THE EFFECTS OF A TALL TOWER ON NOCTURNAL BIRD MIGRATION—A PORTABLE CEILOMETER STUDY

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MUCH concern has been expressed over bird mortality at lighted, man-made structures (e.g. Kemper 1964, Aldrich et al. 1966), but very little effort has been directed toward understanding why such losses occur and developing means to prevent them. An exception to this was the successful reduction of losses at fixed beam ceilometers of some airports by filtering the visible wavelengths out of the beams (Terres 1956). The filtering eliminated the attractiveness of the beams to nocturnal migrants but still permitted the devices to measure cloud ceilings with the ultraviolet light that passed through the filters. Elsewhere losses at the intense fixed ceilometer beams were greatly reduced by turning off the devices when birds were noted in the beams (Laskey 1954). In recent years, most airports have converted to rotating beam ceilometers that have no noticeable effect on migrants.

In Great Britain mortality at the Dungeness Lighthouse (Baldwin 1965) was apparently eliminated when the original revolving, 10-beam, white beacon was replaced with a xenon-filled lamp that emitted bluish light and flashed for 1 sec in every 10. Also, several British lighthouses were illuminated with floodlights that reduced losses somewhat but did not eliminate them. In contrast, mortality at the Long Point Lighthouse in Ontario increased following the installation of floodlights there (Baldwin 1965).

Cochran and Graber (1958) have provided detailed information on bird behavior at tall towers. On the basis of counts of flight calls, they concluded that nocturnal migrants were attracted to the red warning lights on their tower.

In this paper, we report on direct visual observations of nocturnal migrants at a tall tower during four migration seasons and relate our findings to proposed reasons why birds congregate at tall lighted towers.

METHODS

The U.S. Coast Guard Omega Navigation Station in the James River Valley, 3 km west of LaMoure in southeastern North Dakota, is one of eight that will comprise the worldwide Omega Navigation System. The signal emitted by the 366-m tower consists of a 10-sec sequence of eight pulses ranging in frequency from 10.0 to 14.0 kHz with a radiated power of approximately 10 kw. The structure is supported by three sets of five guy wires. In addition, 16 evenly spaced transmitting cables, which form a part of the antenna system, extend from the top of the tower to a perimeter road 732 m away. Five red, nonflashing, 116-w obstruction lights are

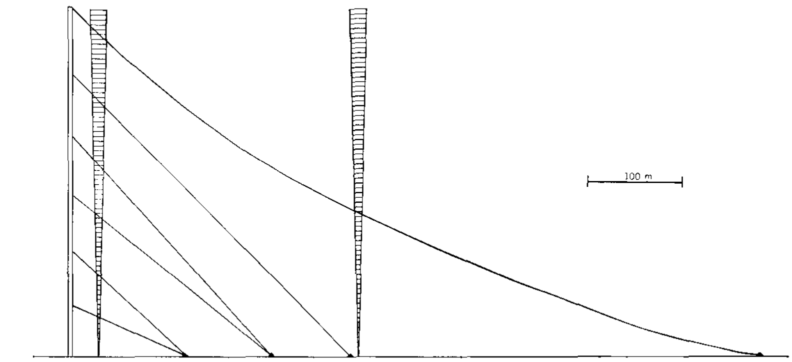

Fig. 1. Locations of the ceilometer observation sites at the Omega tower. The shaded areas represent the field of view of the spotting scope used in the study.

set on the tower at heights of 36, 123, 207, 285, and 326 m; and four red, flashing, 700-w beacons are at heights of 86, 168, 243, and 362 m. The tower site is described in detail by Avery et al. (1974).

Nighttime observations of migrants were made employing the portable ceilometer technique described by Gauthreaux (1969). We used two lamps powered by a 12-v battery during spring 1972 and one lamp and a 6-v battery thereafter. A 20 × 60 spotting scope was used throughout the study, and 7 × 35 binoculars were helpful in following movements of individual birds.

The effective range of our apparatus was estimated on a moonless night by suspending study skins of three species frequently killed at the tower, Sora (*Porzana Carolina*), Common Yellowthroat (*Geothlypis trichas*), and Savannah Sparrow (*Passerculus sandwichensis*), at various distances from the ceilometer on an unlighted, gravel road. With the spotting scope these skins were barely visible at a distance of 500 m.

To obtain comparable quantitative data on bird activity near the tower and away from it, each hour was divided into three 20-min periods. One period was spent watching near the base of the tower, another 305 m northeast of it, and the third was used for rest and changing locations. Occasionally two workers made simultaneous observations at the two sites. The location northeast of the tower was a convenient site at the end of an unlighted gravel service road leading away from the tower. There the ceilometer was beyond the outermost supporting guy wire but within the umbrella of the transmitting cables (Fig. 1). At the site 305 m from the tower, the height of the transmitting cables is only about 150 m. Because most nocturnal migration occurs at higher altitudes (Able 1970, Bellrose 1971), the majority of migrants seen away from the tower were probably unaffected by the cables.

Watches were conducted on an average of four nights per week during the periods 18 April–1 June and 19 August–26 October 1972 and 2 April–31 May and 16 August–27 October 1973. The watch usually began shortly before sunset; and its duration on a given night varied according to the physical condition of the investigator, the availability of freshly charged batteries, and the magnitude of the night's migration recorded in the early part of the evening. The watch was generally terminated if no migration was seen in the first 3 h.

Weather conditions were noted throughout each night. Three classes of cloud cover were recognized: clear (less than 1/10 cloud cover), partly cloudy (1/10–9/10), and overcast (greater than 9/10). Surface wind speed and direction were determined by means of a hand-held anemometer and a weather vane at the tower site. Additional weather data were obtained from the Federal Aviation Administration Flight Station, Jamestown, North Dakota, 72 km north-northwest of LaMoure.

Results of the paired hourly watch periods during fall 1972 and spring and fall 1973 were analyzed with the Wilcoxon signed ranks test (Conover 1971) to determine if differences existed between the number of migrants seen at the tower and 305 m northeast of it under each of the three conditions of cloud cover. Data from the spring of 1972 were not included in this analysis because too few watches were made at the tower.

A second analysis was performed to determine the effect of the tower on the direction that migrants were moving. This analysis included all birds seen in the study. The data were grouped by season (spring or fall), and within each seasonal group the sightings were divided into overcast or nonovercast (clear and partly cloudy) classes. These classes were subdivided by location (at the tower or 305 m to the northeast), resulting in eight distributions of flight directions. The directions were grouped by 30° sectors, and a mean direction was calculated for each of the eight distributions. After the length of the resultant vector and angular deviation were determined, Rayleigh's test was used to determine if each distribution differed significantly from uniformity (Zar 1974). The angular deviation is an index of the degree of tightness of the sample about the mean direction. In this analysis no attempt was made to account for possible night-to-night differences in the mean direction of migration.

The portable ceilometer technique proved ideally suited to this type of study. An attentive worker can record the movements of low-level migrants without difficulty. Once proficiency is attained, the only problem encountered is distinguishing birds from insects and bats. In our study when an object could not be positively recognized as a bird on the basis of form and manner of flight, it was disregarded.

It is conceivable that our ceilometer beam affected the behavior of migrants. Gauthreaux (1969) makes no mention of this, but occasionally birds away from the tower appeared momentarily disoriented in the beam. With the ceilometer off migrants at the tower, visible in the glow of the red warning lights, fluttered as they did with the ceilometer on. Furthermore, when the ceilometer was switched on, birds were present in the beam from the first moment; there was no gradual buildup in the beam as would be expected if they were attracted to it. Therefore, effects of the ceilometer on the observed behavior are believed to be minimal. Cochran and Graber (1958) reached the same conclusion regarding the spotlight they used.

Results

Ceilometer observations.—Table 1 summarizes the results of the paired ceilometer observations by season. On overcast nights throughout each season the number of migrants seen at the tower was significantly greater than the number seen 305 m to the northeast. On clear nights, the reverse was true. Differences between the numbers seen at the two locations on partly cloudy nights were not significant in the fall seasons. Undoubtedly on overcast nights some birds at the tower were recorded more than once because of their milling behavior, but it was impossible

TABLE 1

SUMMARY OF CEILOMETER OBSERVATIONS DURING THREE MIGRATION SEASONS AT THE OMEGA TOWER

Season	Cloud cover	Birds/hour Tower	Birds/hour 305 m	No. of paired watch periods	Level of significance (Wilcoxon)
Fall 1972	Overcast	23.4	2.1	21	0.01
	Partly cloudy	1.1	2.3	40	NS
	Clear	1.4	2.8	63	0.05
Spring 1973	Overcast	18.4	1.5	28	0.05
	Partly cloudy	0.9	2.0	37	0.05
	Clear	1.7	7.2	52	0.001
Fall 1973	Overcast	12.9	1.0	21	0.05
	Partly cloudy	3.3	2.3	21	NS
	Clear	1.1	5.2	61	0.001

to correct for this. We do not believe that this potential bias affected our results greatly.

Birds seen at the tower on overcast nights in the spring did not display a significant mean direction (Fig. 2C), but migrants seen away from the tower on overcast nights showed a significant mean northerly direction (Fig. 2D) similar to those exhibited by birds migrating on nonovercast nights (Figs. 2A, 2B).

Similarly, on nonovercast nights in the fall, virtually no difference existed between the mean flight directions of migrants at the tower and away from it (Figs. 3A, 3B). On overcast nights, migrants seen at the tower indicated a significant mean direction, although the angular deviation was so large as to cast some doubt on the reliability of this directional estimate (Fig. 3C). Only 27 fall migrants were recorded away from the tower on overcast nights with no significant mean direction indicated (Fig. 3D), i.e. the distribution did not differ significantly from uniformity.

In both spring and fall, the angular disperson was greater at the tower than away from it under each class of cloud conditions.

Behavior of migrants.—The majority of the migrants seen at the tower on overcast nights fluttered and milled about but were oriented mainly into the wind. These birds tended to face into the wind regardless of its direction and did so on all sides of the tower, which indicated that they did not orient themselves toward the red tower lights. Occasionally, a bird entered the field of view of the spotting scope, hovered briefly, and left the field of view at the same place it entered, moving sideways and facing into the wind the entire time. The characteristic pattern of flight was several wingbeats followed by a brief pause, permitting the

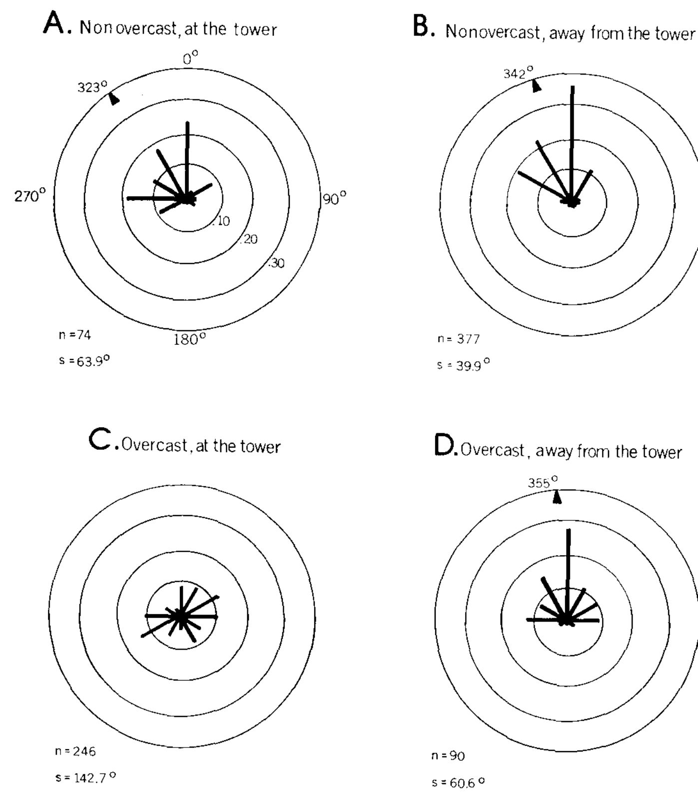

Fig. 2. Relative frequencies of flight directions of spring migrants recorded at the Omega tower site, 1972 and 1973. (Arrowheads indicate significant mean flight directions, $P \leqslant 0.05$; n = number of birds seen, s = angular deviation.)

birds to remain relatively stationary near the tower. This behavior occurred both when the tower was transmitting and when it was not.

On two occasions it was possible to follow the movements of migrants at the tower in greater detail. The morning of 26 August 1973 was foggy at dawn with a light southeasterly wind, and several birds were milling near the tower. Their movements were readily discernable with the naked eye because they were approximately 35 m high, near the first set of red tower lights. The lights were still on even though the sky was becoming light. The birds flew slowly upwind, frequently pausing and fluttering in place, to approximately 20 m southeast of the tower. Then they turned slightly and were blown downwind approximately 50 m northwest of the tower where they stopped and began the slow flight upwind again. As viewed from below, the birds moved counterclockwise

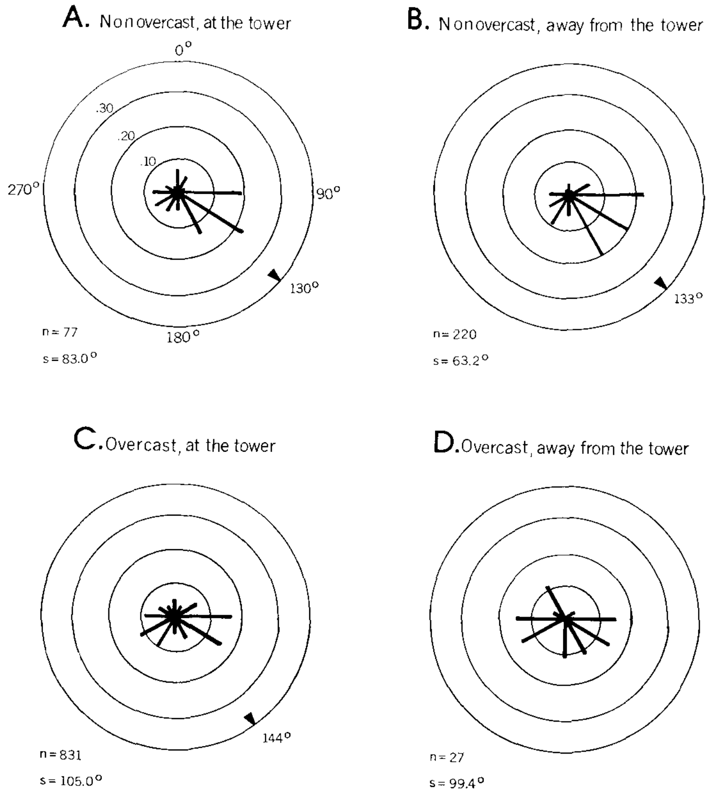

Fig. 3. Relative frequencies of flight directions of fall migrants recorded at the Omega tower site, 1972 and 1973. (Arrowheads indicate significant mean flight directions, $P \leqslant 0.05$; n = number of birds seen, s = angular deviation.)

in a narrow elliptical path. Flight calls were uttered frequently, which is characteristic of birds milling around a tower on overcast nights. This behavior was noted for about 15 min after which the birds were lost from view.

One month later, during the cloudy and rainy night of 25–26 September, movements of individual birds milling near the tower were watched by following them with a hand-held ceilometer. As before, the birds flew slowly upwind, occasionally fluttering in place or moving sideways, to a position near the tower. Then they turned slightly and were blown rapidly downwind, sometimes going well beyond the tower (65 m or more) before stopping and resuming their upwind flight. It seems likely that most losses under these conditions occur through collisions with the tower, guy wires, or other birds, as birds are blown rapidly downwind. This behavior helps to explain why both slow and fast moving birds were observed at the tower with the ceilometer and why the directions of birds seen there on overcast nights were so dispersed (Figs. 2C, 3C).

Other observations.—Twice in the course of the study, the relation of a clearing sky to the congregation of nocturnal migrants at towers was evident. The night of 6–7 September 1972 was overcast, and many birds (up to 30 seen in one 20-min period) were fluttering around the tower. At about 0340 CST, the sky began to clear and, simultaneously, the number of birds seen decreased sharply. In the 10-min period 0330 to 0340, 12 birds were recorded, but only three were seen from 0340 to 0345, and none was seen thereafter. Flight calls were not counted, but they decreased correspondingly.

On the night of 22–23 August 1973 at 2330, the overcast sky began to clear. From 2330 to 2335, 13 birds were seen at the tower, and 4, 1, and 0, were seen in the three successive 5-min periods. Similar behavior has been reported previously at a ceilometer (Laskey 1954) and at another tower (Kemper 1964). During one night, Clarke (1912: 295) observed that birds were attracted to a lighthouse beacon when the sky was overcast and droplets of moisture in the air refracted light from the beacon. When overcast conditions passed, the beam was barely visible and birds passed by, unaffected by it.

The tower was not transmitting during the night of 22–23 August 1973, and from 2207 to 2227, 81 birds were recorded with the ceilometer. The red tower lights were then turned off, and from 2230 to 2235 only six birds were seen. There were also decidedly fewer flight calls in this period. The lights were turned on again, and in the next four 5-min periods, 17, 25, 34, and 25 birds were seen. These findings corroborate those of Cochran and Graber (1958), who noticed that the number of flight calls of migrants at a tower decreased when the tower lights were turned off but "increased dramatically" within minutes after the tower was relighted.

Discussion

Circumstantial evidence exists for the belief that the congregation of nocturnal migrants at towers is related to their ability to orient using celestial cues. The majority of instances of wholesale "attraction" occur on overcast nights when celestial cues are not available to birds flying below the cloud ceiling. Thus, they may be drawn to these bright, red points of light at appropriate altitudes, perhaps mistaking them for stars. Furthermore, as noted earlier, when a previously overcast sky clears, birds leave the tower, presumably guided once more by the appropriate star cues.

This theory presents several difficulties. The behavior is evoked by a wide variety of stimuli. Lights of different colors (red and white), flash rates (including nonflashing), heights, intensities, and configurations all seem to elicit similar phototactic responses in nocturnal migrants. Experimental evidence exists for the abilities of various nonpasserines to distinguish between lights of different wavelengths (e.g. Laughing Gull chicks, *Larus atricilla*, Hailman 1967; Peking and Mallard ducklings, *Anas platyrhynchos*, Oppenheim 1968), flash rates (Rock Dove, *Columba livia*, Granit 1955), and intensities (Rock Dove, Mentzer 1966). Except for the Starling, *Sturnus vulgaris* (Adler and Dalland 1959), the visual capacities of nocturnally migrating passerine species (the birds most affected by towers and other lighted structures) have not been determined. That the various types of lights all appear identical to passerine migrants, however, seems improbable. Nor is it likely that nocturnal migrants, when orienting or navigating, confuse red tower lights or ceilometer beams with stars. In addition, Emlen (1967) has shown that certain star patterns, not individual stars, are sufficient for correct orientation in the Indigo Bunting, *Passerina cyanea*. Tower lights are not likely to be mistaken for specific groups of stars.

The most acceptable explanation of this phenomenon is that presented by Graber (1968). Migrants are not attracted to towers in the sense of being drawn from a distance. Instead, those passing nearby on a cloudy night enter an illuminated area that they are reluctant to leave, much as birds in a lighted room will not fly out of an open window into the darkness. Approaching the edge of the illuminated area, migrants are hesitant to fly into the darkness beyond and instead fly back toward the tower. Inevitably, some strike the tower, guy wires, or other birds and are killed or injured.

On foggy or overcast nights, minute moisture droplets refract light from the tower, greatly increasing the effective illuminated area and therefore arresting more migrants. This probably explains why nearly all mass tower kills occur on overcast nights and why migrants disperse when the sky clears or the ceiling lifts (Laskey 1954). Thus, the increased illuminated area caused by the low clouds, rather than the absence of visible star cues, may be the basis for the correlation of mass tower mortality with overcast skies.

Results presented in this paper (Table 1) provide quantitative evidence that on some overcast nights, migrants congregate around the red warning lights of tall towers. In contrast we consistently recorded significantly fewer birds at the tower than away from it on clear nights. This has not been reported previously and indicates that migrants actively avoided the tower under nonovercast conditions. The greater dispersion of flight directions at the tower than away from it (Figs. 2, 3) suggests that the birds may have been altering their flight paths in the vicinity of the tower in order to avoid it, guy wires, or other birds.

We did not notice any effect of the tower's signal on birds. Our results indicate strongly that the tower lights are the sole factor involved in the congregation of birds. The milling behavior of the migrants occurred both when the tower was transmitting and when it was not. Unfortunately, neither the Omega tower nor the TV tower studied by Cochran and Graber (1958) was transmitting when tests were made with the tower lights off. On the basis of these findings alone, possible effects of the tower's signal on migrants cannot be completely dismissed.

Only two colors of light, red and white, have been involved in reported mass bird kills. Both Clarke (1912) and Lewis (1927) found white beacons, especially flashing ones, on lighthouses and lightships to be more deadly than red beacons. According to Clarke (1912: 25), "When the Galloper lightship has white lights, great numbers of birds were allured to its lanterns, but now that the light is red, bird-visitors are almost unknown." In view of these observations, the effect on nocturnal migrants of white strobe warning lights on towers deserves attention. Several towers are currently equipped with such lights and though they are more readily visible to pilots than are conventional red lights, their effect on birds has not been assessed. If these strobe lights are similar to the flashing beacon on the Dungeness Lighthouse (Baldwin 1965), their use may decrease bird losses at towers. We know of only one tower equipped with white strobe lights that is being monitored for bird losses. James Baird of the Massachusetts Audubon Society reported (pers. comm.) that mortality at a TV tower near Boylston, Massachusetts did not appear to increase when the red warning lights were replaced with white strobe lights in April 1973.

Results presented in this paper provide the most complete description yet of the behavior of nocturnal migrants at a tall tower. But the primary question of what features of lights cause birds to congregate at tall lighted structures under overcast conditions is still unanswered. Further understanding of this phenomenon is possible through a controlled, experimental approach including field tests of the reactions of birds to lights of various wavelengths, intensities, and flash rates on towers under various cloud conditions. Following the movements of individual birds equipped with radio transmitters as they approach a light at various distances and headings may be one useful method. Without such research the nature of phototactic responses in nocturnal migrants will remain speculative, and the development of effective preventive measures to reduce bird losses at towers will be difficult.

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SUMMARY

The results of a study of nocturnal migration during four migration seasons using a portable ceilometer at a 366-m tower in southeastern North Dakota were:

On overcast nights significantly more migrants were seen at the tower than at a site 305 m northeast of it. Conversely, on clear nights significantly more birds were seen away from the tower than at it, which indicates that migrants actively avoided the structure on such nights.

On nonovercast nights, the mean flight directions of migrants were similar at the tower and away from it, whereas the flight directions of birds seen on overcast nights tended to be more dispersed.

Birds seen at the tower on overcast nights generally oriented into the wind and remained close to the tower by fluttering or hovering. Birds did not circle the tower or orient toward the red tower lights.

On two overcast nights, when hundreds of birds congregated at the tower, the migrants were at the tower both when the tower was transmitting and when it was not, which indicates that the signal transmitted by the tower had little, if any, role in migrants' congregating there.

From these results, it is believed that on overcast nights, migrants are not attracted to tall lighted structures simply because celestial cues are unavailable. Rather, the refraction of light by moisture droplets in the air on cloudy nights greatly increases the illuminated space around a tower, and the migrants are arrested within a lighted area that they are reluctant to leave. As they mill about, collisions with the structure and other birds may result in mass mortality. To obtain a fuller understanding of this phenomenon and to develop means for preventing mortality of nocturnal migrants at towers, carefully designed experiments with various types of lights are necessary.

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