Avian collisions at communication towers: I. The role of tower height and guy wires

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Prepared for:

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Abstract. The study reported herein is the first controlled or “experimental” study to examine the relative risks that tower support systems and tower height pose to migrating and other birds. Data comparing tower support systems (guyed vs. self-supported/unguyed) and tower height categories were collected in Michigan during 20 days of the peak of songbird migration at 6 towers in September-October 2003, 23 towers in May 2004, 24 towers in September 2004. 6 towers in May 2005, and 6 towers in September 2005. A separate report focuses on the role of FAA lighting on avian collisions with communication towers. Each tower was systematically and simultaneously searched for bird carcasses, starting at dawn. Carcass removal or scavenging rates and observer detection rates were measured at each tower during each season. Twenty-one towers between 116 and 146 m were part of the Michigan Public Safety Communication System (MPSCS) and the three towers >305 m were private broadcast (television) towers. During the five 20-day sample periods a mean of 8.2 birds per tower was found dead under guyed coiiimunication towers 116-146 m Above Ground Level (AGL), while a mean of 0.5 birds per tower was found under unguyed towers 116-146 m AGL during 3 seasons. Four 20-day sainple periods detected a mean of 34.7 birds per tower under guyed towers >305 in AGL. Using both parametric and nonparametric tests (Mann-Whitney U-test, Kruskal-Wallis test, and Tukey’s Honestly Significant Difference multiple comparison procedure) we determined that unguyed towers 116-146 m AGL experienced significantly fewer fatalities than towers of the same height that were guyed. Approxiniately 54 - 86% fewer fatalities were registered at guyed towers 116-146 m as opposed to guyed towers >305 in. Nearly 16 times more fatalities were found at guyed towers 116-146 m in height as opposed to unguyed towers of the same height. Tall guyed towers were responsible for about 70 times as many birds fatalities as the 116-146 m unguyed towers and nearly 5 times as many as guyed towers 116-146 m. These data provide managers and regulators with the first quantitative data for establishing best practices to minimize collision fatalities of migrating and other birds at federally licensed communication towers.

Introduction

Avian fatalities have been documented at communication towers for more than 55 years (Aronoff 1949, Bernard 1966, Avery et al. 1980, Shire at al. 2000, Kerlinger 2000). Past research suggests that birds, primarily night migrating songbirds, collide with towers of varying heights, especially when night skies are overcast, foggy, or when there is precipitation (Caldwell and Wallace 1966, Avery et al. 1976, Larkin and Frase 1988, Kruse 1996). Large-scale events involving dozens to hundreds of birds have been recorded during inclement weather. However, birds also collide with towers or guy wires on clear nights. It is believed that large numbers of night migrants can be attracted to or disoriented by the lights of tall structures, such as communication towers (Larkin 2000), resulting in collisions.

Banks (1979) estimated that 1.25 million birds per year collided with communication towers, although a recent estimate cites 4-5 million or more birds per year (Manville 2001, Kerlinger 2000). Banks' estimates were derived from sporadic studies at eight guyed towers >800 feet Above Ground Level (AGL). Some of the studies available to Banks recorded thousands of birds colliding with individual towers during a single night of migration (Breckenridge 1958, Bernard 1966, Kemper 1964). Shire et al. (2000) compiled documented cases of bird mortalities at about 50 tall guyed communication towers in the U.S. and tallied about 230 species.

The study reported herein was the first to examine bird collisions with communication towers in which multiple independent variables were examined. We examined the relative roles of tower height (1 16-146 m AGL vs. >305 m AGL) and tower support system (guyed vs. unguyed/self-supported) with respect to numbers of bird fatalities by searching for fatalities under all study towers on the same mornings. Of these two variables, the role of guy wires had been previously examined by mapping the location of fatalities in relation to guy wires (Avery 1976, Kruse 1996, Kerlinger 2000). The approach used in our study was unique because it was the first to control for confounding temporal variables (seasonal and daily variation in migration volume) by conducting simultaneous searches at nearly two dozen towers. The results of this study provide the first quantitative information available regarding the relative magnitude of fatalities at towers of the same height with and without guy wires as well as between mid-sized towers with guy wires and tall towers with guy wires. (In a separate report we examined the role of Federal Aviation Administration [FAA] obstruction lighting with respect to avian collisions with communication towers.)

Data collected in 2003, 2004, and 2005 addressed the following predictions:

1. Communication towers supported by guy wires are responsible for more bird fatalities than towers lacking guy wires (unguyed/self-supported).
2. Communication towers >305 m AGL (tall towers) are responsible for more bird f fatalities than towers 116-146 m AGL (medium sized towers).

Study Area and Methods

Tower selection and description

Research was conducted at communication towers distributed throughout Michigan, USA (between: 46" 33.85' N, 90° 25.06' W and 41" 44.48' N, 83° 28.51' W; Fig. 1). To test for differences in the numbers of bird fatalities at towers of different heights we selected towers within two height categories: 116-146m AGL and >305 in AGL. Towers 116-146 in AGL were part of the Michigan Public Safety Communications System (MPSCS), whereas the taller (>305 m AGL), guyed, towers were television broadcasting towers. All of the towers 116-146 in AGL had the same tower lighting systems from dusk to dawn: one strobe-like, flashing red (L-864) beacon at the top and two strobe-like, flashing red (L-864) beacons at the one-halfheight of the tower; two steady burning (L-810) red lights at one-third and two at the three-quarter height of the tower; FAA 2000). The guyed towers >305 m AGL were equipped with the most common lighting used at older communication towers in the U.S.: a combination of red L-864 beacons and red L-810 lights alternating in levels. However, the L-864 flashing beacons on the tall towers were incandescent lights that dimmed as they flashed, instead of strobing (going completely black between flashes) like those on the MPSCS towers.

Considering that the majority of tower collisions are thought to occur during migration, technicians sampled for carcasses on 20 consecutive days capturing the peak period of spring and fall migration. During fall 2003 (15 September - 4 October) three guyed and three unguyed 116-146-in AGL towers were searched. During spring 2004 (10 - 29 May) 11 guyed and 9 unguyed 116-146-in AGL towers, and three guyed towers >305 in AGL were searched. and during fall 2004 (7-26 September) 12 guyed and nine unguyed 116-146-m AGL towers and three guyed towers >305 m AGL were searched (Fig. 1). During spring (10-29 May) and fall (7-26 September) 2005 three guyed 116-146 m AGL and three guyed >305 m AGL towers were searched. The MPSCS towers searched in 2004 and 2005 were randomly selected from approximately 150 MPSCS towers within the 116-146-111 height category after stratification for tower support system (guyed and unguyed). If a randoinly selected tower was within I.6 km of an extensively-lighted area (e.g., large urban area with sky glow) it was eliminated from the sample and another tower was selected randomly. This procedure prevented a situation where communication tower lights might be less visible to birds or "washed-out" due to the bright lights and sky glow of surrounding areas (Caldwell and Wallace 1966). Similarly, we excluded those towers associated with tower farms (additional communication tower(s) within 0.8 km) and ridge tops to avoid potentially confounding variables. Towers >305 m AGL were selected based on access, granted by tower owners, as well as towers being widely dispersed tlirougliout state. We were requested by the U.S. Fish and Wildlife Service and the Kirtland's Warbler Recovery Team to include two non-randomly selected towers: one was located on a site believed to have high songbird migration traffic and the second was within the breeding range of Kirtland's Warbler (*Dendroica kirtlandii*) an endangered species. Randomly selected towers south of the latter area also allowed sampling for potential collisions of this endangered species.

Carcass searches

Technicians arrived at towers at or before dawn to prevent diurnal and crepuscular scavengers from removing carcasses. All towers were searched simultaneously during the study periods and each technician searched at the same tower every day. Using flagged, straight-line transects, technicians walked at a rate of 45-60 in per min and searched for carcasses within 5 m on either side of the transects (Gehring 2004, Erickson et al. 2003). Transects covered a circular area under each tower with a radius equal to 90% the height of the tower, slightly beyond the lengths of guy wires. Carcasses were placed in plastic bags, and the following information recorded: tower identification number, date, closest transect, distance from tower, azimuth to the tower, estimated number of days since death, and observer's name. Once bagged and labeled, carcasses were frozen for later identification and verification of species. Appropriate USFWS and Michigan Department of Natural Resources (MDNR) permits were secured. Institutional Animal Care and Use Committee protocol was approved (#07-03) via Central Michigan University (CMU).

Observer detection and carcass removal trials

Because technicians do not detect all bird carcasses under communication towers due to dense vegetation, observer fatigue, human error, and scavenging by predators, we quantified each technician's observer detection rate (searcher efficiency) and the rate of carcass removal by scavengers (Erickson et al. 2003). Observer detection trials were conducted for technicians at their designated tower once each field season. Placing 10 bird carcasses within the search area, we determined the percentage of carcasses detected by each technician during each field season and at each tower. For observer detection trials we used bird carcasses representing a range in size and colors, mostly Brown-headed Cowbirds (*Molothr-us ater*) painted to simulate the fall plumage of migrating songbirds. Bird carcasses used for observer detection trials were also painted with an "invisible" paint that glowed fluorescent colors when viewed under a black light. Once birds were collected by the technicians and collected in the laboratory the "invisible" paint prevented confusion between birds that had collided with the towers and detection trial birds.

Similarly, technicians randomly placed 10-15 Brown-headed Cowbird carcasses immediately adjacent to their designated communication tower's search area and monitored the removal (e.g., scavenging) of carcasses daily during the study period. Using these data we calculated a scavenging or removal rate (Erickson et al. 2003). Brown-headed Cowbirds used in the removal trials were not painted. Both observer detection trial birds and removal trial birds were placed in a range of habitats representative of the individual tower search area.

Statistical analyses

We used the Mann-Wliitney U-test to test for differences in the fall 2003, spring 2005, and fall 200.5 data, and the Kruskal-Wallis test combined with Tukey's Honestly Significant Difference (HSD) multiple coinparison procedure to test for differences within the spring 2004 and fall 2004 data (Zar 1998). Raw data were used when testing for significant differences among tower types, rather than data adjusted for scavenging and observer detection rates. We used bootstrapping (5,000 iterations) to estimate the mean and standard deviation of the observer detection rates (Erickson et al. 2003, Manly 1997). Using methods developed by W. Erickson (WEST, Inc.), we used the mean observer detection rate and the carcass removal rate specific for each individual tower to calculate adjustment multipliers by which to correct the observed number of birds per tower. This adjustment method considered the probability that carcasses not found on one day could be found on the following days, depending on the rate of carcass removal (W. Erickson pers. comm.). These two interacting variables were used to determine an average carcass detection probability and the related adjustment multiplier specific to each tower. The statistical software SPSS was used for analysis and $a = 0.05$ (SPSS 2001).

Results

During fall 2003, searches at six towers detected 22 birds of 11 species (Table 1 and Appendix 1). In spring 2004 searches at 23 towers detected 197 birds representing 47 species (Table 2 and Appendix 1), whereas in fall 2004 156 birds were detected at 24 towers, comprising 42 species (Table 3 and Appendix 1). In spring and fall 2005 (six towers each season), 169 and 138 birds of 40 and 36 species were detected, respectively (Table 4. 5 and Appendix 1). Night-migrating songbirds collided most frequently with communication towers, accounting for about 92% of all carcasses found. (Appendix 1). In fall 2003 Red-eyed Vireos (*Vireo olivaceus*) and Magnolia Warblers (*Dendroica magnolia*) were the most common species found. Similarly, in spring 2004 the two most common species were Red-eyed Vireos and Ovenbirds (*Seiurus aurocapillus*). In the fall of 2004 Blackpoll Warblers (*Dendroica striata*) and Ovenbirds were the most common tower fatalities. In the spring of 2005 Red-eyed Vireos and Gray Catbirds (*Dumetella carolinensis*) were the two most common species found while Red-eyed Vireos and Blackpoll Warblers were the most common in the fall of 2005. The majority of carcasses were Passeriformes (69%). but also included small representations of Anseriformes (1%), Falconifonnes (<1%), Galliformes (<1%), Charadriiforines (<1%), Columbiformes (1%), Cuculiformes (<1%), Caprimulgiformes (<1%), Piciformes (<1%), and the mammalian order Chiroptera (<1%). (The relationship between FAA obstruction lighting and bird collisions is examined in a separate report.)

Three bats were found during the fall of 2004 study period. One bat carcass was found at each tower type. The species included: little brown myotis (*Myotis lucifugus*), red bat (*Lasiurus borealis*), and big brown bat (*Eptesicus fuscus*). No bats were included in Table 3, Appendix 1, the descriptive statistics or statistical comparisons.

One of the towers >305 in AGL searched in the spring of 2004 had an "antique" guy system design that is no longer used. Towers of this size constructed today have six sets of guy wires and guy anchor points instead of the three sets supporting this "antique" tower (R. Thomas pers. cornin.). This tower also presented access difficulties and had landscape features that prevented adequate carcass searches. Only three bird carcasses were found under this tower and it was therefore considered an outlier, removed from further statistical analysis and replaced in the fall of 2004 field season with a tower more representative of most towers >305 m AGL.

Occasionally, birds found under towers appeared to have been killed by predators (e.g., Cooper's Hawk, *Accipiter cooperii*) and plucked at the site. If the species of the dead bird was a typical prey item of an avian predator, like Cooper's Hawk, and if the shafts of the plucked feathers had beak impressions the specimen was removed from further analyses. We included summary statistics of data both with and without these questionable birds (Table 3).

When comparing bird fatalities among tower types the two previously mentioned outliers were removed (i.e., unique tower >305 m AGL in the spring of 2004, and the three predator killed birds under an unguyed tower in the fall of 2004).

A Mann-Whitney U-test determined that in the fall of 2003 unguyed towers 116-146 m AGL were associated with lower bird fatality rates than guyed towers in tlie same height category (U = 0.00, P = 0.037). Similarly. Kruskal-Wallis tests found significant differences among tower types in both the spring of 2004 (χ^2_2 = 16.839, P $\leq$ 0.001) and the fall of 2004 (χ^2 = 15.614, P $\leq$ 0.001). In the spring of 2004 all 3 tower types were statistically different from one another. Guyed towers >305 m AGL were responsible for more bird fatalities than both guyed (P $\leq$ 0.001) and unguyed (P $\leq$ 0.001) towers 116-146 m AGL. Similarly, more birds were found under guyed towers 116-146 m AGL than unguyed towers in the same tower height category (P = 0.01). Data collected in the fall of 2004 also demonstrated that guyed towers >305 m AGL were associated with higher bird fatalities than both guyed (P $\leq$ 0.001) and unguyed (P $\leq$ 0.001) towers 116-146 m AGL. Although the data followed the same trends as the spring 2004. low levels of bird fatalities at the majority of towers 116-146 in AGL in the fall of 2004 resulted in non-significant differences in bird fatalities between guyed and unguyed structures (P = 0.12). Despite a non-significant difference statistically, the rate of fatalities at guyed towers was approximately three times greater per tower than at the unguyed towers. Data collected in the spring of 2005 again demonstrated significant differences between guyed towers >305 m AGL and guyed towers 116-146 m AGL (W = 6.0, P = 0.040). Liltely due to small sample sizes and a potential outlier, data collected in the fall of2005 was not significantly different between guyed towers >305 m AGL and guyed towers 116-146 m AGL (W = *7.5*, P = 0.138). Despite not being statistically significant, more than six times as many fatalities were registered at the guyed towers >305 m than at guyed towers 116-146m.

The mean observer detection rate (via bootstrapping) was 0.48 (SD = 1.10, N = 6)) in the fall of 2003, 0.40 (SD = 0.03, N = 28) in the spring of 2004, and 0.27 (SD =0.03, N = 28) in the fall 2004. Technicians studying towers in the spring and fall of 2005 had mean observer detection rates of0.31 (SD =0.04, N = 28) and 0.24 (SD –0.31, N = 28), respectively. Carcasses placed near the tower search area for removal trials (e.g., scavenging) remained on the ground a mean of 6.10 days (SD = 2.73, N = 1) in the fall of 2003, 5.66 days (SD = 2.53, N = 23) in the spring of 2004, and a mean of 6.89 days (SD = 3.07, N = 24) in the fall of 2004. In spring and fall of 2005 carcasses remained on the ground for means of 8.61 days (SD = 4.88, N = 24) and 6.69 days (SD = 2.98, N = 24), respectively. Including both observer detection rates and carcass removal rates we estimated the adjustment multipliers specific to each tower to range between 1.76 and 2.04 (mean = 1.92, SD = 0.14) in the fall of 2003, 1.23 and 2.63 (mean = 1.68, SD = 0.37) in the spring of 2004, and 1.24 and 3.41 (mean = 2.00, SD = 0.55) in the fall of 2004. In the spring of 2005 multipliers ranged between I. 18 and 2.83 (mean =1.74, SD = 0.52), while the fall of 2005 ranged between 1.58 and 5.07 (mean = 2.45, SD = 0.87). Because there was low variability among towers in carcass removal and detection rates, and those rates are distributed among tower types, the statistical analyses for comparisons of tower types were done using the raw carcass data.

Table 1. The numbers of bird carcasses found at 6 Michigan communication towers between 15 September and 4 October 2003.

Tower support	**Height category AGL**	**Numbers of towers searched**	**Numbers of carcasses found**
Unguyed	116-146 m	3	0 (inean = 0.0, SE = 0.0)
Guyed	116-146 m	3	22 (mean = 7.3, SE = 1.2)
Total		**6**	**22**

Table 2. The numbers of bird carcasses found at 23 Michigan communication towers between 10 and 29 May 2004.

Tower support	**Height category AGL**	**Numbers of towers searched**	**Numbers of carcasses found**
Unguyed	116-146 m	9	5 (mean = 0.6, SE = 0.2)
Guyed	1 16-146 m	11	121 (mean = 11.0, SE = 2.6)
Guyed	≥305 m	3 (2)[a]	71 (mean = 23.7, SE = 11.8) (68; mean = 34.0, SE = 10)[a]
Total		**23 (22)”**	**197 (194)”**

[a] data with outlier tall tower removed

Table 3. The numbers of bird carcasses found at 24 Michigan communication towers between 7 and 26 September 2004.

Tower support	Height category AGL	Numbers of towers searched	Numbers of carcasses found
Unguyed	116-146 m	9	12 (mean = 1.33, SE = 0.62) 9 (mean = 1.00, SE = 0.33)[a]
Guyed	116-146 m	12	51 (mean = 4.25, SE = 0.65)
Guyed	≥305 m	3	93 (mean = 31.00, SE = 5.86)
Total		**24**	**156** **(153)[a]**

[a] data without birds likely killed and plucked on site by raptor.

Table 4. The numbers of bird carcasses found at 6 Michigan communication towers between 10 and 29 May 2005.

Tower support	Height category AGL	Numbers of towers searched	Numbers of carcasses found
Guyed	116-146 m	3	37 (mean = 12.3, SE = 4.84)
Guyed	≥ 305 m	3	132 (mean = 44.0, SE = 11.55)
Total		**6**	**169**

Table 5. The numbers of bird carcasses found at 6 Michigan communication towers between 7 and 26 September 2005.

Tower support	Height category AGL	Numbers of towers searched	Numbers of carcasses found
Guyed	116-146 m	3	18 (mean = 6.00, SE = 2.65)
Guyed	≥ 305 m	3	120 (mean = 40.00, SE = 18.03)
Total		**6**	**138**

Discussion

Although bird collisions with communication towers have been documented since 1949 (Aronoff 1949, Bernard 1966), studies were not designed in a manner that would permit the testing of hypotheses regarding tower variables including structural characteristics or specifications. The present study represents the first study designed to test and quantify differences between towers of different heights and towers with and without guy wires.

Our results are consistent with the prediction that guyed towers are associated with higher bird fatality rates than unguyed towers. According to these data bird fatalities may be prevented by 69% -100% by constructing unguyed towers instead of guyed towers. These results are consistent with results reported by Kruse (1996), who plotted the location of migrant bird carcasses under three guyed communication towers. Kruse (1996) found a significant positive correlation between the locations of tower guy wires and bird carcasses, thus supporting the hypothesis that birds collide mostly with the tower guy wires. Although our data from the fall of 2004 supported this trend, the lack of detected statistical difference using multiple comparisons may be the result of an overall lower tower fatality rate at all towers 116-146 m AGL during this field season. According to the National Oceanic and Atmospheric Administration, Michigan's September 2004 was the 2nd driest month in 110 years (www.noaa.gov). Previous research suggests a positive relationship between foggy or cloud-covered nights and bird collisions with communication towers (Avery et al. 1976, Larltin 2000). Therefore. it is possible that this atypically clear Michigan fall resulted in fewer bird-tower interactions than what might have occurred during a typical fall migration season.

It is also important to consider that although bird fatalities were much lower at unguyed towers, it is possible that some birds were attracted to and circled around these structures displaying behaviors similar to those observed at other towers with FAA lights (Larltin and Frase 1988, Gauthreaux 2006). The implication of this energy-consuming behavior on the survival of individual migrating birds is unknown. A second report (Gehring and Kerlinger 2007) will focus on the relationship between tower light systems and bird fatalities; thereby, providing additional information on possible inethods of preventing the attraction of birds to towers, and the negative impacts resulting from those light systems.

Our results also support the prediction that many more avian collisions occur at taller towers. Data indicate that 68%-86% fewer fatalities were registered at guyed towers 116-146 m AGL than at towers > 305 in AGL. Similarly, a long-term study at a communication tower in Florida detected a dramatic decrease in bird fatalities after the tower height was decreased from 308 m to 91 m AGL (Kerlinger 2000). Night-migrating songbirds typically fly between about 91 in and 610 m AGL, depending on cloud cover, wind velocity, and other factors (Kerlinger and Moore 1989). It is possible that the study towers >305 m AGL impacted more migrants because their height included a greater portion of the altitude at which migrants fly. Towers 116-146 m AGL may have impacted only those birds migrating in the lower ranges of migration altitudes due to low cloud cover or wind velocity. This is supported by the low numbers of bird mortalities observed at guyed study towers 116-146 m AGL during the unusually clear, cloudless, fall of 2004 field season, when the birds could have been flying higher.

The comparison of bird fatalities at towers of different height categories may be confounded by the difference in tower lighting systems between the two categories. A separate report will examine the relationship between avian fatalities at communication towers and tower lighting systems (Gehring and Kerlinger 2007).

During our study periods in fall 2003, and spring and fall 2004 and 2005, technicians did not observe any large bird fatality events like those involving hundreds (or even dozens) of birds reported elsewhere. In our study, the largest one night fatality events at individual towers included two nights during which 11 and 16 fatalities were found at towers >305 m AGL during 2004 and 2005, respectively. Most fatalities involved single individuals on given days. These fatalities, though they may not be the spectacular events that trigger newspaper headlines, occur continuously throughout the migration season. The absence of large-scale fatality events in our database appears to be consistent with the documented decrease in large bird fatality events since the early 1980s (Nehring 1998, Morris et al. 2003) and may be related to the fact that many species of night migrants have declined in past decades.

Few other studies of avian collisions with communication towers have quantified observer detection rates and carcass removal rates (FCC 2005). However, recent research on avian and bat fatalities at wind turbines provides a source of comparison. When considering birds similar in size to those which typically collide with communication towers (e.g., warblers, vireos), Johnson et al. (2002) determined that observers working under wind turbines detected a mean of 0.29 of the carcasses and the mean length of time a carcass remained on the ground was 4.69 days. This is similar to the observer detection and removal rates determined in this study. Multiplier rates can be used to better understand the number of carcasses likely missed at each tower per field season due to both observer detection rates and carcass removal. The numbers of fatalities presented in this report do not reflect these adjustments. Adjustments for observer detection and scavenging rates would increase our estimates of fatalities at the towers we studied. These adjustments were not needed for our statistical analyses because the rates were similar among sites and did not materially change the results of the analyses.

The diversity of species that collided with communication towers in 2003-2005 study was consistent with other similar research (Shire et al. 2000, FCC 2005). The large proportions of Red-eyed Vireo, Ovenbird, Swainson's Thrush (*Catharus ustulatus*), and Magnolia Warbler (*Dendroica magnolia*) carcasses observed under towers may be related to the relative abundances of these species migrating through the region during the sample periods. It is likely that additional species collided with the study towers but were not detected due to removal of carcasses by scavengers and observer detection errors. In addition, this study was designed to encompass the peak of neotropical songbird migration; thereby, potentially missing the peak migration periods of several species including many of the migrants that do not fly south of the United States.

Comparisons of bird fatalities at towers with different support systems and at towers in different height categories may be confounded to some degree by the migration intensity at each site. The fact that study towers with different support systems and towers of different heights were spread over such a large geographic area strongly suggests that our results and conclusions are representative of the fatality numbers and species composition at the types of towers we studied. We feel that tower studies conducted in other geographic settings would be valuable for replication and validation of our results.

Our findings are likely to be generally applicable to towers shorter and taller than those that we studied. In other words, towers of any height with guy wires are responsible for inore fatalities than towers without guy wires and taller towers are responsible for more fatalities than shorter towers (of the same support structure). However, future research on avian collisions with communication towers should examine tower heights between 146 m and 305 in AGL, as well as towers shorter than 116 m and taller than –350 m AGL. If conducted, a methodology similar to ours should be used to facilitate geographic and structural comparisons of' fatality rates of night migrants.

Given the increasing number of communication towers in the U.S. and a growing interest in addressing the bird collision issue, this study is of particular importance (Shire et al. 2000, Erickson et al. 2001, FCC 2003, *2005, 2006).* Our results show that bird fatalities may be reduced by 69% to nearly 100% by constructing unguyed towers instead of guyed towers, and 54%-86% by constructing guyed towers 116-146 m AGL instead of guyed towers >305 m AGL. This infomiation is the most useful provided to date for mitigating and preventing avian fatalities at towers. This research provides quantitative information necessary to the FCC, the National Environmental Policy Act (NEPA) responsible agency that governs communication towers (FCC 2005). The present study also provides regulatory bodies, trust agencies, and other stakeholders with quantitative and statistically valid information regarding the relative risk of towers of different heights and towers with and without guy wires. This information can be directly applied to future tower design, siting, licensing, and permitting and would reduce substantially the numbers of fatalities of migratory and nonmigratory birds resulting from tower collisions.

Acknowledgements

Many dedicated, enthusiastic, and hard working technicians conducted the predawn searches under communication towers. Their efforts made this research possible. The value of this study was greatly enhanced by the tower engineers and owners who have granted permission to access privately owned towers. We appreciate the recruiting and advertising assistance of Michigan organizations and Internet list servers. P. Kerlinger (Cui-ry & Kerlinger, LLC) designed and wrote the original research proposal upon which this study is based. Many individuals regularly provide ideas, suggestions, and support for this project, including but not limited to: A. Manville

(USFWS), T. Gehring (CMU), C. Czarnecki (USFWS), S. Lewis (USFWS), C. Mensing (USFWS), B. Fisher (USFWS), G. Winegrad (American Bird Conservancy (ABC)), C. Schumacher (United States Forest Service (USFS)), E. Paul (Ornithological Council), J. Dingledine (USFWS), P. Lederle (MDNR), D. Wang (CMU), R. Rustem (MDNR). M. Herbert (MDNR), and J. Janson (MDNR). The State of Michigan (including Michigan State Police) granted their financial support, permission to access MPSCS tower sites. and tower information. Our thanks to M. Scieszka, I. Lopez (both State of Michigan), and P. Ryan (Perkins Coie) for their contributions to the project. We would like to express our heartfelt gratitude to the USFWS, the MDNR and the National Fish and Wildlife Foundation (NFWF) for granting additional hinds to improve this project. F. Moore (University of Southern Mississippi (USM)), M. Avery (United States Department of Agriculture), G. Winegrad (ABC), R. Rustem (MDNR) and an anonymous reviewer made time to provide official reviews for the NFWF grant proposal procedure. Logistical assistance was provided by the FAA, FCC, and M. Curry (Curry & Kerlinger, LLC). Members of the Communication Tower Working Group and the Kirtland's Warbler Recovery Team provided ideas and suggestions. The Michigan Department of Natural Resources, USFWS, CMU and the USFS provided the permits necessary to complete this research. The avian species identification data were validated by C. Putnam. Central Michigan University provided necessary logistical support. W. Erickson (WEST, Inc.) generously provided suggestions, and advice regarding many aspects of this research. The use of NEXRAD technology is possible via the assistance and knowledge of R. Diehl (USM).

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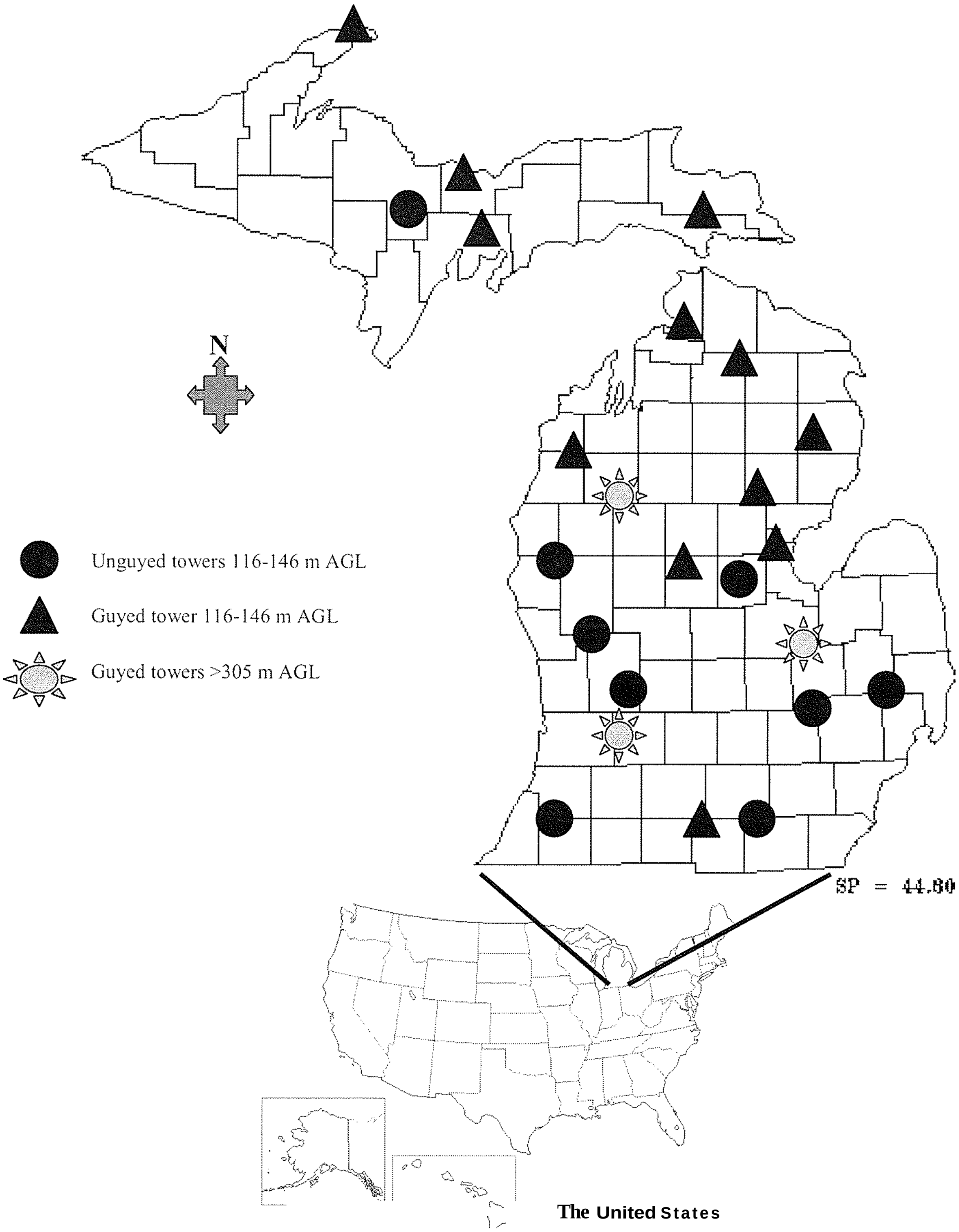

Figure 1. Map of communication towers included in study of avian collisions in Michigan, USA.

Appendix 1. Avian mortalities (by species) at Michigan communication towers during 20 days of migration.

Bird Species[a] and Number of carcasses found	**Fall 2003 (6 towers)**	**Spring 2004 (23 towers)**	**Fall 2004 (24 towers)**	**Spring 2005 (6 towers)**	**Fall 2005 (6 towers)**	**Total**
Long-tailed Duck (*Clangula hyemalis*)		1 (<1%)				1 (<1%)
Turkey Vulture (*Cathartes aura*)			2 (1%)			2 (<1%)
Red-tailed Hawk (*Buteo jamaicensis)*			1 (<1%)			1 (<1%)
Wild Turkey (*Meleagris gallopavo*)			1 (<1%)	1 (<1%)	1 (<1%)	3 (<1%)
Lesser Yellowlegs (*Tringa jlavipes)*		1 (<1%)				1 (<1%)
Short-billed Dowitcher (*Limnodromus griseus*)		1 (<1%)				1 (<1%)
Herring Gull (*Larus argentatus*)		1 (<1%)				1 (<1%)
Mourning Dove (*Zenaida macroura*)		1 (<1%)	4 *(3%)*		11 (8%)	16 (2%)
Common Nighthawk (*Chordeiles minor*)		1 (<1%)				1 (<1%)
Yellow-billed Cuckoo (*Coccyzus americanus*)			1 (<1%)			1 (<1%)
Black-billed Cuckoo (*Coccyzus erythropthalmus*)			1 (<1%)			1 (<1%)
Red-headed Woodpecker (*Melanerpes erythrocephalus*)			1 (<1%)			1 (<1%)
Northern Flicker (*Colaptes auratus*)		1 (<1%)	1 (<1%)		1 (<1%)	3 (<1%)
Eastern Wood-Pewee (*Contopus virens*)		1 (<1%)				1 (<1%)
Least Flycatcher *(Einpidonax minimus*)		2 (1%)				2 (<1%)
Yellow-bellied Flycatcher (*Empidonax flaviventris*)				1 (<1%)		1 (<1%)
Blue Jay (*Cyanocitta cristata*)		1 (<1%)	5 (3%)	3 (2%)	1 (<1%)	10 (1%)
Common Raven (*Corvus corax*)			1 (<1%)			1 (<1%)
Tufted Titinouse (*Baeolophus bicolor)*			2 (1%)			2 (<1%)

White-breasted Nuthatch *(Sitta carolinensis)*					1 (<1%)	1 (<1%)
Red-breasted Nuthatch *(Sitta canadensis)*			3 (2%)		1 (<1%)	4 (1%)
House Wren (*Troglodytes aedon*)				1 (<1%)		1 (<1%)
Marsh Wren (*Cistothorus palustr-is*)				1 (<1%)		1 (<1%)
Winter Wren (*Troglodytes troglodytes*)				1 (<1%)		1 (<1%)
Eastern Bluebird (*Sialia sialis*)			1 (<1%)			1 (<1%)
American Robin (*Turdus migrator-ius)*		2 (1%)	6 (4%)	2 (1%)	1 (<1%)	11 (2%)
Wood Thrush (*Hylocichla mustelina*)		1 (<1%)		5 (3%)		6 (1%
Swainson's Thrush (*Catharus ustulatus*)		13 (7%)	3 (2%)	1 (<1%)	3 (2%)	20 (3%)
Gray-cheeked Thrush (*Catharus minimus*)		1 (<1%)	1 (<1%)			2 (<1%)
Veery (*Catharus fuscescens*)		2 (1%)	1 (<1%)	6 (4%)		9 (1%)
Gray Catbird *(Dunietella carolinensis)*		4 (2%)		19 (12%)		23 (3%)
Brown Thrasher (*Toxostoma rufum*)					1 (<1%)	1 (<1%)
Ruby-crowned Kinglet (*Regulus calendula*)		1 (<1%)				1 (<1%)
European Starling (*Sturnus vulgaris*)		1 (<1%)	3 (2%)			4 (1%)
Yellow-throated Vireo (*Vireo flavifrons*)		2 (1%)		1 (<1%)	1 (<1%)	4 (1%)
Red-eyed Vireo *(Vireo olivaceus*)	3 (13%)	27 (14%)	6 (4%)	20 (12%)	12 (9%)	68 (10%)
Philadelphia Vireo (*Vireo philadelphicus*)		1 (<1%)	1 (<1%)	1 (<1%)	1 (<1%)	4 (1%)
Blue-headed Vireo *(Vireo solital-ius* j	1 (5%)		1 (<1%)			2 (<1%)
Cedar Waxwing *(Bombycilla cedrorum*)			1 (<1%)	1 (<1%)	2 (2%)	4 (1%)
Black-and-white Warbler (*Mniotilta varia*)		4 (2%)	1 (<1%)		1 (<1%)	6 (1%)
Tennessee Warbler (*Vermivora peregrina*)		1 (<1%)	5 (3%)	1 (<1%)		7 (1%)
Nashville Warbler (*Vermivora ruficapilla*)	1 (5%)	1 (<1%)	6 (4%)		9 (7%)	17 (3%)

Yellow Warbler (*Dendroica petechia)*		1 (<1%)		12 (7%)	1 (<1%)	14 (2%)
Magnolia Warbler (*Dendroica magnolia)*	3 (13%)	5 (3%)	7 (5%)	1 (<1%)	3 (2%)	19 (3%)
Cape May Warbler (*Dendroica tigrina*)	2 (9%)	1 (<1%)	3 (2%)		3 (2%)	9 (1%)
Black-throated Blue Warbler (*Dendroicn caerulescens*)		1 (<1%)	2 (1%)		1 (<1%)	4 (1%)
Black-throated Green Warbler (*Dendroica virens*)	2 (9%)	5 (3%)	1 (<1%)	1 (<1%)	2 (2%)	11 (2%)
Cerulean Warbler (*Dendroica cerulea*)				1 (<1%)		1 (<1%)
Blackburnian Warbler (*Dendroica fusca*)		3 (2%)	1 (<1%)	1 (<1%)		5 (1%)
Yellow-rumped Warbler (*Dendroica coronata*)				1 (<1%)		1 (<1%)
Chestnut-sided Warbler (*Dendroica pensylvanica*)		2 (1%)	2 (1%)	3 (2%)	2 (2%)	9 (1%)
Bay-breasted Warbler (*Dendroica castanea)*	1 (5%)	1 (<1%)	2 (1%)	1 (<1%)	2 (2%)	7 (1%)
Blackpoll Warbler (*Dendroica striata*)	2 (9%)		20 (13%)		19 (14%)	41 (6%)
American Redstart (*Setophaga ruticilla*)	2 (9%)		3 (2%)	4 (2%)	2 (2%)	11 (2%)
Pine Warbler (*Dendroica pinus*)			1 (<1%)		2 (2%)	3 (<1%)
Palm Warbler (*Dendroicn palmarum*)			1 (<1%)			1 (<1%)
Ovenbird (*Seiurus aurocapillus*)		18 (9%)	11 (7%)	15 (9%)	4 (3%)	48 (7%)
Northern Waterthrush (*Seiurus noveboracensis*)			1 (<1%)		1 (<1%)	2 (<1%)
Connecticut Warbler (*Oporornis agilis*)		1 (<1%)				1 (<1%)
Mourning Warbler (*Oporornis philadelphia*)		1 (<1%)			2 (2%)	3 (<1%)
Common Yellowthroat (*Geothlypis trichas*)		5 (3%)		15 (9%)	4 (3%)	24 (4%)
Wilson's Warbler (*Wilsonia pusilla*)			1 (<1%)		2 (2%)	3 (<1%)
Canada Warbler (*Wilsonia canadensis)*		2 (1%)	1 (<1%)	2 (1%)		5 (1%)
Hooded Warbler (*Wilsonia citrina*)				1 (<1%)		1 (<1%)

Bobolink (*Dolichonyx oryzivorus*)		1 (<1%)				1 (<1%)
Brown-headed Cowbird (*Molothrus ater)*		1 (<1%)		1 (4%)		2 (<1%)
Baltimore Oriole (*Icterus galbula)*				2 (1%)		2 (<1%)
Scarlet Tanager (*Piranga olivacen)*		4 (2%)		1 (<1%)		5 (1%)
Northern Cardinal (*Cardinalis cardinalis*)			2 (1%)			2 (<1%)
Rose-breasted Grosbeak (*Pheucticus ludovicianus*)		5 (3%)		6 (4%)	2 (2%)	13 (2%)
Indigo Bunting (*Passerina cyanea)*		4 (2%)		3 (2%)		7 (1%)
Savannah Sparrow (*Passerculus sandwichensis*)	1 (5%)	2 (1%)		3 (2%)	2 (2%)	8 (1%)
Grasshopper Sparrow *(Ammodramus savannarum*)		1 (<1%)				1 (<1%)
Chipping Sparrow (*Spizella passel-ina)*		1 (<1%)		3 (2%)	1 (<1%)	5 (1%)
White-throated Sparrow (*Zonotrichia albicollis*)	1 (5%)	1 (<1%)	1 (<1%)	1(<1%)	1 (<1%)	5 (1%)
White-crowned Sparrow (*Zonotrichia leucophrys*)				1(<1%)		1 (<1%)
Lincoln's Sparrow (*Melospiza lincolnii*)		2 (1%)		1(<1%)	1 (<1%)	4 (1%)
Swamp Sparrow (*Melospiza georgiana*)				1(<1%)	2 (2%)	3 (<1%)
Unknown duck"		4 (2%)			1 (<1%)	5 (1%)
Unknown –crow size[b]		5 (3%)		1 (<1%)	1 (<1%)	7 (1%)
Unknown Icteridae[b]	1 (5%)	2 (1%)			3 (2%)	6 (1%)
Unknown -thrush size"		14 (7%)	17 (11%)	11(7%)	8 (6%)	50 (7%)
Unknown –warbler/vireo size"	2 (9%)	32 (16%)	19 (12%)	7 (4%)	18 (13%)	78 (12%)
Total:	**22**	**197**	**156**	**165**	**137**	**677**

[a] all names of birds follow the *AOU Check-list of North American Birds*
[b] bird carcass heavily scavenged preventing identification of species

Avian collisions at communication towers: 11. The role of Federal Aviation Administration obstruction lighting systems

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Abstract: In a previous report, we demonstrated that two structural attributes, height and guy wires, contribute greatly to the numbers of bird collision fatalities at communication towers. The objective of the present study was to determine the relative collision risks that different nighttime Federal Aviation Administration (FAA) obstruction lighting systems pose to migratory birds. The following nighttime tower lighting systems were compared: white strobe beacons (L-865) only, red strobe-like beacons (L-864) only, red flashing incandescent beacons (L-864) only, and red strobe-like beacons (L-864) combined with steady burning (non-flashing) red lights (L-810). Avian fatality data comparing nighttime tower light systems were collected simultaneously in Michigan on 20 consecutive days during peak songbird migration at 24 towers in May 2005 and September 2005 (total 40 days). In addition, numbers of fatalities observed at towers searched in 2003 and 2004 that were equipped with standard FAA red strobe-like beacons and steady burning lights were compared to those towers searched in 2005. During the two 20-day sample periods a mean of 3.7 birds were found under towers 116-146 m Above Ground Level (AGL) equipped with only L-864 or L-865 flashing obstruction beacons, whereas towers of the same height configured with steady burning L-810 lights in addition to the L-864 flashing beacons were responsible for 13.0 fatalities per season. Kruskal-Wallis test, Analysis of Variance, student-t test. and multiple comparisons procedures determined that towers lit at night with only flashing beacons (L-864 or L-865) were involved in significantly fewer avian fatalities than towers lit with systems that included the FAA status quo lighting system (a combination of L-864 red, strobe-like beacons and steady burning L-8 10 lights). There were no significant differences in fatality rates between 116-146 m towers with red strobes, white strobes, and red incandescent flashing lights. Comparison of fatalities at towers with only the flashing beacons searched in 2005 also demonstrated fewer fatalities than status quo lit towers searched in 2004 and 2003. Our results demonstrate that avian fatalities can be reduced dramatically at guyed communication towers, perhaps by 50-70%, by removing steady burning L-8 10 lights. Changing lights on existing and new communication towers provides a feasible means to dramatically reduce collision fatalities at communication towers (two other methods include tower height reduction and guy wire elimination on new towers). One advantage of our findings is that lighting can be changed at minimal cost on existing towers and such changes on new or existing towers greatly reduces the

cost of operating towers. Removing L-810 lights from towers is one of the most effective means of achieving a significant reduction in avian fatalities at existing communication towers.

Introduction

In a previous report (Gehring and Kerlinger 2007), we quantitatively demonstrated that communication tower height and support structure (guy wires) play a major role in avian collision mortality at these structures. Although these variables have been shown to be extremely important in determining how likely birds are to collide with communication towers, a third variable, Federal Aviation Administration (FAA) obstruction lighting (Fig. 1), has also been suggested to be a major factor in determining how many birds collide with communication towers (Avery et al. 1980, Avery et al. 1976).

Past research suggests that birds, primarily night migrating, neotropical songbirds, are either attracted to or disoriented by communication tower lights, especially when night skies are overcast, foggy, or when there is precipitation (e.g., Avery et al. 1976, Caldwell and Wallace 1966, Cochran and Graber 1958). However, there are few studies that have attempted to study how lights influence bird behavior at communication towers. These studies included either turning off FAA lights on communication towers or comparing communication towers with different types of obstruction lighting. Larkin and Frase (1988) used a tracking radar to show that with fog and low cloud ceiling, night migrants appeared to be attracted to lights on a tall (>305 m AGL), guyed communication tower, but flew away when lights were extinguished. Cochran and Graber (1958) and Avery et al. (1976) used counts of bird call notes and ceilometers (spotlights) to observe night-migrating birds congregated and flying near tall (>305 m AGL), guyed communication towers equipped with standard FAA obstruction lights. Similarly, when the researchers temporarily extinguished the tower lights the birds dispersed from the tower area. Gauthreaux and Belser (2006) used a marine radar to demonstrate that more night migrants flew in circular flight patterns near a guyed communication tower (>305 171 AGL) with red flashing incandescent L-864 beacons (Fig. 1) and steady burning red L-810 lights than near a guyed tower (>305 m AGL) of similar height equipped only with L-865 white strobes. Most recently, a study by Kerlinger et al. (in press) at several wind power installations showed that there was no detectable difference in fatality rates between wind turbines deployed with red strobe-like L-864 beacons and turbines with no FAA obstruction lighting.

The study described herein was the first to simultaneously monitor fatalities of migratory birds at communication towers of the same height and support systems (guyed and unguyed) that had been equipped with different types of FAA-type obstruction lighting. It was also the first study to examine communication towers equipped only with red flashing obstruction beacons (L-864), with respect to collision fatalities, as opposed to the usual combination of red flashing beacons (L-864) and non-flashing lights (L-810) that are the standard form of lighting on communication towers (Fig. 1).

The objective of the study was to determine whether there were fewer collisions at communication towers equipped with flashing lights of various types and colors as opposed to towers equipped with the standard type of FAA obstruction lights. The latter lighting includes red flashing, L-864 strobe-like beacons combined with steady burning (non-flashing) red L-810 FAA lights. In addition, we sought to determine whether there were differences in fatality rates among towers equipped with white strobes, red strobe-like lights, and red incandescent flashing beacons.

Study Area and Methods

The towers studied and their dimensions were reported previously (Gehring and Kerlinger 2007). Briefly, research was conducted at communication towers distributed throughout Michigan, USA (between: 46" *33.85*' N, 90° 25.06' W and 41° 44.48' N, 83° 28.51' W; Fig. 2). The Michigan Public Safety Communication System (MPSCS) towers searched in *2005* were randomly selected from approximately 150 MPSCS towers within the 116-146-m height category, after stratification for tower support system. If a randomly selected tower was within 1.6 km of an extensively-lighted area (e.g., large urban area) we eliminated that tower from the sample and randomly selected another tower. This procedure prevented a situation where communication tower lights might be less visible to birds or "washed-out" due to sky glow in the surrounding areas (Caldwell and Wallace 1966). Similarly, we avoided those towers associated with tower farms (additional communication tower(s) within 0.81 km) and ridge tops to avoid additional potentially confounding variables. Towers >305 m AGL were selected because access was granted by tower owners and an effort was made to disperse the towers throughout the state. Two of the MPSCS towers were selected nonrandomly. One was selected at the urging of wildlife agencies and environmental organizations who believed the site hosted large numbers of migrating songbirds. The other lion-randomly selected tower was included after discussions and consultation with members of the Kirtland's Warbler (*Dendroica kirtlandii*) Recovery Team. The latter tower was in close proximity to this endangered species' breeding areas.

We randomly assigned nighttime lighting systems to MPSCS towers 116-146 m AGL. Given that the FAA currently only allows towers to be lit at night with white strobes (L-865), or red flashing lights (L-864) combined with red non-flashing lights (L-810), we were required to request marking and lighting variances for those towers selected for change. After receiving FAA marking and lighting variances, personnel at the MPSCS changed the tower lights to study specifications. The following lighting systems were each installed at three guyed towers and three unguyed towers: white strobes (top and one-half height of tower), red strobe-like lights (top and one-half height of tower), and red, flashing, incandescent beacons (top and one-half height of tower) (Fig. 2). Three guyed towers maintained the status quo red strobe-like lights (top and one-half height of tower) combined with red, non-flashing lights (L-810) one-third and three-quarter the height of the tower (i.e., status quo, Fig. 1). The guyed towers >305 m AGL, had standard, red, flashing incandescent beacons (L-864) combined with non-flashing, incandescent beacons (L-810).

Carcass searches

Methods used to search for carcasses were described in a previous report (Gehring and Kerlinger *2007).* In 2005, the towers were searched 10-29 May and 7-26 September. Technicians arrived at the towers at or before dawn in an effort to prevent diurnal and crepuscular scavengers from removing carcasses. Searching the same tower every day, technicians conducted tower searches simultaneously at their designated towers. Using flagged, straight-line transects, technicians walked at a rate of 45-60 in per min and searched for carcasses within 5 m on either side of each transect (Gehring 2004, Erickson et al. 2003). Transects covered a circular area under each tower with a radius equal to 90% the height of the tower. Bird carcasses were placed in plastic bags, and the following data were recorded: tower identification number, date, closest transect, distance from tower, azimuth to the tower, estimated number of days since death, and observer's name. Once bagged and labeled, carcasses were frozen for later identification and verification of species. Gehring maintained the appropriate USFWS and Michigan Department of Natural Resources (MDNR) permits and secured Lnstitutional Animal Care and Use Committee protocol approval (#07-03) via Central Michigan University (CMU).

Observer detection and carcass removal trials

Because technicians do not observe all bird carcasses under communication towers due to dense vegetation, observer fatigue, human error, arid scavenging by predators, it was necessary to quantify each technician's observer detection rate and the rate of carcass removal (Erickson et al. 2003). Observer detection trials were conducted with technicians at their designated tower once each field season. Technicians were not notified when the observer detectioii trial would occur, or how many and what species of bird carcasses would be placed at their tower site. By placing 10 bird carcasses within the tower search area, we quantified the proportion of bird carcasses detected by each technician. For observer detection trials we used bird carcasses representing a range in size and colors, but predominantly Brown-headed Cowbirds (*Molothrus ater*) painted to simulate the fall plumage of migrating songbirds. Bird carcasses used for observer detection trials were also painted with an "invisible" paint that glowed fluorescent colors when viewed under a black light. When analyzing the study data. the "invisible" paint prevented any confusion between birds that had collided with the towers and birds placed in the plots for observer detection trials.

Similarly, technicians placed 10-15 bird carcasses (predominantly Brown-headed Cowbirds) immediately adjacent to the edges of their designated communication tower's search area and monitored the removal (e.g., scavenging) of carcasses daily during the study period. Using these data we calculated a scavenging or removal rate (Erickson et al. 2003). Bird carcasses used in the removal trials were not painted, as this foreign scent might have prevented scavengers from removing carcasses. Both observer detection trial birds and removal trial birds were placed in a range of habitats characteristic of the individual tower search area.

Statistical analyses

We used the Kruskal-Wallis test combined with Tukey's Honestly Significant Difference (HSD) multiple comparison procedures to test for differences among the tower types (lighting systems, guyed/unguyed, medium/tall height) from spring and fall 2005 (Zar 1998). To specifically examine the differeiices in avian fatalities among towers lit with different lighting systems we compared (using Analysis of Variance;

ANOVA) the data from guyed, medium-height towers from both spring and fall 2005 combined and we also examined the data from towers with status quo lighting studied in fall 2003 and spring and fall 2004 (Gehring and Kerlinger 2007). We used Fisher (LSD) multiple coinparisons on these data after testing for significant differences (Zar 1998). We also used a two-sample t-test on these combined data to compare the numbers of avian fatalities at guyed, medium-height towers lit with a combination of flashing beacons and non-flashing lights to the numbers of avian fatalities at all guyed, medium-lieight towers with only red or white flashing obstruction beacons. Raw data were used when testing for significant differences ainong tower types, not data adjusted for scavenging and observer detection rates. We used bootstrapping (5,000 iterations) to estimate the mean and standard deviation of the observer detection rates (Ericltsoii et al. 2003, Manly 1997). Using methods developed by W. Ericltson (WEST, Inc.), we used the mean observer detection rate and the carcass reinoval rate specific for each individual tower to calculate adjustment multipliers by which to correct the observed number of birds per tower. This adjustment method considered the probability that carcasses not found on one day could be found on the following days, depending on the rate of carcass removal (W. Erickson pers. comm.). These two interacting variables were used to determine an average carcass detection probability and the related adjustment multiplier specific to each tower. We used statistical software SPSS (2001) for Krusltal-Wallis and related multiple comparisons with an $a = 0.10$. We used XLSTAT 2006.5 (2006) for ANOVA, related multiple comparisons, and student's t-test with an $a = 0.10$.

Results

During the 20-day study period in spring 2005, searches at 24 towers detected 203 birds of 47 species (71 birds at MPSCS towers; Table 1 aiid Appendix I). In the fall of 2005, searches of 24 towers detected 173 birds representing 42 species (53 birds at MPSCS towers; Table 2 and Appendix 1). Most species found under the communication towers were night-migrating songbirds (Appendix 1). In the spring of 2005 the three most common bird species found were Red-eyed Vireo (*Vireo olivaceus*), Gray Catbird (*Dumetella carolinensis*), and Oveiibird (*Seiurus aurocapillus*). In the fall of 2005 Blackpoll Warbler (*Dendroica striata*), Red-eyed Vireo, and Mourning Dove (*Zenaida macroura*) were the most common species that collided with study towers. The degree of tissue decay and scavenging prevented verification of injuries consistent with a tower collision. The greatest number of carcasses found in one night was 16 at a tower >305 m AGL, whereas at 116-146 m towers the greatest number found at a single tower for a single night was eight.

The mean observer detection rate (via bootstrapping) was 0.31 (SD =0.04) in spring of 2005 and 0.24 (SD =0.31) in fall 2005. Carcasses placed near the tower search areas for removal trials (e.g., scavenging) remained on the grouiid for a mean of 8.61 days (SD = 4.88) in the spring of 2005 and 6.69 days (SD = 2.98) in the fall of 2005. Including both observer detection rates aiid carcass removal rates we estimated the adjustment multipliers specific to each tower to range between 1.18 and 2.83 (mean =1.74, SD = 0.52) in the spring of 2005 and 1.58 and 5.07 (mean = 2.45, SD = 0.87) in the fall of 2005.

Kruskal-Wallis tests found significant differences among tower types in both spring 2005 (χ^2 = 13.33, P = 0.06) and fall 2005 (χ^2 = 13.71, P = 0.06). In the spring of 2005 multiple comparisons determined that guyed towers >305 m AGL were involved in more avian fatalities than all medium towers regardless of the medium tower's lighting system or support system (P ≤ 0.10). Multiple comparisons also determined that medium guyed towers illuminated with both lion-flashing red lights (L-81Os) and flashing, red strobe–like lights were involved in more avian fatalities than towers lit only with white strobes (both unguyed and guyed) (P ≤ 0.10). Similarly, data from the fall of 2005 determined that more birds were found under guyed towers >305 m AGL than all other medium towers regardless of the medium tower's lighting system or support system (P ≤ 0.03). However, no statistical differences were found among the remaining tower lighting and support system categories in solely the fall 2005 data.

Analysis of Variance of the data collected at guyed, medium height towers from both seasons in 2005 combined detected a significant difference among the different lighting system (F = 3.55, P = 0.03). Fisher's LSD test determined that towers illuminated during the night with flashing beacons (L-864) in addition to non-flashing lights (L-810) were involved in more avian fatalities than towers lit during the night with only white strobes (L-865, P < 0.01), towers lit with only red, flashing, incandescent beacons (L-864, P = 0.02). and towers lit with only red strobe-like beacons (L-864, P = 0.04). There were no statistical differences among the guyed, medium towers lacking tion-flashing lights (P ≥ 0.42). In other words, there was no significant difference in the fatality rates among towers lit only with red strobes vs. white strobes vs. red incandescent flashing beacons. The two-sample t-test supported the ANOVA results demonstrating that towers lit during the night with non-flashing lights (L-810) in addition to flashing beacons (L-864) were involved in more avian fatalities than towers lit only with flashing beacons (L-864 or L-865. t = -3.24, P < 0.01).

Additional support for the differences between the numbers of fatalities at 116-146 m AGL MPSCS towers with standard lighting (L-864 and L-810 combined) and towers with only flashing lights comes from data collected at towers studied in fall 2003 (Table 3), and spring and fall 2004 (Tables 4 and 5). At three guyed towers studied in fall 2003 a mean of 7.3 fatalities were found duriiig a 20-day search period. At I 1 guyed towers searched during spring 2004, the mean fatality rate per tower was 11.0 and in fall 2005 at 12 towers the fatality rate per tower was 4.25 fatalities per tower. Although there is a slight overlap among these means, the numbers of fatalities at towers with standard FAA lighting is generally much greater than at the towers with only flashing red beacons studied in spring and fall 2005.

Table 1. Comparison of bird carcasses found at 24 Michigan communication towers (21 MPSCS towers and three privately owned towers) during 20 days of spring migration 2005 at towers with different FAA lighting modes.

Tower support	**Height category AGL**	**Light System**	**Number of towers searched**	**Number of carcasses found**
Unguyed	116-146 m (380-480 ft)	White Strobe (L-865)	3	3 (mean = 1.00, SE = 1.00)
		Red Strobe (L-864)	3	4 (mean = 1.33, SE = 0.88)
		Red Flashing Incandescent (L-864)	3	4 (mean = 1.33, SE = 0.67)
Guyed	116-146 m (380-480 ft)	White Strobe (L-865)	3	3 (mean = 1.00, SE = 0.58)
		Red Strobe (L-864)	3	12 (mean = 4.00, SE = 1.00)
		Red Flashing Incandescent (L-864)	3	8 (mean = 2.67, SE = 0.33)
		Status Quo (flashing and steady burning red beacons) (L-864 and L-810)	3	37 (mean = 12.3, SE = 4.84)
Guyed	≥305 m (1000 ft) (privately owned towers)	Status Quo (flashing and steady burning red beacons) (L-864 and L-810)	3	132 (mean = 44.00, SE = 11.55)
Total	**All towers**		**24**	**203 (71 at MPSCS towers)**

Table 2. Comparison of bird carcasses found at 24 Michigan communication towers (21 MPSCS towers and three privately owned towers) during 20 days of fall migration 2005 at towers with different FAA lighting modes.

Tower support	**Height category AGL**	**Light System**	**Number of towers searched**	**Number of carcasses found**
Unguyed	116-146 m (380-480 ft)	White Strobe (L-865)	3	2 (mean = 0.67, SE = 0.67)
		Red Strobe (L-864)	3	1 (mean = 0.33, SE = 0.33)
		Red Flashing Incandescent (L-864)	3	2 (mean = 0.67, SE = 0.33)
Guyed	116-146 m (380-480 ft)	White Strobe (L-865)	3	8 (mean = 2.67, SE = 2.19)
		Red Strobe (L-864)	3	8 (mean = 2.67, SE = 2.19)
		Red Flashing Incandescent (L-864)	3	14 (mean = 4.67, SE = 0.33)
		Status Quo (w/ steady burning red beacons) (L-S64 and L-810)	3	18 (mean = 6.00, SE = 2.65)
Guyed	≥305 m (1000 ft) (privately owned towers)	Status Quo (flashing and steady burning i-ed beacons) (L-S64 and L-8 10)	3	120 (mean = 40.00, SE = 18.03)
Total	**All towers**		**24**	**173 (53 at MPSCS towers)**

Table 3. The numbers of bird carcasses found at three Michigan MPSCS communication towers with status quo lighting (red, flashing beacons (L-864) and steady burning red lights (L-810)) between 15 September and 4 October 2003.

Tower support	Height category AGL	Numbers of towers searched	Numbers of carcasses found
Unguyed	116-146 m	3	0 (mean = 0.0, SE = 0.0)
Guyed	116-146 m	3	22 (mean = 7.3, SE = 1.2)
Total		**6**	**22**

Table 4. The numbers of bird carcasses found at 23 Michigan communication towers with status quo lighting (flashing beacons (L-864) and steady burning red lights (L-810)) between 10 May and 29 May 2004.

Tower support	Height category AGL	Numbers of towers searched	Numbers of carcasses found
Unguyed	116-146 m	9	5 (mean = 0.6, SE = 0.2)
Guyed	116-146 m	11	121 (mean = 11.0, SE = 2.6)
Guyed	≥305 m	3 (2)[a]	71 (mean = 23.7, SE = 11.8) (68; mean = 34.0, SE = 10)[a]
Total		**23** **(22)**[a]	**197** **(194)**[a]

[a] data with outlier tall tower removed

Table 5. The numbers of bird carcasses found at 24 Michigan communication towers with status quo (flashing beacons (L-864) and steady burning red (L-810)) lighting between 7 September and 26 September 2004.

Tower support	Height category AGL	Numbers of towers searched	Numbers of carcasses found
Unguyed	116-146 m	9	12 (mean = 1.33, SE = 0.62) 9 (mean = 1.00, SE = 0.33)[a]
Guyed	116-146 m	12	51 (mean = 4.25, SE = 0.65)
Guyed	≥305 m	3	93 (mean = 31.00, SE = 5.86)
Total		**24**	**156** ***(153)***[a]

[a] data without birds likely killed and plucked on site by raptor.

Discussion

There is little quantitative information about the relationship between the types of FAA lights on cornrnunication towers and the attraction of birds to those towers. Regulatory agencies, including the USFWS, FAA, and Federal Communication Commission (FCC), have expressed interest in additional scientific data on this topic, in the form of studies such as this one.

Gauthreaux and Belser (2006) used marine radar to compare the flight paths of birds in an unlit control area, to birds near a communication tower with white strobes (L-865), and to birds near a tower lit with red flashing, incandescent beacons (L-864) combined with steady burning. red, lights (L-8 10). Birds flew in straight flight paths over the control area, but birds flying near the communication towers deviated from a straight flight path and tended to concentrate near the towers. More birds congregated at the tower lit with red. flashing incandescent beacons combined with steady burning, red, lights than at towers lit with white strobes. They also concluded that there had been no studies of bird flight behaviors at communication towers deployed only with flashing red beacons. Our research results niay be consistent with and complement the results of Gauthreaux and Belser (2006). if birds concentrate more often at towers with status quo FAA lights that include steady burning red lights than at towers with only white flashing strobes, as Gauthreaux and Belser report, it seems reasonable that more would collide with the former type of tower. We found more fatalities at towers with status quo lights that included steady burning red lights as opposed to towers lit with only white flashing strobes, red strobe-like beacons, and red incandescent flashing beacons.

Kerlinger et al. (in press) qualitatively compared fatality rates of night migrants at wind turbines lit only with red flashing strobe-like lights (L-864) with fatality rates at turbines that were not lit. They found no difference and suggested that red strobe-like lights did not appear to attract or disorient night migrants, resulting in collisions with wind turbines ranging in height from just over 60 m to nearly 122 m in height. These data support our results and interpretation that flashing beacons did not attract or disorient as many birds as non-flashing lights. Turbines are typically lit with one or two (side-by-side at the same height) simultaneously flashing strobes or strobe-like lights (usually red, occasionally white) and usually lack steady burning lights. it is noteworthy that hundreds of turbines in the U.S. are allowed to be left unlit despite being taller than 199 feet (and up to about 400 feet), the height above which communication towers are required to be lit (FAA 2000).

Our study is the first to compare collision rates at communication towers equipped with different types of FAA obstruction lighting. The results also provide the first scientifically validated and economically feasible means of reducing fatalities of night migrating birds at communication towers. Our results strongly suggest that by extinguishing steady burning, red L-810 lights on towers in the 116-146 m height range, leaving only the L-864 (red strobe and red incandescent) or L-865 (white strobe) flashing beacons, fatality rates could be reduced by as much as about 50-70% (data from 2005). The fatality rates at towers with only flashing lights averaged 3.7 fatalities per 20-day migration study period vs. 13.0 fatalities at towers with steady burning red lights and flashing lights. These reductions are further supported by considering the mean numbers of birds collected at towers with steady burning red lights and flashing beacons in previous field seasons (Tables 3, 4, and 5). By simply removing the L-810 lights from all communication towers, it is possible that more than one to two plus inillion bird collisions with coininunication towers might be averted each year, assuming that about four inillion birds per year collide with communication towers (estimate from USFWS 2000). Because guyed towers (or guy wires of those towers) now standing are not likely to be removed from the landscape, changing FAA obstruction lighting provides virtually the only means of reducing fatalities at existing towers.

The elimination of steady burning, red L-810 lights, leaving only flashing L-864 lights would also be beneficial for tower owners. Although fatalities would not be completely eliminated, the numbers of fatalities would undoubtedly be reduced greatly. The economic incentive for removing L-8 10 lights is substantial. Electric consumption, and therefore electric costs, as well as tower maintenance costs (changing of bulbs -- labor and bulb cost) would be greatly reduced. The elimination of these same lights would also benefit the Federal Communication Commission (FCC) and the Federal Aviation Administration (FAA). Because the FCC is tasked with licensing towers under the National Environmental Policy Act (NEPA), they should welcome a means of reducing fatalities thereby increasing federal compliance with the Migratory Bird Treaty Act (MBTA). A similar situation exists for the FAA. By recommending L-810 steady burning red lights, the FAA advisory circular basically makes it difficult for tower owners and operators, not to mention the FCC, to comply with the MBTA. Removal of the L-810 lights from towers should be encouraged by both the FCC and FAA.

Currently, the only FAA approved nighttime lighting system for communication towers that lacks steady-burning lights is the white strobe (L-865) system. While white strobe systems provide an FAA approved option to significantly reduce avian collisions, there is a general public disapproval of these systems because they are more vexatious to humans than red strobes. In addition, converting communication towers with traditional lighting systems to white strobe systems can be prohibitively costly for tower companies. We did not find a statistical difference in avian fatality rates among towers lit only with the different types of flashing lights (white and red strobe, red incandescent). Our results suggest that the flashing quality of a light was more important to causing avian collisions than the color of the light. The FAA is currently exploring the possibility of changing their recommendations to allow the non-flashing, L-810, red lights to be extinguished on towers lit with standard red light systems. Given their priority of air safety, the FAA will need to conduct proper tower visibility or conspicuity testing before such recommendations are changed in order to allow for this cost efficient and effective option for tower companies.

Although the removal of steady burning red L-8 10 lights from guyed towers in the 116-146 in AGL height range resulted in dramatically fewer fatalities, we did not test whether similar light changes on taller towers (greater than 147 m AGL) reduced fatalities at those towers. Future research should focus on taller guyed towers, specifically by replicating the design used in the present study. By searching for carcasses simultaneously under towers that are similar in structure but have different lighting systems, it should be relatively easy to determine whether the removal of steady burning red L-810 lights will prove effective at taller towers. Though there are fewer tall towers than towers in the 116-146 m AGL height range, towers ≥ 305 m AGL are responsible for several times the numbers of fatalities than shorter towers (Gehring and Kerlinger 2007). Studies of how the lights on taller towers impact fatality rates should be the focus of future conservation research.

Acknowledgements

Many dedicated, enthusiastic, and hard working technicians conducted the predawn searches under communication towers. Their efforts made this research possible. The value of this study was greatly enhanced by the tower engineers and owners who have granted permission to access privately owned towers. 1 appreciate the recruiting and advertising assistance of Michigan organizations and Internet list servers. Many individuals regularly provide ideas, suggestions, and support for this project, including but not limited to: P. Brown (MNFI), C. Czarnecki (USFWS), S. Lewis (USFWS), C. Mensing (USFWS), T. Rich (PIF), B. Fisher (USFWS), G. Winegrad (American Bird Conservancy (ABC)), C. Schumacher (United States Forest Service (USFS)), E. Paul (Ornithological Council), J. Dingledine (USFWS), P. Lederle (MDNR), D. Wang (CMU), R. Rustem (MDNR), B. Noel (ASU), M. Herbert (MDNR), T. Gehring (CMU), and J. Janson (MDNR). The State of Michigan granted their financial support, permission to access MPSCS tower sites, and tower information. I would like to express my gratitude to the USFWS, the MDNR and the National Fish and Wildlife Foundation (NFWF) for granting additional funds to improve this project. F. Moore (University of Southern Mississippi (USM)), M. Avery (United States Department of Agriculture), G. Winegrad (ABC), R. Rustem (MDNR) and an anonymous reviewer made time to provide official reviews for the NFWF grant proposal procedure. Logistical assistance was provided by the FAA, FCC, M. Scieszka and I. Lopez (State of Michigan), P. Ryan (Perkins Coie), and M. Curry (Curry & Kerlinger, LLC). Members of the Communication Tower Working Group and the Kirtland's Warbler Recovery Team provided ideas and suggestions. The Michigan Department of Natural Resources, USFWS, CMU and the USFS provided the permits necessary to complete this research. Michigan Natural Features Inventory (MNFI) and Central Michigan University provided necessary logistical support. W. Erickson (WEST, Inc.) generously provided suggestions, and advice regarding many aspects of this research.

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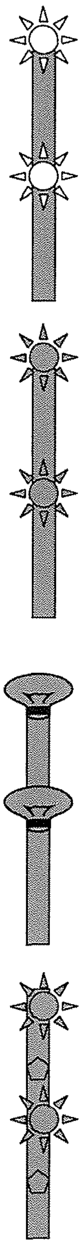

- 3 guyed towers 116-146 m (380-480 ft) AGL with white strobes (L-865) at the top and mid level; no non-flashing (L-810) incandescent lights
- 3 unguyed towers 116-146 m (380-480 ft) AGL with white strobes (L-865) at the top and mid level; no non-flashing (L-810) incandescent lights

- 3 guyed towers 116-146 m (380-480 ft) AGL with red strobes (L-864) at the top level and mid level; no non-flashing (L-810) incandescent lights
- 3 unguyed towers 116-146 m (380-480 ft) AGL with red strobes (L-864) at the top and mid level; no non-flashing (L-810) incandescent lights

- 3 guyed towers 116-146 m (380-480 ft) AGL with red, flashing (L-864) incandescent lights at the top and mid level; no non-flashing (L-810) incandescent lights
- 3 unguyed towers 116-146 m (380-480 ft) AGL with red. flashing (L-864) incandescent lights at the top and mid level; no non-flashing (L-810) incandescent lights

- 3 guyed towers 116-146 m (380-480 ft) AGL with red strobes (L-864) at the top arid mid level; *with* red non-flashing (L-810) incandescent lights at ¾ and 1/3 height of the tower (current/status quo lighting system for many communication towers including MPSCS towers)

Figure 1. Four different communication tower obstruction lighting systems were installed on the Michigan Public Safety Communication System towers. The areas under these towers were simultaneously and systematically searched for bird carcasses during 20 consecutive mornings surrounding the peak of songbird migration in the spring and fall of 2005.

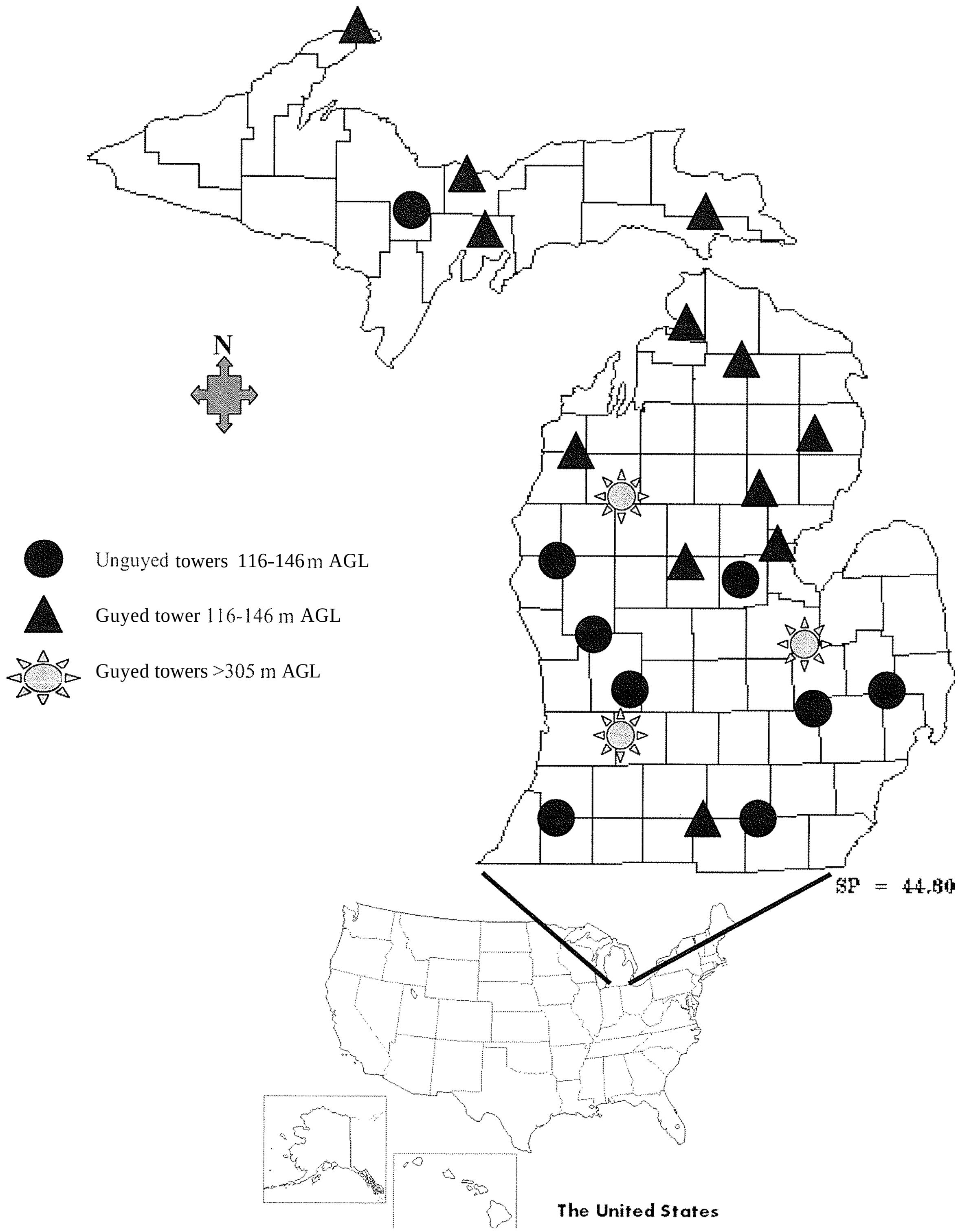

Figure 2. Map of communication towers included in study of avian collisions in Michigan, USA.

Appendix 1. The number and percent of total of avian fatalities (by species) at 24 communication towers located throughout Michigan, USA during May 2005 and September 2005 (20 days each month).

Bird Species"	**Spring 2005 (24 towers)**	**Fall 2005 (24 towers)**	**Total**
Wild Turkey (*Meleagris gallopavo*)	2 (<1%)	2 (1%)	4 (1%)
Ruffed Grouse (*Bonasa umbellus*)	3 (1%)	1 (<1%)	4 (1%)
Ring-necked Pheasant (*Phnsianzis colchicus*)	1 (<1%)		1 (<1%)
Mourning Dove (*Zenaida macroura*)	1 (<1%)	13 (8%)	14
Hairy Woodpecker (*Picoides villosus*)	1 (<1%)		1 (<1%)
Northern Flicker (*Colnptes auratus*)		1 (<1%)	1 (<1%)
Yellow-bellied Flycatcher (*Empidonax flaviventris*)	2 (<1%)		2 (1%)
Blue Jay (*Cyanocitta cristata*)	3 (1%)	1 (<1%)	4 (1%)
House Wren (*Troglodytes aedon*)	2 (<1%)		2 (1%)
Winter Wren (*Troglodytes troglodytes*)	1 (<1%)		1 (<1%)
Marsh Wren (*Cistothorus palustris*)	1 (<1%)		1 (<1%)
Red-breasted Nuthatcli (*Sitta canadensis*)		1 (<1%)	1 (<1%)
White-breasted Nuthatch (*Sitta carolinensis*)		1 (<1%)	1 (<1%)
American Robin (*Turdus migratorius*)	4 (2%)	1 (<1%)	5 (1%)
Wood Thrush (*Hylocichla mustelina*)	5 (3%)		5 (1%)
Swainson's Thrush (*Catharus ustulatus*)	3 (1%)	4 (2%)	7 (2%)
Veery (*Catharus fuscescens*)	6 (3%)		6 (2%)
Brown Thrasher (*Toxostoma rufum*)		I (<1%)	1 (<1%)
Gray Catbird (*Dumetella carolinensis*)	22 (11%)		22 (6%)
Cedar Waxwing (*Bombycilla cedrorum*)	1 (<1%)		1 (<1%)
Yellow-throated Vireo (*Vireo flavifrons*)	1 (<1%)	1 (<1%)	2 (1%)
Red-eyed Vireo (*Vir-eo olivaceus*)	26 (13%)	12 (7%)	38 (10%)
Philadelphia Vireo (*Vii-eo philadelphicus*)	1 (<1%)	1 (<1%)	2 (1%)
Cedar Waxwing (*Bombycilla cedrorum*)		3 (2%)	3 (1%)
Black-and-white Warbler (*Mniotilta var-in*)	1 (<1%)	3 (2%)	4 (1%)
Tennessee Wai-bler (*Vermivora peregrina*)	1 (<1%)	3 (2%)	4 (1%)
Hooded Warbler (*Wilsonia citrina*)	1 (<1%)		1 (<1%)
Nashville Warbler (*Vermivora ruficapilla*)		10 (6%)	10 (3%)
Yellow Warbler (*Dendroica petechia*)	12 (6%)	I (<1%)	13 (3%)
Magnolia Warbler (*Dendroica magnolia*)	2 (<1%)	4 (2%)	6 (2%)
Yellow-rumped Warbler (*Dendroica coronata*)	1 (<1%)	1 (<1%)	2 (1%)
Cape May Warbler (*Dendroica tigrina*)		4 (2%)	4 (1%)
Black-throated Blue Warbler (*Dendroica caerulescens*)	1 (<1%)	2 (1%)	3 (1%)
Cerulean Warbler (*Dendroica cerulean*)	1 (<1%)		1 (<1%)
Black-throated Green Warbler (*Dendroica virens*)	1 (<1%)	3 (2%)	4 (1%)
Blackburnian Warbler (*Dendroica fusca*)	1 (<1%)		1 (<1%)
Chestnut-sided Warbler (*Dendroica pensylvanica*)	5 (3%)	3 (2%)	8 (2%)
Bay-breasted Warbler (*Dendroica castanea*)	1 (<1%)	2 (1%)	3 (1%)
Blackpoll Warbler (*Dendroica striata*)		20 (12%)	20 (5%)

American Redstart (*Setophaga ruticilla*)	5 (3%)	2 (1%)	7 (2%)
Pine Warbler (*Dendroica pinus*)		2 (1%)	2 (1%)
Ovenbird (*Seiurus aurocapillus*)	17 (8%)	5 (3%)	22 (6%)
Northern Waterthrush (*Seiurus noveboracensis*)		1 (<1%)	1 (<1%)
Mourning Warbler (*Oporornis philadelphia*)		3 (2%)	3 (1%)
Common Yellowthroat (*Geothlypis trichas*)	15 (7%)	4 (2%)	19 (5%)
Wilson's Warbler (*Wilsonia pusilla*)		3 (2%)	3 (1%)
Canada Warbler (*Wilsonia canadensis*)	2 (<1%)		2 (1%)
Baltimore Oriole (*Icterus galbula*)	2 (<1%)		2 (1%)
Brown-headed Cowbird (*Molothrus ater*)	2 (<1%)		2 (1%)
Scarlet Tanager (*Piranga olivacea*)		1 (<1%)	1 (<1%)
Rose-breasted Grosbeak (*Pheuctirus ludovicinnus*)	6 (3%)	2 (1%)	8 (2%)
Indigo Bunting (*Passel-inn cyanea*)	3 (1%)		3 (1%)
House Finch (*Carpodacus mexicanus*)	1 (<1%)		1 (<1%)
Savannah Sparrow (*Passerculus sandwichensis*)	3 (1%)	2 (1%)	5 (1%)
Chipping Sparrow (*Spizella passerina*)	3 (1%)	1 (<1%)	4 (1%)
White-throated Sparrow (*Zonotrichia albicollis*)	1 (<1%)	2 (1%)	3 (1%)
White-crowned Sparrow (*Zonotrichia leucophrys*)	1 (<1%)	1 (<1%)	2 (1%)
Lincoln's Sparrow (*Melospiza lincolnii*)	1 (<1%)	I (<1%)	2 (1%)
Swamp Sparrow (*Melospiza georgiana*)	1 (<1%)	2 (1%)	3 (1%)
Common Grackle (*Quiscalus quiscula*)		1 (<1%)	1 (<1%)
Unknown duck[b]		1 (<1%)	1 (<1%)
Unknown -Rail'	1 (<1%)		1 (<1%)
Unknown – woodpecker[b]	1 (<1%)		1 (<1%)
Unknown Icteridae"		3 (2%)	3 (1%)
Unknown - crow size[b]		3 (2%)	3 (1%)
Unknown -thrush size[b]	14 (7%)	13 (8%)	27 (7%)
Unknown –warbler/vireo size[b]	9 (4%)	21 (12%)	30 (8%)
Total:	**203 (71 at MPSCS towers)**	**173 (53 at MPSCS towers)**	**376 (124 at MPSCS towers)**

"all names of birds follow the *AOU Check-list of North American Birds*

[b] bird carcass heavily scavenged preventing identification of species

[c] bird lodged high in tree preventing identification of species