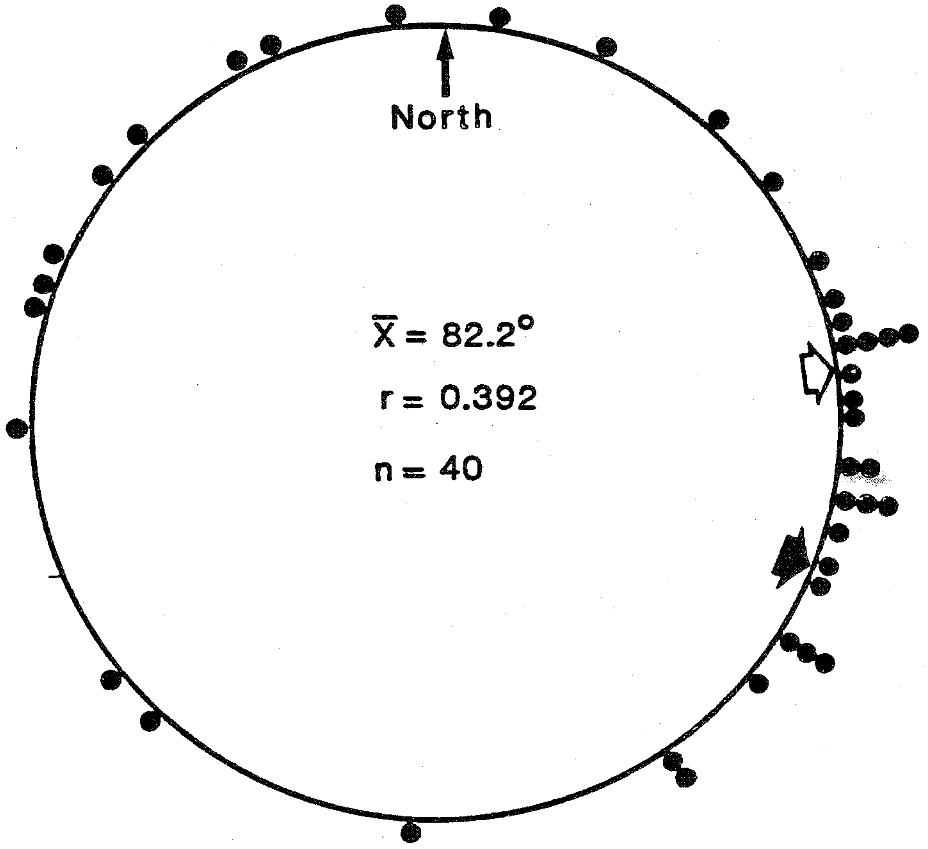


Figure 20. Distribution of all nightly mean passerine bird flight tracks observed in the Wind Resource Study Area during spring 1982 (open arrow = mean flight track, closed arrow = mean direction toward which wind was blowing).

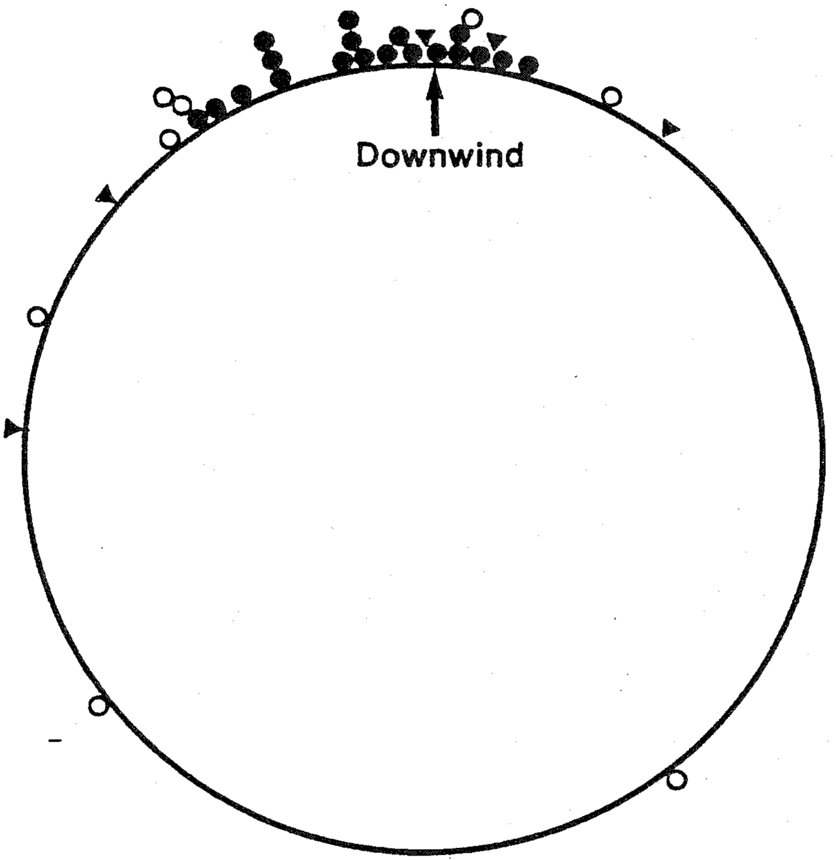


Figure 21. Nightly mean flight tracks under: ● high winds (>7 mph), ▼ moderate winds (4 - 7 mph), and ○ low winds (2 - 4 mph) in relation to downwind set at (0°).

n = 6). Under low winds (0.5 - 4 mph), mean nightly flight tracks are randomly distributed with respect to downwind (mean of means = 311.1°; r = 0.524; $p > 0.1$, Rayleigh test; n = 7). A highly significant positive correlation exists between mean nightly wind direction and mean nightly flight tracks (r = 0.961; $p < 0.001$, 2-tail test; n = 19) (Figure 22a) under high winds, while insignificant correlations occurred for moderate (r = 0.807; $p > 0.05$, 2-tail test; n = 6) (Figure 22b) and low winds (r=0.588; $p > 0.1$, 2-tail test; n = 7) (Figure 22c).

The relationship between wind direction and flight tracks is further shown by an analysis of the direction of migration under no or very low winds (0 - 0.7 mph) (Figure 23; mean of nightly means = 305°; r = 0.906; $p < 0.001$, Rayleigh test; n = 8). Under these conditions the direction of migration was appropriate for spring and was very similar to the direction observed under the same conditions in the WRSA during spring 1981 (McCrary et al. 1981). The mean of all individual pooled flight tracks was 301.2° (r = 0.483; $p < 0.0001$, Rayleigh test; n = 807). This distribution is significantly different from the flight track distribution under high, moderate, and low winds ($p < 0.001$, Watson-Williams test).

The influence of wind on single migrant flight tracks is particularly apparent from site-to-site and night-to-night. During this study, some sites within the WRSA were characterized by almost constant strong (mean = 16.4 mph) westerly surface winds (see sites 1 and 3, Table 11). Flight tracks at these sites (Figure 24a) were consistently in an easterly (downwind) direction (combined mean of nightly means for

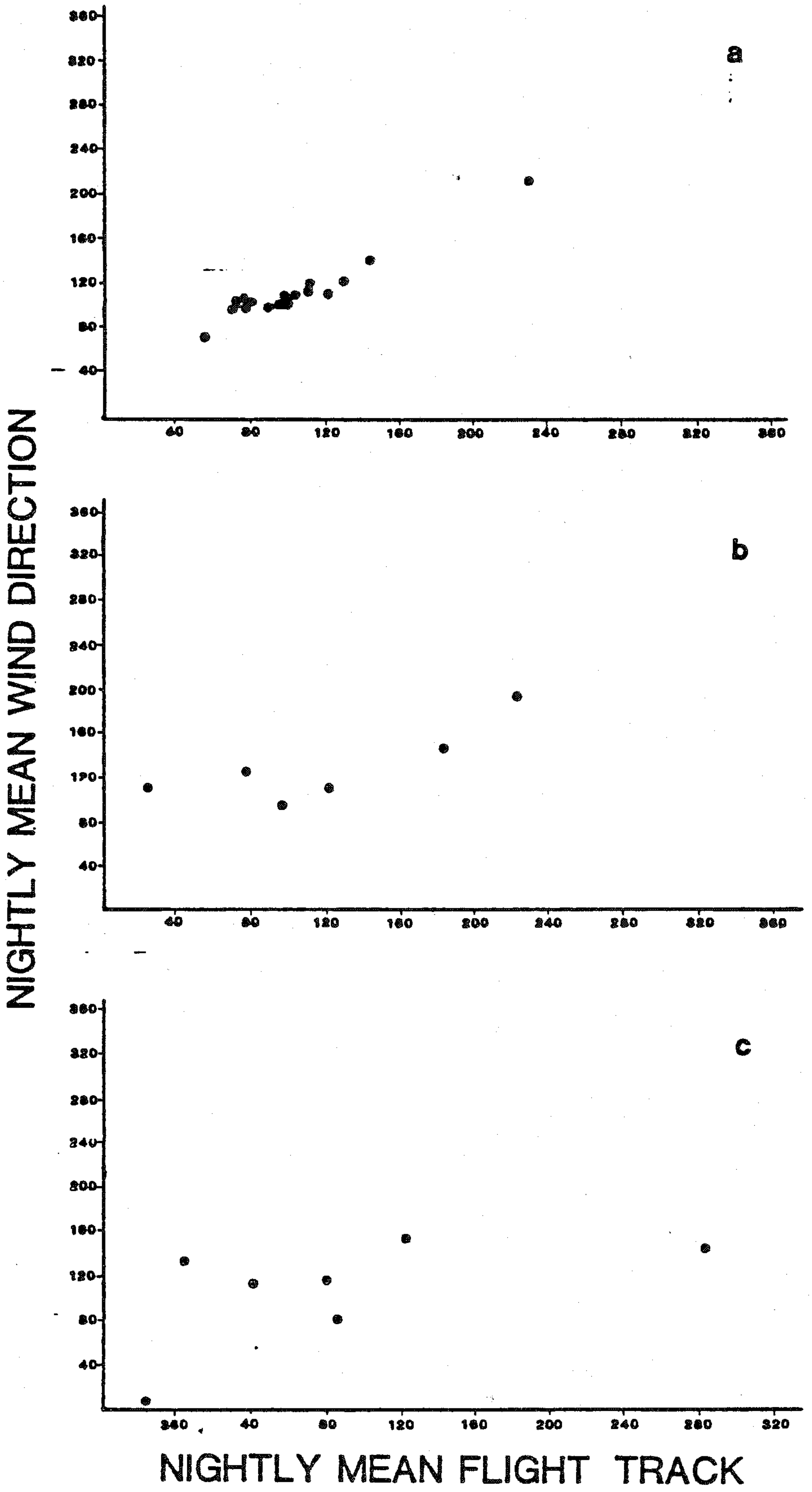


Figure 22. A plot of passerine nightly mean flight tracks on the corresponding directions toward which surface winds were blowing: a. high winds (>7 mph), b. moderate winds (4 - 7 mph), c. low winds (0.2 - 4 mph).

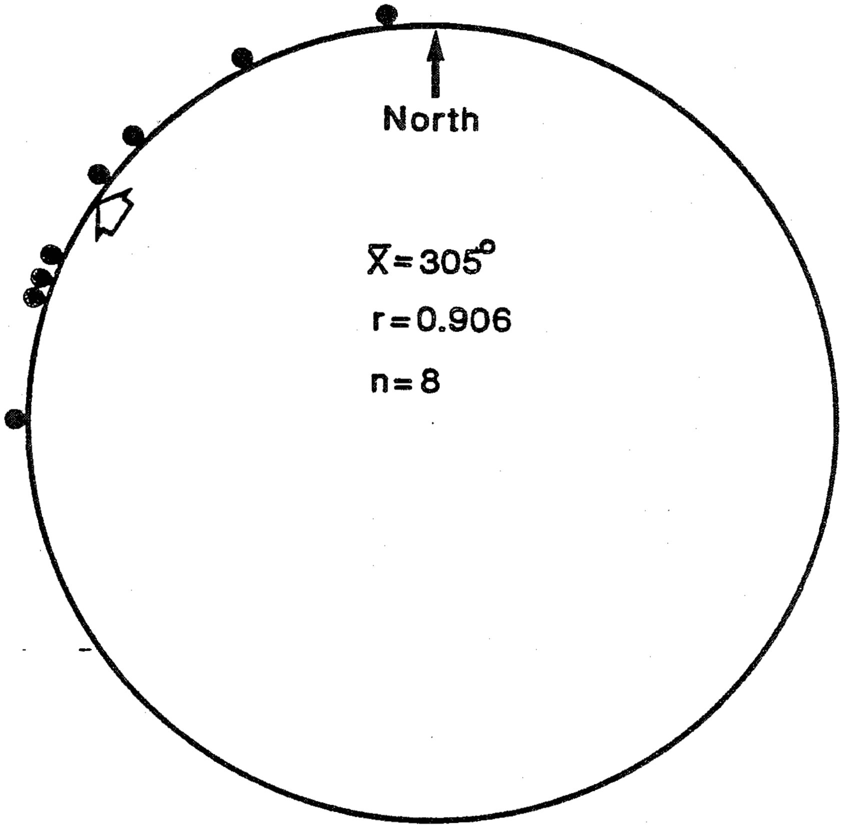


Figure 23. Distribution of nightly mean passerine flight tracks under no or very low winds (0 - 0.7 mph) (open arrow = mean of nightly mean flight tracks.

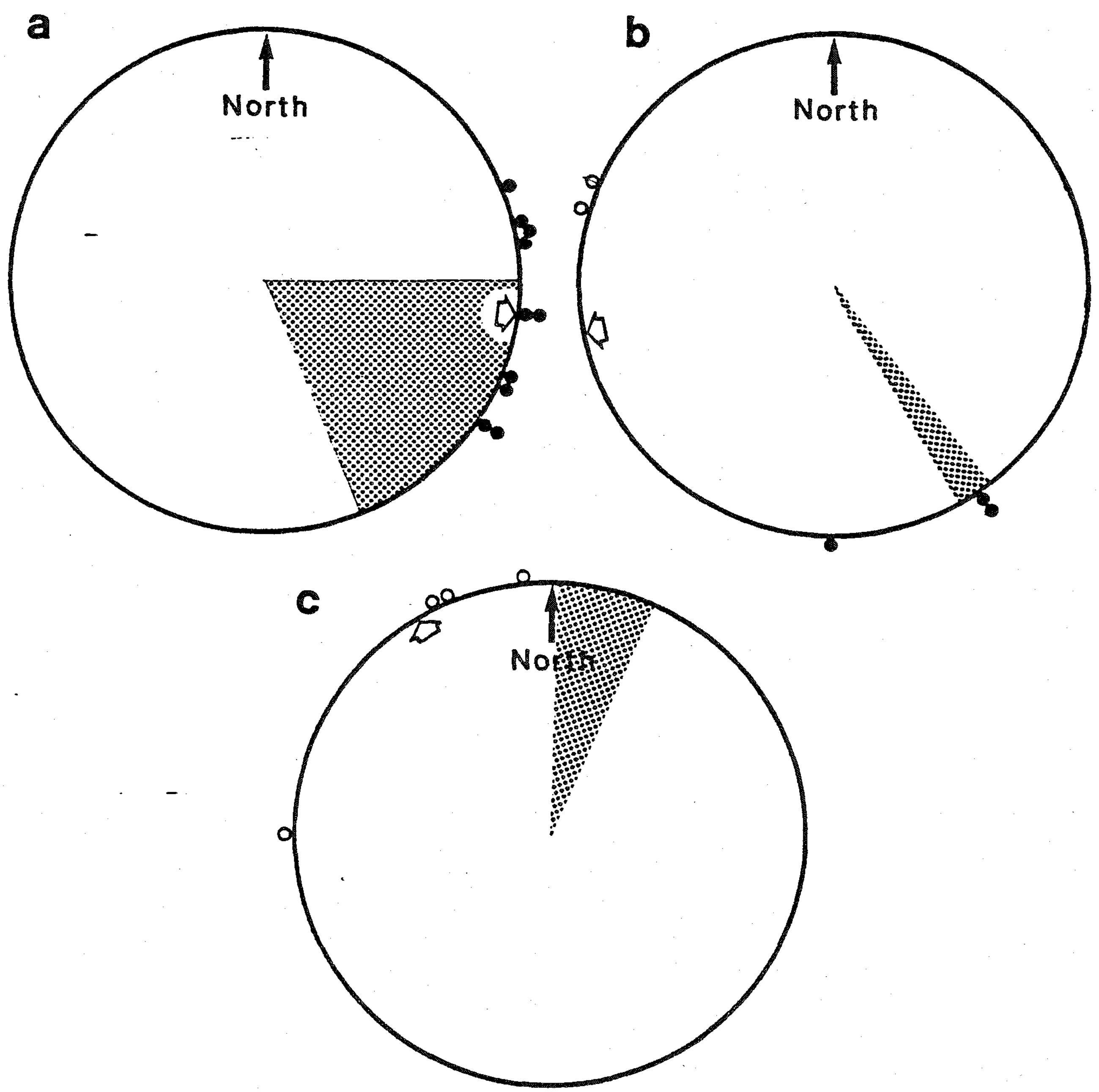


Figure 24. Variations between sites in the distribution of nightly mean passerine flight tracks: a) Sites 1 and 3 under strong (mean = 16.4 mph) westerly surface winds, b) Site 6 under variable wind velocity (0 - 17 mph) but constant direction, c) Site 7 under consistent low wind speeds (mean = 0.3 mph) (shaded area represents range of directions which winds were blowing toward, open arrow indicates mean of nightly mean flight tracks, (●) = nightly mean flight tracks under high winds (>7 mph), (○) = nightly mean flight tracks under very low winds (<1 mph)).

sites 1 and 3 = 96.5°; r = 0.95; $p < 0.001$, Rayleigh test; n = 11). At site 6 wind speed was variable from night-to-night (range of nightly means 0-17 mph), while wind direction was consistently from the northwest (313°). Correspondingly, mean nightly flight tracks at this site show a bipolar distribution (Figure 24b). In contrast to the above, almost no wind (mean = 0.3 mph) occurred at site 7, and mean nightly flight tracks at this site were in a northwesterly direction (mean of means = 324.5°, r = 0.855, n = 4) (Figure 24c).

Unlike those of single migrants, the flight tracks of flocks show little relationship to wind speed and direction (Table 12). Most flocks were flying in either a northerly (315° - 45°) direction (46.5%) or in a northwesterly (285° - 345°) direction (77%) which seems to be the more typical direction of spring migration in the Coachella Valley (Table 12 and Figure 25a). The mean of all individual pooled flight tracks in relation to north was 321.4° (r = 0.729; $p < 0.0001$, Rayleigh test; n = 43). Flocks observed under high winds (>7 mph) were not associated with the downwind direction when set at 0° (mean = 243.2°; r = 0.427; $p > 0.05$, Rayleigh test; n = 15) (Figure 25b), and dispersion in relation to downwind was random.

Table 12. Nocturnal flight directions of flocks in the Wind Resource Study Area during spring 1982.

Date	n	Wind (degrees	speed)	Mean track (degrees)	r
		Site 1			
15 March	-	284 (104)[a]	23.4	---	-----
19 March	2	293 (113)	6.6	304	0.998
4 April	-	293 (113)	26.8	---	-----
13 April	-	300 (120)	25.0	---	-----
17 April	1	282 (102)	15.3	30	1.000
25 April	1	278 (98)	13.6	23	1.000
		Site 2			
18 March	-	293 (113)	6.3	---	-----
23 March	-	293 (113)	3.8	---	-----
28 March	-	255 (75)	25.0	---	-----
13 April	1	278 (98)	22.2	60	1.000
21 April	-	36 (216)	9.6	---	-----
25 April	1	287 (107)	19.3	68	1.000
		Site 3			
20 March	-	337 (157)	2.0	---	-----
28 March	-	245 (65)	40.0	---	-----
5 April	-	279 (99)	24.8	---	-----
12 April	1	282 (102)	20.0	60	1.000
18 April	3	276 (96)	4.0	283	0.855
24 April	2	281 (101)	19.0	60	0.924
		Site 4			
16 March	-	298 (118)	2.7	---	-----
25 March	-	310 (130)	5.2	---	-----
31 March	2	292 (112)	16.2	304	0.981
5 April	-	302 (122)	30.0	---	-----
15 April	-	290 (110)	37.2	---	-----
21 April	1	315 (135)	1.4	315	1.000
29 April	-	290 (110)	25.6	---	-----
30 April	-	290 (110)	20.6	---	-----

Table 12. continued

Date	n	Wind (degrees	speed)	Mean track (degrees)	r
		Site 5			
24 March	3	23 (203)	0.2	343	0.998
27 March	-	260 (80)	1.8	---	-----
14 April	7	---	----	293	0.908
20 April	-	15 (195)	6.0	---	-----
26 April	8	---	0.0	311	0.841
		Site 6			
3 April	-	322 (142)	17.0	---	-----
8 April	1	326 (146)	0.7	330	1.000
15 April	-	322 (142)	11.8	---	-----
22 April	6	---	0.0	310	0.990
29 April	2	328 (148)	6.3	319	0.998
		Site 7			
6 April	-	---	0.0	---	-----
14 April	1	---	0.0	000	1.000
22 April	-	192 (12)	2.0	---	-----
28 April	-	---	0.0	---	-----

[a] direction toward which wind was blowing

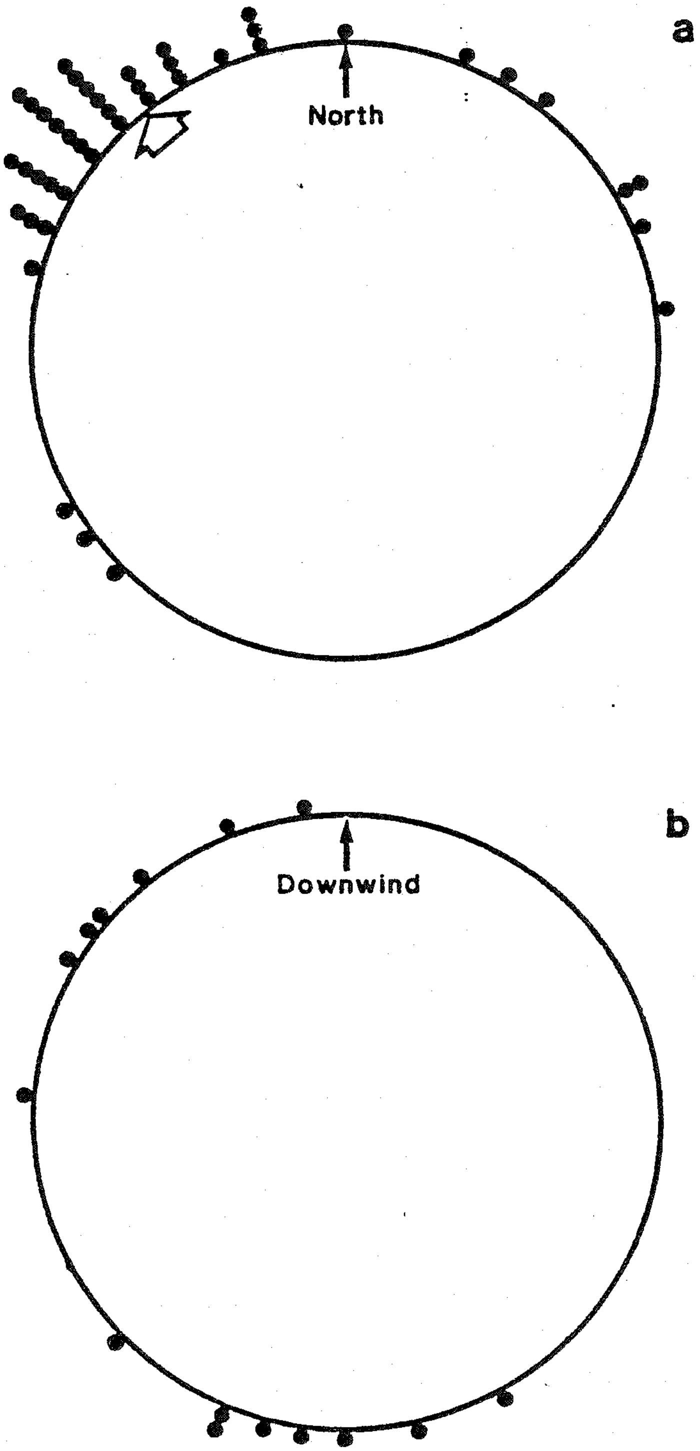


Figure 25. Flock flight tracks observed in the Wind Resource Study Area during spring 1982. a) distribution of all individual flock flight tracks. b) distribution of individual flock flight tracks in relation to downwind set at (0°).

DISCUSSION

Since the 1950's, a vast amount of data has been collected and published on nocturnal bird migration. This research includes at least some information and discussion on most major topics of interest in avian migration research and involves data from many parts of the world. The methodologies used to study nocturnal bird migration are numerous and include moon-watching, use of ceilometers, counts of flight calls, airplanes outfitted with powerful lights, radar, and radio-telemetry. However, even within these categories there is a great deal of variation from study to study. For example, ceilometer observations may involve the use of binoculars, spotting scopes, or night vision scopes encompassing a variety of magnification powers, and radar studies have utilized an array of equipment too numerous to mention. As might be expected, all of these techniques contain their own unique problems and biases which, in combination with the highly variable nature of the subject itself, make any comparative discussion extremely difficult.

The results of this study provide the first detailed account of nocturnal bird migration in southern California including the first radar observations on migration along the Pacific flyway of North America. However, due to the complexity of the subject, it is beyond the scope of this report to include a detailed comparison of all related research. In the following brief discussion, we have attempted to draw general comparisons with only a few of the more significant studies on nocturnal migration.

Since the early 1900's, the Coachella Valley and San Gorgonio Pass have been recognized as an important route for bird migration (Howell 1923). Past research, however, has not included actual migration traffic rates for this area. The results of this study provide the first estimate of spring traffic rates throughout the migratory airspace for the Coachella Valley and San Gorgonio Pass (previous research by McCrary et al. in 1981 was restricted to much lower altitudes).

Most ornithologists have generally assumed that migration traffic rates are much lower in the western United States than in the east. However, this does not appear to have been the case during spring 1982 in the WRSA, where the mean MTR (4,006) was comparable to those observed in other areas of North America during spring migration. Gauthreaux (1971) recorded a mean MTR of 4,800 in Louisiana during spring, while Able and Gauthreaux (1975) recorded a mean of 2,507 in Georgia. Migration in fall, however, has been recorded at considerably higher magnitudes in the eastern United States (for a review see Moorhouse 1980). Because of the radical differences in the equipment and techniques employed in these studies (WSR 57 weather surveillance radar vs. a vertical marine radar; correction factors for determining MTR's based on estimated altitudes vs correction factors determined from actual altitudes), it is difficult to draw sound comparisons about the relative densities of migration between eastern and western North

America. The only previous study actually conducted in the Pacific states was in Hayward, California (Moorhouse 1980) where spring traffic rates (mean MTR = 559) were much lower than those observed in the WRSA. However, Moorhouse's observations were limited to 7X50 binoculars and two 100 watt ceilometers, and thus are not truely comparable with results from this study.

Although spring traffic rates in the WRSA are at least equal if not greater than those for the few other areas studied in the United States, because of the lack of data for surrounding areas, we cannot state categorically that the WRSA is a major pathway for spring migration in southern California. The geographical alignment of the Coachella Valley and the west coast of North America might indicate that the WRSA would be a heavily used migratory pathway, and has long been considered as such by ornithologists (Howell 1923, Miller 1957). This is further supported with results from diurnal studies of migrants in the WRSA which indicate that avian densities and diversities equal or exceed those from other areas of southern California (McKernan et al. in prep.).

Little information exists on the altitudinal distribution of nocturnal migration. Because of equipment limitations, most radar studies of migration have been able to detect only those birds flying above 365 m (Bellrose and Graber 1963, Blokpoel and Burton 1975, Graber 1968, Lack 1960), and the few studies that have included birds flying below this altitude were limited by measurement accuracies of, at best, several hundred meters (Able 1970, Richardson 1976). In general, our study agrees with the findings of Able (1970) for fall migration in Louisiana, where he determined that the altitudinal distribution of nocturnal passerine migration was pyramidal in shape with the greatest number of birds occurring in his lowest height class (below 381 m). Within this range we also found that the distribution of passerine migration was usually somewhat pyramidal, with the greatest number of birds flying below 300 m, although a distinct decrease occurred in the number of migrants flying below 200 m. Marked similarities also occurred in the nightly pattern of change in altitude between the two studies. In both cases the mean altitude of migration increased sharply after the first hour, although the maximum altitude occurred later in the WRSA. In both studies the peak mean altitude was followed by a gradual decline in altitude through the early morning hours. As expected from this change in mean altitude, the number of migrants in the lower altitudes decreased after the first hour, but increased again before sunrise.

The influence of weather on bird migration remains a highly controversial topic of research (for a review see Richardson 1978). Most studies on this aspect of migration have been conducted in eastern North America and Europe; only one study on the relationship between nocturnal migration and weather has been conducted in California (Moorhouse 1980). We examined the relationship between nocturnal migration and both synoptic weather patterns and specific weather variables. These analyses indicate that during spring, synoptic weather patterns in general have little or no effect on either the magnitude or altitude of nocturnal passerine migration in the WRSA. This is quite different from the more obvious response of migrants to synoptic weather in eastern North America and Europe where peak movements tend to occur in the western and central portions of high pressure systems, the eastern portion of a low, or during an intervening transitional stage (see Richardson 1978). This lack of similarity between these areas and the WRSA may be expected in light of the much less severe nature of weather fronts in southern California during spring and the overall predominance of high pressure which has been shown to be conducive to bird migration. A complicating factor in this analysis may be the effect of the almost constant opposing winds which characterize the WRSA during spring which may tend to overshadow any synoptic weather effects.

Along with general weather patterns, birds also exhibit migratory responses to individual weather variables. Wind direction and speed, temperature, pressure, and humidity have all been shown to effect bird migration. In general, more migration occurs in spring during following or calm winds, falling pressure, high and/or rising temperature, and low humidity (see Richardson 1978). During spring in the WRSA the inter-relationship between temperature and date had, by far, the greatest effect on migration magnitude. Although we found this similarity, some important differences occurred between most other areas studied and the WRSA. As mentioned earlier, we found no correlation between MTR's and wind speed during spring 1982. This seems to be a function of the almost constant strong westerly winds of the WRSA and the lack of following winds (SE). In this study there was actually a slight positive relationship between westerly winds and migration magnitude. However, there is indirect evidence from both spring 1981 and 1982 for the occurrence of major peak movements when winds in the Coachella Valley are calm; this was especially noticeable during spring 1981 (McCrary et al. 1981).

Another difference with the general pattern in eastern North America and Europe was the lack of relationship between pressure and migration magnitude in the WRSA. This may be explained by the relatively constant barometric pressure which was prevalent during the peak period of migration (15 April through the end of May), when the greatest 24 hour change in pressure was only 0.58 lb/in (range of barometric pressure at 1900, 30.31 - 31.73 lb/in). This constancy was even more apparent in May when the range of nightly barometric pressure values was only 30.31 - 31.15 lb/in.

These differences again may be related to the relatively mild, more constant weather patterns characteristic of the WRSA and surrounding areas, as compared to other localities where migration has been studied.

The results of this study and research in spring 1981 (McCrary 1981) indicate that in the WRSA wind speed and direction have a significant effect on the flight directions of nocturnal passerine migrants as first shown by Gauthreaux and Able (1970). Most passerine migration in the WRSA is not in the typically northern direction of spring migration in the northern hemisphere. Instead, most birds were flying in an easterly or southeasterly direction which closely corresponds to the strong westerly and northwesterly winds characteristic of the WRSA during spring. Although Gauthreaux and Able (1970) found that many passerines selectively fly downwind even under low wind speeds, in the WRSA birds apparently fly downwind only after wind speed has reached 7-10 mph. Under high winds (>7 mph), nightly mean passerine flight tracks were significantly correlated with wind direction, while no relationship occurred between flight tracks and moderate (4 - 7 mph) or low (0.5 - 4 mph) winds.

The relationship between wind and migratory drift is further shown under no or very low winds (0 - 0.7 mph) under which conditions the mean passerine flight direction was in the expected northerly direction.

Unlike passerine migrants, the flight directions of all flocks observed in the WRSA was in the expected northerly direction regardless of wind speed and direction. This may be explained by the greater power and flight speed of most waterbird species composing flocks compared to most passerines.

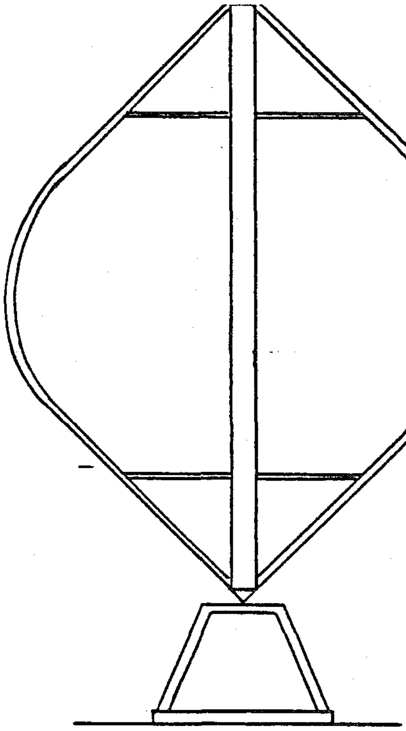
The preferred direction of migration in the Coachella Valley as indicated in this study is to the northwest (315°). The mean flight direction of all flocks, regardless of wind speed and direction was 321°, while the mean flight direction of passerines under no or very low winds was 301°. Similarly, in spring 1981 the mean flight direction of flocks in the WRSA was 304°, while the mean flight direction of passerines under no or very low winds was approximately 330° (McCrary et al. 1981).

PART 2. POTENTIAL IMPACT OF WIND TURBINE GENERATOR DEVELOPMENT ON NOCTURNAL BIRD MIGRATION IN THE SAN GORGONIO WIND RESOURCE STUDY AREA

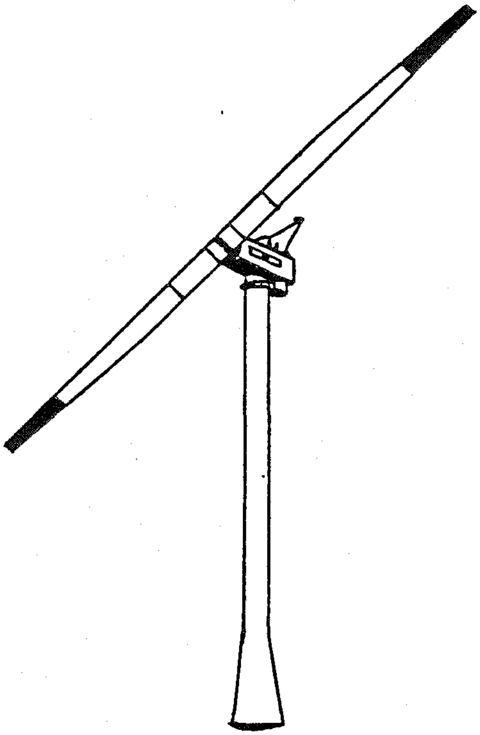
RESULTS

Most WTG's considered for construction in the WRSA will have a maximum height of less than 110 m (for examples see Figures 26 and 27). Presently only one WTG, the Hamilton Standard WTS-4, will extend above 110 m. Future turbine designs, however, may be considerably taller in order to take advantage of the greater wind velocities and lower turbulence of higher altitudes. For example, the Mod 5B WTG is planned with a maximum height of approximately 140 m and a rotor diameter of 128 m. Although the entire population of nocturnal migrants utilizing the WRSA during spring has to be considered to assess the biological significance of any WTG related mortality, based on currently available wind turbines only those birds flying in the zone of altitudes from ground level to 110 m seem likely to be affected by wind turbines and power lines.

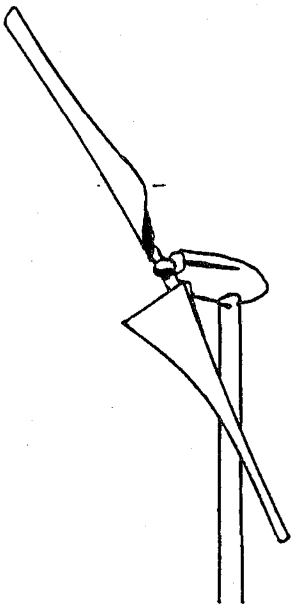
During spring 1982 the number of birds flying below 111 m was relatively evenly distributed, with slightly more migration occurring from 93 - 110 m (Figure 28). However, considerable variation occurred in the distribution of migration below 111 m between sites (Table 13). The greatest concentration of migrants occurred from 19 - 73 m at site 3 where 15.7% of migration was below 74 m, as compared to only 5.7% at site 6. The mean MTR below 111 m for all sites was 365 ± 44 SE, however, there was again variation between sites. The highest mean



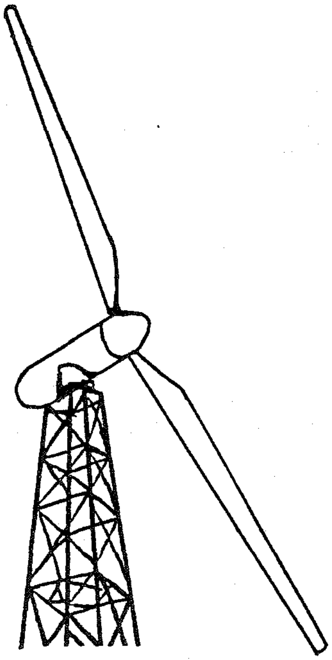
DAF 500 kW WTG
Maximum height - 41 m
Rotor diameter - 24 m
Rotor speed - 45 rpm
structure supported by 3 guy wires



Boeing Mod-2 WTG
Maximum height - 107 m
Rotor diameter - 91 m
Rotor speed - 17.5 rpm



Carter Wind Generator Model 25
Maximum height - 29.3 m
Rotor diameter - 9.8 m
Rotor speed - 120 rpm
Tower supported by 4 guy wires



Westinghouse WWG-0500
Maximum height - 49.7 m
Rotor diameter - 38.1 m
Rotor speed - 42 rpm

Figure 26. Examples of wind turbine generators planned for use in the San Gorgonio Wind Resource Area.

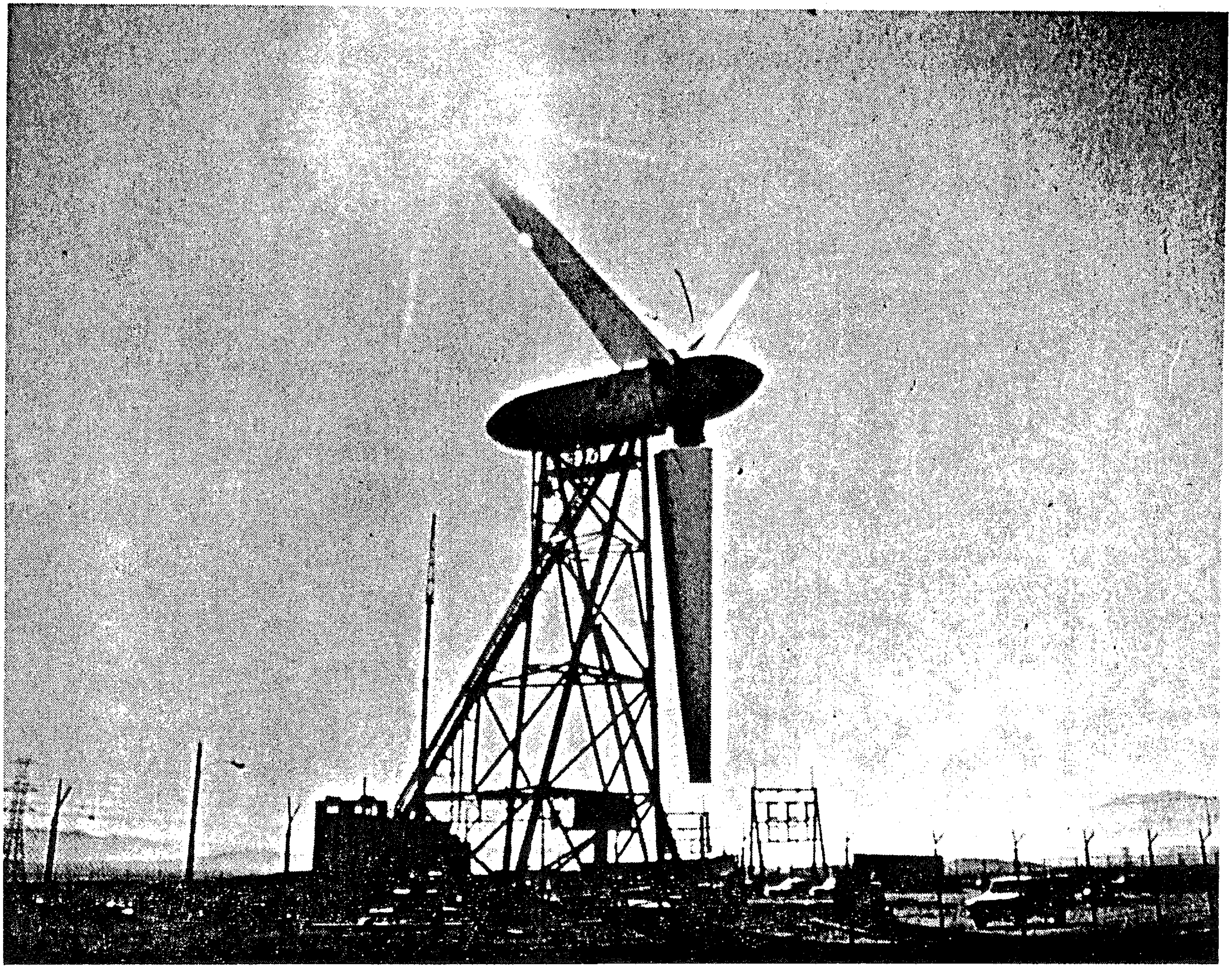


Figure 27. Bendix wind turbine constructed in 1980 near the Devers substation (maximum height = 58.7 m, rotor diameter = 50.3 m, rotor speed = 23 rpm). Study site 2 is located just east of this turbine (Figure 3).

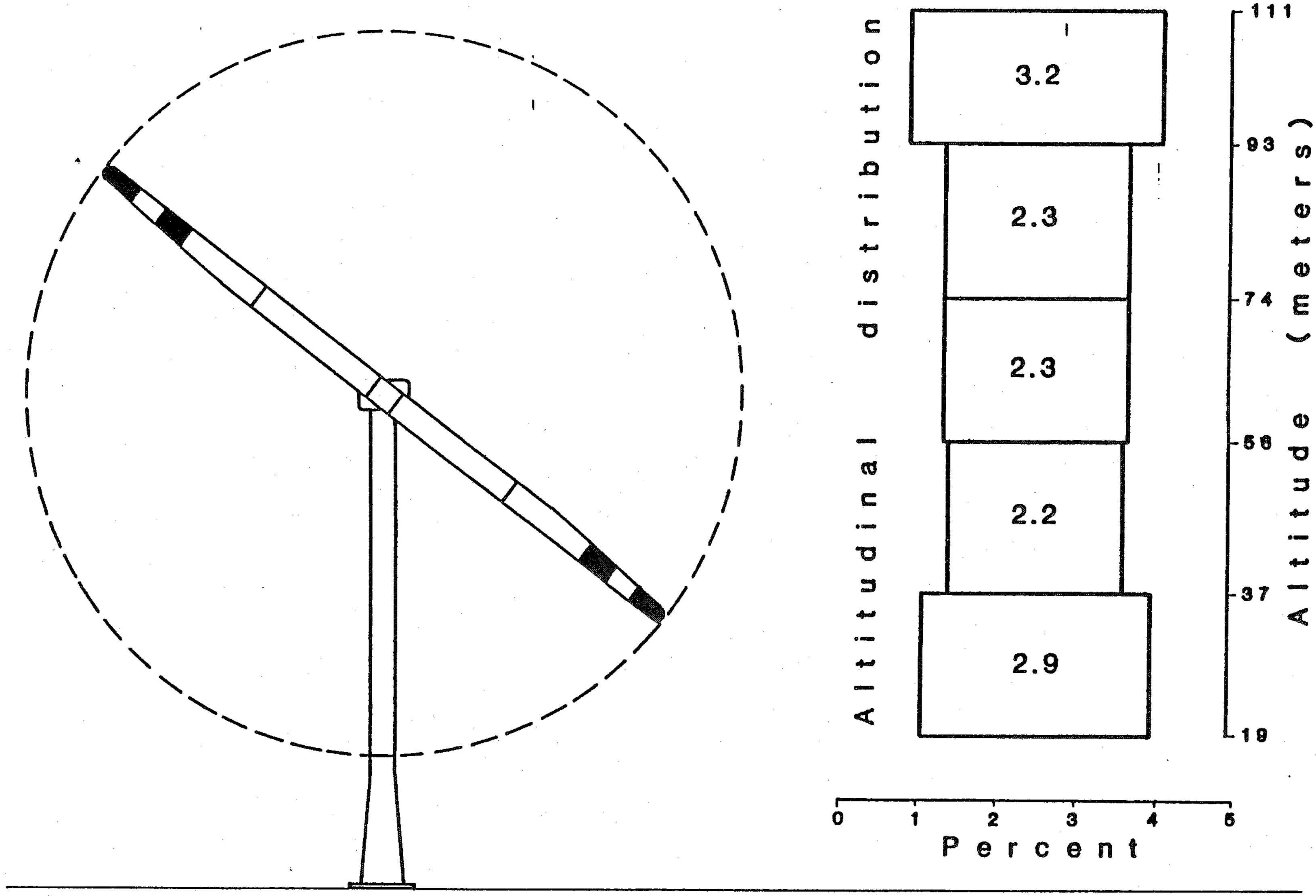


Figure 28. Altitudinal distribution of passerine migrants below 111 m in the Wind Resource Study Area during spring 1982.

Table 13. Mean MTR's below 111 m for nocturnal passerine migrants in the Wind Resource Study Area during spring 1982.

Site	Height Class (meters) 19-36	37-55	56-73	74-92	93-110	ALL±SE
1	79(2.7)[a]	59(2.0)	98(3.4)	20(0.7)	71(2.4)	328±85
2	75(2.3)	161(4.9)	94(2.9)	112(3.4)	148(4.5)	591±213
3	264(7.2)	183(5.0)	127(3.5)	37(1.0)	149(4.1)	760±124
4	84(2.5)	42(1.9)	57(1.7)	74(2.2)	71(3.4)	328±63
5	37(1.2)	27(0.9)	78(2.5)	63(2.0)	145(4.6)	351±63
6	95(2.3)	73(1.8)	65(1.6)	109(2.8)	113(2.9)	455±90
7	144(3.7)	61(1.6)	74(1.9)	107(2.8)	116(3.0)	503±117
ALL	104	101	103	93	127	365±44

[a] percent of birds in total air column (19 - 1,483 m).

MTR's occurred at site 2 (591 ± 213 SE) and 3 (760 ± 124 SE), with the other sites ranging from 328 - 503 (Table 13). Most observations below 111 m were of single migrants; only two flocks of three birds each were observed in this altitudinal zone.

Figure 29 shows the nightly pattern of migration magnitude for each of 5 height classes below 111 m. The general pattern of bird migration in the lower height classes shows a decrease in concentration after 1900 with an increase in the early morning; most of the nightly change in the concentration of birds occurred from 19 - 55 m.

The seasonal pattern of nocturnal spring migration below 111 m (Figure 30) was similar to that for all altitudes (Figure 10). Nightly mean MTR's below 111 m were low from late march through mid-April. After 11 April, mean MTR's increased to a peak from 22 - 25 April.

<u>Observations on Nocturnal Flight Behavior of Birds Near Structures</u>

We conducted observations on nocturnal migrants flying near a high tension transmission tower at site 2 for 6 nights during May (Table 14). These observations were conducted in a similar manner to those in spring 1981 (McCrary et al. 1981) where the top of the tower was dimly illuminated by ceilometer. However, the image intensifier developed electrical problems on 1 May and thereafter image intensifier observations were limited to 45 minutes per night with the remaining time confined to binoculars and 20X spotting scopes. We did not view

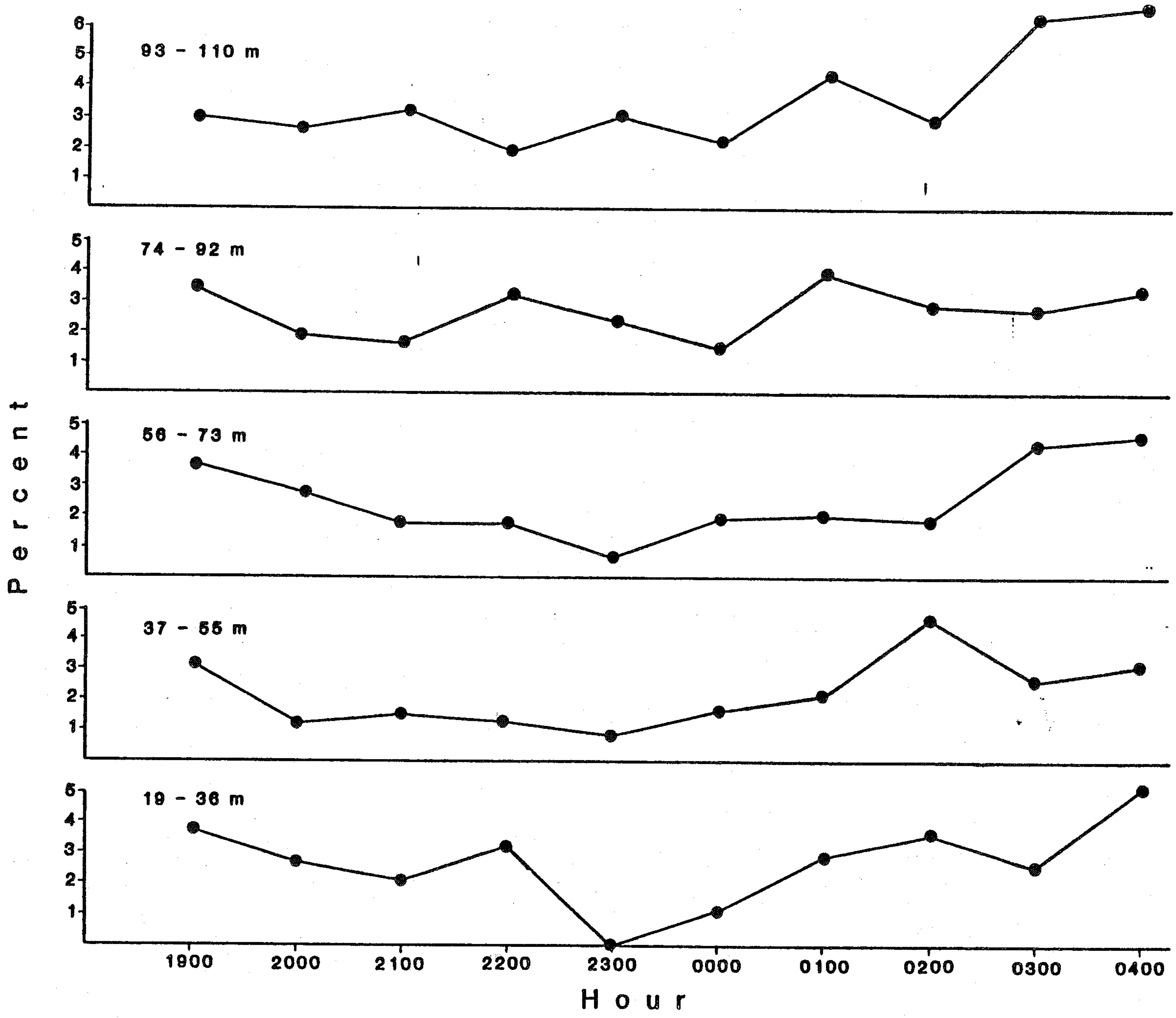


Figure 29. Nightly pattern of single migrants in 5 height classes below 111 m.

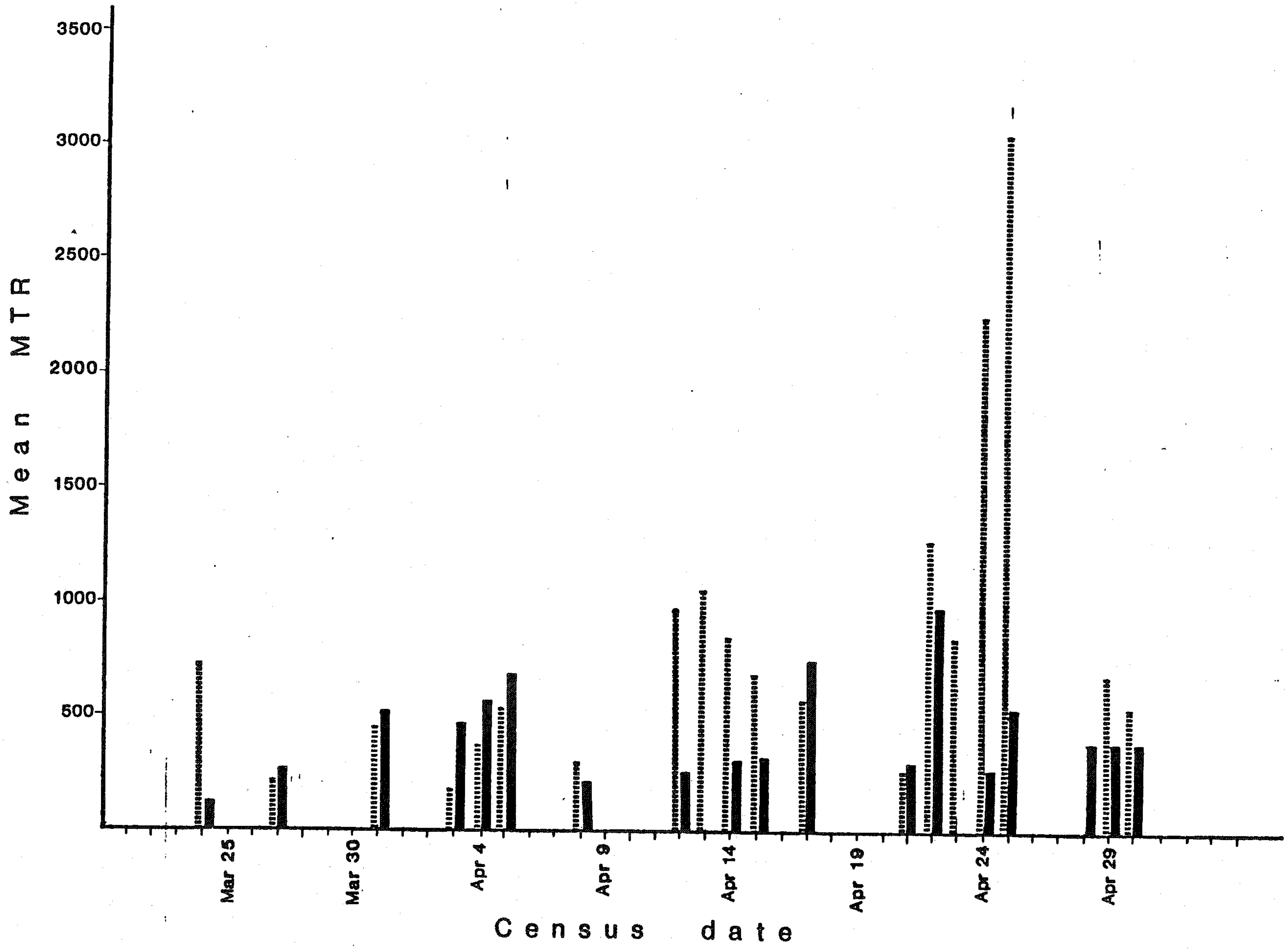


Figure 30. Variation in nightly mean passerine MTR's from 19 - 111 m by date, all sites combined. Migration occurred on all nights of observation. (Broken line = before midnight, solid line = after midnight).

Table 14. Observations of nocturnal avian flight behavior at a high tension transmission tower near Study Site 2.

Date	Time	birds	wind speed (mph)	Flight Reaction		
				none	moderate	high
14 May	2120-2145 (25)[a]	3	18	100	—	—
	2230-2315 (45)	5	18	80	20	—
18 May	1940-0415[b] (235)	17	26	76.9	15.4	7.7
19 May	1930-2200 (150)	12	14.3	83.3	16.7	—
20 May	1940-2030 (50)	10	13	80	10	10
22 May	2040-2200 (80)	21	20	85.7	9.5	4.8
23 May	2030-2100 (60)	22	5	63.6	22.7	13.6

[a] number of minutes of continuous observation

[b] 20-30 minutes of observation per hour

the Bendix wind turbine during this study, as its blades had been removed for engineering modifications.

Although not directly comparable because of the above mentioned equipment failure, the results of these horizontal observations are similar to those in 1981. In 1981, this transmission tower had the greatest effect on the flight behavior of nocturnal migrants (McCrary et al. 1981) when up to 22.2% and 22.0% of birds showed a moderate and high reaction, respectively. In spring 1982, this structure had a similar effect, when up to 22.7% and 13.6% of birds displayed a moderate and high reaction (Table 14). Other structures observed in spring 1981 (meteorological tower at site 1, smaller transmission tower at site 6, and Bendix wind turbine) apparently had a much lower effect on bird flight behavior than the above (McCrary et al. 1981), although it should be noted that the wind turbine was not working during those observations. In both studies the behavior of birds was occasionally highly erratic near the transmission tower at site 2 and included some instances of circling the structure.

We are uncertain at this time why this particular tower effects bird flight behavior to a greater extent than other structures. This may be a function of the higher concentration of migrants at low altitudes characteristic of site 2 (see Altitude of Spring Migration) or it may be related to some aspect of the tower itself (height, electromagnetic fields, reflective surface, lighting, etc.). Although it was difficult to determine the actual distance birds were flying in relation to the tower because we were viewing them on a 2-dimensional plane (TV monitor), there appeared to be no obvious attraction of birds. Rather, the flight paths of birds exhibiting a moderate to high reaction were, by chance, in close proximity to the tower, while those not reacting were at some distance from it.

DISCUSSION

Bird deaths from collisions with man-made structures have been reported for almost a century (Cooke 1888, Kumlien 1888), and numerous bird deaths from collisions occur annually throughout the world. Estimates of annual mortality from collisions in the U.S. alone range from 5 million to 80 million birds (Banks 1979, Klem 1979) and as many as 30,000 birds have been killed on a single night at one TV tower in Wisconsin (Kemper 1964). Although avian collisions with most structures other than buildings and some transmission lines occur only sporadically, some radio and TV towers may consistently kill many hundreds of birds each year. A partial list of structures involved in bird collisions includes radio and TV towers, smoke stacks, transmission and distribution lines, cooling towers, and lighthouses (see Avery et al. 1980). Although most of these structures are relatively tall, many shorter structures have also been implicated (fences, telephone and telegraph poles and wires, light poles, etc.). Wind turbines, although relatively new, have also been responsible for bird collisions. In fall 1982 at least 3 birds - American Kestrel (*Falco sparverius*), American Coot (*Fulica americana*), and European Starling (*Sturnus vulgaris*) - died from colliding with a Mod-2 turbine located in the San Francisco Bay area (S. Byrne, pers. comm.).

The vast majority of birds killed by collisions with man-made structures are passerines (i.e. sparrows, warblers, blackbirds, etc.). For example, over 99% of all bird kills at a 300 m tower in Illinois were passerines (Graber 1968), while 86% were passerines at a 366 m tower in North Dakota (Avery et al. 1978). Flocking species in the orders Anseriformes (waterfowl) and Charadriiformes (shorebirds and gulls) die from collisions with much less frequency during migration, although large numbers of wintering waterfowl are killed in collisions with transmission lines (see Avery et al. 1980). During a 25 year study of mortality at a 308 m TV tower in Florida only 0.3% of 42,384 known avian fatalities were waterfowl, less than 0.2% were shorebirds and gulls, and 96.7% were passerines (Crawford 1981).

The paucity of collision fatalities in flocking species during migration probably results from lower numbers of flocking migrants compared to passerines and the slightly higher altitudes of flocks. We found that the mean MTR and altitude of flocks was 44.4 and 362 m, respectively, as compared to 4,006 and 351 m for passerine birds.

If no attractant is involved, the number of avian collisions with structures is apparently a function of the nature of the structure itself (height, size, shape, presence of guy wires, etc) and the number of migrants flying in close proximity to the structure. The total number of birds aloft and the concentration of migrants in the lower altitudes near a structure may be a function of a variety of factors including location in respect to preferred migratory pathways, time of year, time of day, topography, weather, and structure lighting. Highest collision rates in the eastern U.S. occur at night during fall migration under overcast skies with or without the presence of rain, drizzle, or fog (for a review see Avery 1976). Little information is available on the frequency, seasonal pattern, or relationship with weather of collisions in the western United States (see Avery et al. 1980).

Some studies indicate that lighting of structures may play an important role in avian collisions. Nocturnal migrants are attracted to or linger at some lighted structures especially under overcast skies (Cochran and Graber 1958). Under these conditions during periods of heavy migration swarms of passerine birds may collect around structures (Avery et al. 1976, Cochran and Graber 1958). One theory explaining the phototactic response of nocturnal passerine migrants to lighted structures suggests that under overcast skies birds may mistake lights for stars and actually spiral into a structure (Kemper 1964). However, numerous problems exist with this explanation (see Avery et al. 1976), and birds probably do not confuse lights with stars. Graber (1968) explains this phenomenon as not an attraction to towers but rather as a reluctance on the part of those nocturnal migrants flying near the structure to leave an illuminated area under cloudy skies. He compares this to the behavior of birds in a lighted room where they are reluctant to fly out an open window into the darkness; this behavior has been corroborated by Avery et al. (1976). The lingering and milling of birds around structures resulting from this effect apparently produces the high levels of avian mortality that have been recorded at tall lighted structures on some nights. Avery et al. (1976) further suggest that under overcast or foggy nights minute moisture droplets in the air tend to increase the illuminated area around a structure thus arresting more migrants. It should be noted that many bird collisions occur on clear nights during both spring and fall, although the greatest impacts have occurred under overcast skies.

Observations during this study and in spring 1981 (McCrary et al. 1981) indicate this phototactic behavior of birds to lighted structures also occasionally occurs in the WRSA. As in this study, tower observations in spring 1981 were conducted with one ceilometer directed horizontally toward a high tension transmission tower located near site 2. On several occasions in both years, individual birds and small flocks were seen to circle or fly erratically around the partially lighted tower in a similar fashion to that described for birds by Avery et al. (1976) and Cochran and Graber (1958). Thus, in this study and during spring 1981 some birds may have exhibited a high reaction to the transmission tower because of the light from the ceilometer and reflections off the metal surfaces of the tower which created an illuminated area around it. From this it is implied that lighting is an important factor to consider when discussing the likelyhood of avian collisions with wind turbines.

Until ground counts of dead or injured birds can be conducted under an array of operating turbines, we cannot fully assess the impact to birds of WTG construction and operation in the WRSA. However, studies on other man-made structures indicate that the number of collisions will be a function of the number of birds flying at the

Considering a 10 hour night and a spring migratory season of 50 days, an average of 182,500 birds per kilometer may fly through the WRSA in the altitudinal zone of risk (19 - 110 m) per spring. This is approximately 9% of the estimated spring 1982 population of all nocturnal passerine migrants utilizing the WRSA (approximately 2 million birds per km as determine from the mean MTR for all altitudes). The actual proportion of migrants we classify as at risk that will collide with turbines remains to be determined; however, from reports of avian mortality at other man-made structures, at least some collisions will undoubtedly occur.

Although we cannot presently determine the number of bird collisions which will occur in the WRSA WTG park, some aspects of the timing and geographical variation can be predicted with the results of this study. Since most movement occurs early in the evening, bird collisions are more likely to occur during the first 2-3 hours after sunset (1900 - 2100). The chance of collisions occurring during this period is further increased by the lower flight altitudes of migrants during the first 1-2 hours of the night. Similarly, collisions will probably be much more infrequent after midnight, as this period corresponds with very low MTR's and higher altitudes. Seasonally, collisions are likely to be more numerous after 15 April and may continue at higher levels through the end of May; March and early April were characterized by only light migration. Although there was little difference in overall migration magnitude between sites indicating that migration generally occurs along a broad front in the WRSA, the altitudinal distribution of migration was lower at sites 2 and 3; thus, more collisions may be expected at these sites. As indicated by the mean altitude and altitudinal distribution at site 3, wind turbines constructed along ridges may potentially result in the greatest number of collisions. This study indicates that most passerine birds during migration maintain a relatively constant altitude above ground level unless their flight paths are interrupted by abrupt changes in topography. In the case of ridges the altitude of birds in relation to ground level decreases as they fly over a ridge and is probably lowest at the crest.

Theoretical Model of Avian Collisions with Wind Turbine Generators

In Table 15 we provide a theoretical analysis of potential spring collision rates for 5 wind turbine generator designs presently considered for use in the San Gorgonio Wind Resource Area. However, the same analysis could be carried out for other turbines as well. The purpose of this model is to provide a preliminary evaluation of the potential for avian collisions in relation to WTG design for probable utilization in the WRSA. The wind turbine technologies used in this predictive model were selected to represent a cross section of various turbine designs currently available and not to evaluate specific manufacturers. Other wind turbine designs not considered in this model could also have similar predicted impacts if tested. Based on the results of this study, we use a spring migration period of 50 days from approximately 12 April through May. The birds that would actually be

Considering a 10 hour night and a spring migratory season of 50 days, an average of 182,500 birds per kilometer may fly through the WRSA in the altitudinal zone of risk (19 - 110 m) per spring. This is approximately 9% of the estimated spring 1982 population of all nocturnal passerine migrants utilizing the WRSA (approximately 2 million birds per km as determine from the mean MTR for all altitudes). The actual proportion of migrants we classify as at risk that will collide with turbines remains to be determined; however, from reports of avian mortality at other man-made structures, at least some collisions will undoubtedly occur.

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Long term studies of waterfowl flight behavior in relation to a transmission line in Washington indicate that approximately 87% of birds flying at or below line height will react to the presence of the line (for a summary of waterfowl avoidance behavior see Beaulaurier 1981).- Although we have not had an opportunity to study an operating turbine, from our nocturnal observations on birds flying near structures (transmission towers) during three migratory seasons, we believe an avoidance rate approaching 95% may be a more realistic estimate. Finally, although not based on actual avoidance behavior, no collision fatalities were found from ground counts conducted at a Mod-2 turbine located near San Francisco during spring 1983 migration (S. Byrne, PG&E; pers. comm.).

Table 15 indicates that, other than the rate of avian avoidance, blade diameter and corresponding turbine sweep area are the most important factors in predicting potential avian collision rates with wind turbines. However, many other aspects of wind turbine design may also be important in the frequency of bird collisions. These design features include:

- Turbine height,
- Rotor solidity (the ratio between blade area and the area swept by the spinning rotor),
- Number of blades
- Blade diameter,
- Blade velocity,
- Blade depth

- Blade width
- Power output
- Presence and number of guy wires supporting the turbine,
- Turbine lighting.
- Blade color

Table 16 provides additional information on the 5 turbines considered in the predictive model (Table 15). Rotor solidity is a function of the number of blades in a turbine design, blade velocity, blade depth, and blade width. Rogers et al. (1976) have suggested that the low rotor solidity of some turbine designs may allow for birds to actually fly through an operating turbine without being struck by the turbine's blades. This is dependent on the area swept by the blade during the time it takes a bird to fly through. Rogers et al. (1976) provide a potentially useful formula for calculating the probability of collision assuming no avoidance.

$$\text{Prob} = \frac{N(R)(D)}{Va}$$

where: Prob = Probability of collision
Va = the bird's axial velocity (m/s)
N = Number of blades
R = Blade rotational speed (rps)
D = Average depth of blade (m)

This calculation is only useful in analyzing the probability that a moving blade will strike a bird but cannot be used for the reverse situation which may also occur. It does, however, point out the potential importance of rotor solidity in avian collision rates.

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CONCLUSIONS

During spring migration the WRSA is heavily utilized by birds as a migratory flyway. This view is supported not only by the results of this present study, but also from previous research in the area (McCrary et al. 1981, McKernan et al., in prep). We estimate that approximately 32 million birds flew through the Coachella Valley during spring 1982 based on an average width of the valley of 16 km.

During spring 1982 migration in the WRSA most birds flew from 200 - 400 m above ground. However, many birds were recorded flying much lower than this, and a distinct proportion of all migrants were below 111 m (12.9%). Since most turbines considered for use in the WRSA are below 111 m in height, nocturnal migrants flying below 111 m are those that may potentially collide with wind turbine generators.

Numerous studies of avian mortality have shown that the nocturnal flight behavior of most migratory birds makes them particularly susceptible to collisions with a variety of man-made structures. Although many of these structures are considerably taller than the wind turbines presently planned for use in the WRSA, many shorter structures have also been implicated in bird mortality. From these studies avian collisions with wind turbines in the WRSA will almost undoubtedly occur. Because of the complex array of turbine designs (turbine height, number of blades, blade speed, presence and number of guy wires, etc.) available for use, the variety of possible geometrical placements of wind turbines and the present lack of the actual number of turbines to be constructed, we are unable to predict the amount of collision related avian mortality that may occur from proposed wind energy development of the WRSA. However, from the altitudinal distribution of nocturnal migrants and the number of birds aloft at night, we estimate that approximately 182,000 birds/km could potentially come into contact with wind turbine generators each spring in the WRSA. Although only a small fraction of these birds likely to collide with wind turbines in the WRSA, even a collision rate of 0.5% would yield several thousand deaths per spring season.

Lighting has also been shown to play an important role in bird collision rates, and although there is no apparent attraction of birds to lights, they may linger near a lighted wind turbine, thus further increasing the probability of colliding with blades, guy wires, towers, etc. Although our present understanding of the influence on birds of different lighting variables (color, blink rate, intensity) is limited, lighting manipulation may possibly lower collision rates with wind turbines.

Although it is difficult to pinpoint actual numbers of avian deaths resulting from collisions with wind turbines, the timing of potential peak collision periods can be determined from cumulative data on nightly and seasonal patterns of the magnitude and altitude of migration. Most collisions will likely occur during the first 2-3 hours of the night (1900 - 2100) when MTR's are the highest and

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2. Structure lighting is an important aspect in avian collisions and as potential mitigation in the WRSA we recommend the initiation of a study of how turbine lighting effects bird collisions. This study would involve the same methodology as the above and would be restricted to only those lighting guidelines approved by FAA and OSHA.

3. Based on the results of this study at site 3 (Painted Hill), the turbines constructed on ridges should be restricted to the smaller designs (maximum height < 100 ft) and lower densities until monitoring studies in these situations have been conducted.

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Site	Mar 15	Mar 16	Mar 18	Mar 19	Mar 23	Mar 24	Mar 27	Mar 28	Mar 31	Apr 3	Apr 4	Apr 5	Apr 8	Apr 12	Apr 13	Apr 14	Apr 15	Apr 17	Apr 20	Apr 21	Apr 22
1	B			B							B			A				B			
2			B		C		A								B				A		
3	A			A				B			A			B				A			
4		B				A			C			B				A				B	
5						B	B								A				B		
6										C			C				C				C
7												A				B				A	

Site	Apr 24	Apr 25	Apr 28	Apr 29	Apr 30	May 2	May 3	May 6	May 10	May 11	May 12	May 13	May 14	May 15	May 18	May 19	May 20	May 21	May 22	May 23	
1	A					B			A											C	
2		B										B	C	C	C	C	C		B		
3	B					A			B												
4			A		B						A										
5		A					B					A							A		
6				C				C		C								C			
7			B		A						B										

A — After midnight

B — Before midnight

C — All night

Appendix A. Spring 1982 schedual of data collection in the WRSA.

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1	B			B							B			A				B			
2			B		C		A								B				A		
3	A			A				B			A			B				A			
4		B				A			C			B				A				B	
5						B	B								A				B		
6										C			C				C				C
7												A				B				A	

Site	Apr 24	Apr 25	Apr 28	Apr 29	Apr 30	May 2	May 3	May 6	May 10	May 11	May 12	May 13	May 14	May 15	May 18	May 19	May 20	May 21	May 22	May 23	
1	A					B			A											C	
2		B										B	C	C	C	C	C		B		
3	B					A			B												
4			A		B						A										
5		A					B				A								A		
6				C				C		C								C			
7			B		A						B										

A — After midnight

B — Before midnight

C — All night

Appendix A. Spring 1982 schedual of data collection in the WRSA.

(Appendix B. cont.)

Short-billed Dowitcher
(*Limnodromus griseus*)

Long-billed Dowitcher
(*Limnodromus scolopaceus*)

Common Snipe
(*Gallinago gallinago*)

Wilson's Phalarope
(*Phalaropus tricolor*)

Red-necked Phalarope
(*Phalaropus lobatus*)

* Parasitic Jaeger
(*Stercorarius parasiticus*)

Laughing Gull
(*Larus atricilla*)

Franklin's Gull
(*Larus pipixcan*)

Bonaparte's Gull
(*Larus philadelphia*)

* Mew Gull
(*Larus canus*)

Ring-billed Gull
(*Larus delawarensis*)

California gull
(*Larus californicus*)

Herring Gull
(*Larus argentatus*)

* Black-legged Kittiwake
(*Rissa tridactyla*)

* Sabine's Gull
(*Xema sabini*)

Gull-billed Tern
(*Sterna nilotica*)

Caspian Tern
(*Sterna caspia*)

Common Tern
(*Sterna hirundo*)

Forster's Tern
(*Sterna forsteri*)

Black Tern
(*Chlidonias niger*)

Black Skimmer
(*Rynchops niger*)

Western Screech-Owl
(*Otus kinnicottii*)

Long-eared Owl
(*Asio otus*)

Short-eared Owl
(*Asio flammeus*)

Lesser Nighthawk
(*Chordeiles acutipennis*)

Common Poorwill
(*Phalaenoptilus nuttallii*)

Northern Flicker
(*Colaptes auratus*)

Olive-sided Flycatcher
(*Contopus borealis*)

Western Wood-Pewee
(*Contopus sordidulus*)

Willow Flycatcher
(*Empidonax trallii*)

Hammond's Flycatcher
(*Empidonax hammondii*)

Dusky Flycatcher
(*Empidonax oberholseri*)

Gray Flycatcher
(*Empidonax wrightii*)

Western Flycatcher
(*Empidonax difficilis*)

(Appendix B. cont.)

Black Phoebe
(*Sayornis nigricans*)

Say's Phoebe
(*Sayornis saya*)

Vermilion Flycatcher
(*Pyrocephalus rubinus*)

Ash-throated Flycatcher
(*Myiarchus cinerascens*)

Cassin's Kingbird
(*Tyrannus vociferus*)

Western Kingbird
(*Tyrannus verticalis*)

Horned Lark
(*Eremophila alpestris*)

White-breasted Nuthatch
(*Sitta carolinensis*)

House Wren
(*Troglodytes aedon*)

American Dipper
(*Cinclus mexicanus*)

Golden-crowned Kinglet
(*Regulus satrapa*)

Ruby-crowned Kinglet
(*Regulus calendula*)

Blue-gray Gnatcatcher
(*Polioptila caerulea*)

Western Bluebird
(*Sialia mexicana*)

Mountain Bluebird
(*Sialia currucoides*)

Townsend's Solitaire
(*Myadestes townsendii*)

Swainson's Thrush
(*Catharus ustulatus*)

Hermit Thrush
(*Catharus guttatus*)

American Robin
(*Turdus migratorius*)

Varied Thrush
(*Ixoreus naevius*)

Sage Thrasher
(*Oreoscoptes montanus*)

* Brown Thrasher
(*Toxostoma rufom*)

* Bendire's Thrasher
(*Toxostoma bendirei*)

Water Pipit
(*Anthus spinoletta*)

Cedar Waxwing
(*Bombycilla cedrorum*)

Bell's Vireo
(*Vireo bellii*)

Gray Vireo
(*Vireo vicinior*)

Solitary Vireo
(*Vireo solitarius*)

* Yellow-throated Vireo
(*Vireo flavifrons*)

Warbling Vireo
(*Vireo dilvus*)

* Golden-winged Warbler
(*Vermivora chrysoptera*)

* Tennessee Warbler
(*Vermivora peregrina*)

Orange-crowned Warbler
(*Vermivora celata*)

Nashville Warbler
(*Vermivora ruficapilla*)

(Appendix B. cont.)

Short-billed Dowitcher
(*Limnodromus griseus*)

Long-billed Dowitcher
(*Limnodromus scolopaceus*)

Common Snipe
(*Gallinago gallinago*)

Wilson's Phalarope
(*Phalaropus tricolor*)

Red-necked Phalarope
(*Phalaropus lobatus*)

* Parasitic Jaeger
(*Stercorarius parasiticus*)

Laughing Gull
(*Larus atricilla*)

Franklin's Gull
(*Larus pipixcan*)

Bonaparte's Gull
(*Larus philadelphia*)

* Mew Gull
(*Larus canus*)

Ring-billed Gull
(*Larus delawarensis*)

California gull
(*Larus californicus*)

Herring Gull
(*Larus argentatus*)

* Black-legged Kittiwake
(*Rissa tridactyla*)

* Sabine's Gull
(*Xema sabini*)

Gull-billed Tern
(*Sterna nilotica*)

Caspian Tern
(*Sterna caspia*)

Common Tern
(*Sterna hirundo*)

Forster's Tern
(*Sterna forsteri*)

Black Tern
(*Chlidonias niger*)

Black Skimmer
(*Rynchops niger*)

Western Screech-Owl
(*Otus kinnicottii*)

Long-eared Owl
(*Asio otus*)

Short-eared Owl
(*Asio flammeus*)

Lesser Nighthawk
(*Chordeiles acutipennis*)

Common Poorwill
(*Phalaenoptilus nuttallii*)

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* Tennessee Warbler
(*Vermivora peregrina*)

Orange-crowned Warbler
(*Vermivora celata*)

Nashville Warbler
(*Vermivora ruficapilla*)

(Appendix B. cont.)

* Virginias Warbler
(Vermivora virginiae)

Lucy's Warbler
(Vermivora luciae)

* Northern Parula
(Parula americana)

Yellow Warbler
(Dendroica petechia)

* Chestnut-sided Warbler
(Dendroica pensylvanica)

* Magnolia Warbler
(Dendroica magnolia)

* Black-throated Blue Warbler
(Dendroica caerulescens)

Yellow-rumped Warbler
(Dendroica coronata)

Black-throated Gray Warbler
(Dendroica nigrescens)

Townsend's Warbler
(Dendroica townsendi)

Hermit Warbler
(Dendroica occidentalis)

* Black-throated Green Warbler
(Dendroica virnes)

* Blackburnian Warbler
(Dendroica fusca)

* Palm Warbler
(Dendroica palmarum)

* Black-and-White Warbler
(Mniotilta varia)

* American Redstart
(Setophaga ruticilla)

* Ovenbird
(Seiurus aurocapillus)

* Northern Waterthrush
(Seiurus noveboracensis)

MacGillivray's Warbler
(Oporornis tolmiei)

Common Yellowthroat
(Geothlypis trichas)

Wilson's Warbler
(Wilsonia pusilla)

* Canada Warbler
(Wilsonia canadensis)

Yellow-breasted Chat
(Icteria virens)

Summer Tanager
(Piranga rubra)

Western Tanager
(Piranga ludoviciana)

* Rose-breasted Grosbeak
(Pheucticus ludovicianus)

Black-headed Grosbeak
(Pheucticus melanocephalus)

Blue Grosbeak
(Guiraca caerulea)

Lazuli Bunting
(Passerina amoena)

* Indigo Bunting
(Passerina cyanea)

Green-tailed Towhee
(Pipilo chlorurus)

Chipping Sparrow
(Spizella pallida)

Brewer's Sparrow
(Spizella breweri)

Black-chinned Sparrow
(Spizella atrogularsis)

(Appendix B. cont.)

Vesper Sparrow
(Pooescetes gramineus)

Lark Sparrow
(Chondestes grammocus)

Sage Sparrow
(Amphispiza belli)

Savannah Sparrow
(Passerculus sandwichensis)

Fox Sparrow
(Passerella iliaca)

Song Sparrow
(Melospiza melodia)

Lincoln's Sparrow
(Melospiza lincolnii)

* Swamp Sparrow
(Melospiza georgiana)

* White-throated Sparrow
(Zonotrichia albicollis

Golden-crowned Sparrow
(Zonotrichia atricapilla)

White-crowned Sparrow
(Zonotrichia leucophrys)

* Harris Sparrow
(Zonotrichia querula)

Dark-eyed Junco
(Junco heymalis)

* Orchard Oriole
(Icterus spurius)

Hooded Oriole
(Icterus cucullatus)

Northern Oriole
(Icterus galbula)

Scott's Oriole
(Icterus parisorum)

Lesser Goldfinch
(Carduelis psaltria)

Lawrence's Goldfinch
(Carduelis lawrencei)

American Goldfinch
(Carduelis tristis)

* Denotes accidental occurrence

Appendix C. Synoptic Weather Patterns

A. Pacific high pressure - This pattern occurs most frequently in southern California and is characterized by moderate air temperature, no precipitation, and constant high barometric pressure.

B. Low pressure cold front - Cold fronts are usually restricted to winter and early spring in southern California where they generally travel from west to east. This pattern is characterized by strong north and northwest winds, lower air temperature and barometric pressure, and increased relative humidity. Precipitation may occur depending on the intensity and position of the front.

C. Low pressure front to the east of southern California - This is a transitional- period between the passage of a cold front over southern California and the development of a Pacific high. It is characterized by moderate to strong westerly winds, decreasing cloud cover, lower air temperatures and humidity. Precipitation mya occasionally occur, depending on the location of the trailing edge of the cold front.

D. Complex weather pattern - This pattern is characterized by a series of scattered low pressures (ie. over the Great Basin, Pacific Northwest, and Pacific Ocean). Individual weather variables characteristic of this pattern are highly complex and subject to abrupt changes.

Appendix D. Definitions of Weather Variables.

nitedate	Date on which the night commenced
cloudcover	percent cloud cover at 1900 from Palm Springs airport
cloudheight1	cloud height of first layer at 1900 in meters from Palm Springs airport
cloudheight2	cloud height of second layer at 1900 in meters from Palm Springs airport
sitecldcov	percent cloud cover as estimated at each site
precip	occurrence of precipitation in 24 hours before or after observation
pressure	barometric pressure at sea level (Thermal airport)
presschange	24 hour change in pressure at 1900 from Palm Springs airport
temp	temperature (°C) at 1900 from Palm Springs airport
tempchange	24 hour change in temperature (°C)
visib	visibility in kilometers at 1900 (Palm Springs airport)
winddirec(E-W)	sine of mean nightly wind direction
winddirec(N-S)	cosine of mean nightly wind direction
windvector(E-W)	sine of mean nightly wind direction times mean nightly wind speed
windvector(N-S)	cosine of mean nightly wind direction times mean nightly wind speed.
windspeed	mean nightly wind speed at site (mph)