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Research Article

The Role of Tower Height and Guy Wires on Avian Collisions With Communication Towers

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ABSTRACT Every year an estimated 4–5 million migratory birds collide with communication towers in the United States. We examined the relative risks that tower support systems and tower height pose to migrating and other birds. We collected data comparing tower support systems (guyed vs. unguyed) and tower height categories 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, and 6 towers in both May and September 2005. We systematically and simultaneously searched for bird carcasses under each tower and measured carcass removal and observer detection rates each season. Of those towers, 21 were between 116 and 146 m above ground level (AGL, medium) and 3 were >305 m AGL (tall). During the five 20-day sample periods we found a mean of 8.2 bird carcasses per guyed medium tower and a mean of 0.5 bird carcasses under unguyed medium towers. During four 20-day sample periods we detected a mean of 34.7 birds per guyed tall tower. 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 medium towers were involved in significantly fewer fatalities than guyed medium towers. We detected 54–86% fewer fatalities at guyed medium towers than at guyed tall towers. We found 16 times more fatalities at guyed medium towers than at unguyed medium towers. Tall, guyed towers were responsible for 70 times as many bird fatalities as the unguyed medium towers and nearly five times as many as guyed medium towers. These findings will provide managers and regulators, such as the US Fish and Wildlife Service, with quantitative data; thereby, allowing them to effectively work with the Federal Communications Commission in siting and authorizing tower placement.

KEY WORDS collision, communication tower height, guy wires, Michigan, neotropical migratory songbird, unguyed or self-supported towers.

Avian fatalities have been documented at communication towers for approximately 60 years (Aronoff 1949, Avery et al. 1980, Kerlinger 2000, Manville 2007, Gehring et al. 2009). Past research suggests that birds, primarily night-migrating songbirds, collide with towers during spring and fall migration. Large-scale events involving as many as >12,000 birds have been recorded when night skies are overcast, foggy, or rainy (Caldwell and Wallace 1966, Avery et al. 1976, Larkin and Frase 1988, Kruse 1996, Kemper 1996), although birds also collide with towers or guy wires on clear nights (Manville 2007). Larkin (2000) found that many night migrants can be attracted to or disoriented by the lights of tall structures, such as communication towers, resulting in collisions.

Banks (1979) estimated that 1.25 million birds collided with communication towers in the United States every year. However, Manville (2001, 2005, 2007) extrapolated Banks' (1979) estimate to the >100,000 towers currently in the United States and estimated that 4–5 million birds were killed per year. Given the limited sample of towers that Banks' (1979) used in his estimates there is a need for more complete quantification of avian fatalities at towers with various characteristics.

Communication towers include cellular towers, television, and radio broadcast towers, as well as public safety communication system towers. These structures are built to meet the needs of the communication tower industry while minimizing construction costs. Taller, more costly, towers generally serve larger geographic areas than do shorter towers. Towers are generally supported by guy wires unless the available land base or substrate type under the tower fails to support the large area needed for the anchoring of guy wires. In these cases, the more costly, unguyed or self-supported (hereafter unguyed) towers are constructed with a smaller footprint.

Crawford and Engstrom (2001) suggested that taller towers were more likely to cause avian collisions based on a long-term study at one communication tower reduced from 308 m

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AGL to 91 m AGL during their sample period. This reduction in tower height was temporally related to a significant decrease in bird fatalities. The relationship between avian fatalities and guy wires was examined by mapping the location of fatalities in relation to guy wires (Kruse 1996, Kerlinger 2000). Kruse (1996) detected a significant positive correlation between locations of tower guy wires and locations of bird carcasses.

We examined the relative roles of tower height (medium [116–146 m AGL] vs. tall [>305 m AGL] towers) and tower support system (guyed vs. unguyed) on bird fatalities. Our first objective was to determine if towers with guy wire supports were responsible for more bird fatalities than were unguyed towers. Our second objective was to identify the relationship between tower height and numbers of avian collisions. Our third objective was to quantify the differences in avian collisions among tower types, which may be useful for determining overall numbers of fatalities at communication towers and guidance for minimization of this worldwide source of avian mortality.

STUDY AREA

We conducted our research at communication towers distributed throughout Michigan, USA (46° 33.85′ N, 90° 25.06′ W to 41° 44.48′ N, 83° 28.51′ W; Fig. 1). The region was flat, other than some lakeshores and rivers, and supported many neotropical migratory songbirds as they traveled between northern breeding areas and southern wintering habitats. Towers were imbedded in several cover type matrices, including continuous forests, agricultural row crops, and heterogeneous mixes of agriculture and forest fragments. Migratory songbirds demonstrated broad-front migration through Michigan, with no obvious migration corridors, but some shorelines of the Great Lakes had high concentrations of birds especially near dawn and dusk (Diehl et al. 2003).

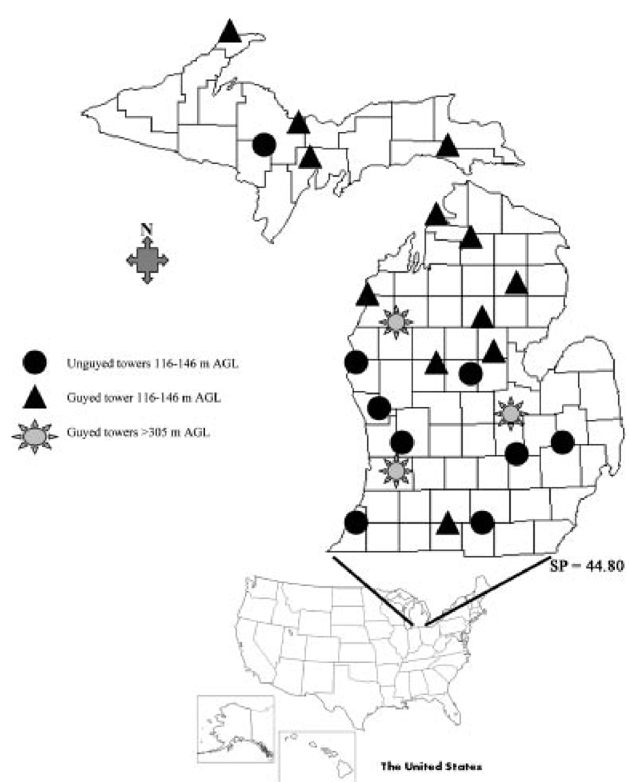

Figure 1. Map of communication towers of different heights and support systems included in study of avian collisions in Michigan, USA between 15 September 2003 and 26 September 2005. AGL, above ground level.

METHODS

Tower Selection and Description

To test for differences in the numbers of bird fatalities at towers of different heights we selected towers within two height categories: medium (116–146 m AGL) and tall (>305 m AGL). Medium towers were part of the Michigan Public Safety Communications System (MPSCS), and tall, guyed towers were commercial television broadcasting towers. Medium towers were similar in height and structure to the 800-MHz law enforcement safety towers erected across the United States and elsewhere and were also similar in structure to >25,000 communication towers in North America. All medium study towers had the same tower lighting systems from dusk to dawn, consisting of 1 strobe-like, flashing red (L-864) beacon at the top, two strobe-like, flashing red (L-864) beacons at 50% the height of the tower, and two steady burning (L-810) red lights at both 33% and 75% the height of the tower (Federal Aviation Administration 2000). Tall, guyed towers were equipped with the most common lighting used at older communication towers in the United States, consisting of a combination of red flashing beacons (L-864) and red non-flashing lights (L-810) alternating in levels. Tall study towers were similar in structure and lighting to approximately 1,500 towers in the United States that are >244 m AGL in height.

Because most tower collisions are thought to occur during migration, trained technicians sampled for carcasses on 20 consecutive days, capturing peak periods of spring and fall migration. During fall of 2003 (15 Sep–4 Oct) technicians completed a small pilot study and searched three guyed and three unguyed medium towers. During spring of 2004 (10–29 May) we increased our sample to 11 guyed and 9 unguyed medium towers and 3 tall guyed towers; during fall of 2004 (7–26 September) we gained access to an additional site and searched 12 guyed and 9 unguyed medium towers and 3 tall guyed towers (Fig. 1). In 2005 tower lighting systems were altered on most medium towers, leaving 3 medium guyed and 3 tall guyed towers with comparable lighting systems for both spring (10–29 May) and fall (7–26 September).

We included the same towers in the 2004 and 2005 study seasons, however technicians changed throughout the study. After stratification for tower support system (guyed and unguyed), we randomly selected the MPSCS towers we searched in 2004 and 2005 from approximately 170 medium MPSCS towers. We eliminated towers within 1.6 km of extensively lit areas (e.g., large urban areas with sky glow) and tower antenna farms (i.e., additional communication tower(s) within 0.8 km) from selection to prevent sampling communication towers where lights might be less visible to birds against other local lights (Caldwell and Wallace 1966). We selected tall towers based on access, granted by tower owners, as well as an effort to widely disperse towers throughout the state. The United States Fish and Wildlife Service (USFWS) and the Kirtland's Warbler Recovery Team requested that we include two non-randomly selected MPSCS towers: one located on a site believed to have high songbird migration traffic and the other within the breeding range of Kirtland's warbler (*Dendroica kirtlandii*), an endangered species. One of the tall towers searched in spring 2004 had an outdated guy system with only three guy anchors instead of the more contemporary 6. We removed data from this tower from further analysis and replaced it with a more representative tall tower in fall 2004.

Carcass Searches

Technicians arrived at towers near dawn to prevent diurnal and crepuscular scavengers from removing carcasses. All towers were searched simultaneously during study periods and each technician searched the same tower every day. Using flagged, straight-line transects, technicians walked 45–60 m/min and searched for carcasses within 5 m on either side of transects (Erickson et al. 2003, Gehring et al. 2009). Transects covered a circular area under each tower with a radius equal to 90% the height of the tower, slightly beyond the anchor points for the guy wires. Technicians placed carcasses in plastic bags and 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 they bagged and labeled carcasses they froze them for later identification and verification of species. We secured appropriate USFWS (no. MB076436-0) and Michigan Department of Natural Resources and the Environment (MDNRE; no. SC1173) permits. Institutional Animal Care and Use Committee protocol was approved (no. 07-03) via Central Michigan University.

Observer Detection and Carcass Removal Trials

Because technicians did 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 (i.e., searcher efficiency) and the rate of carcass removal by scavengers (i.e., scavenger removal rate; Erickson et al. 2003). We conducted observer detection trials for technicians at their designated tower once each field season. Placing 10 bird carcasses within the search area, we determined the proportion 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, but most were brown-headed cowbirds (*Molothrus ater*) painted to simulate plumage of migrating songbirds. We also painted bird carcasses used for observer detection trials with a fluorescing ultraviolet paint not visible to technicians but visible under a black light for additional certainty that trial birds were not mistaken for tower collisions.

Similarly, technicians randomly placed 10–15 unpainted brown-headed cowbird carcasses immediately adjacent to their designated communication tower's search area in a range of cover types representative of the search area and monitored 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). Quantification of observer detection and carcass removal provides information on the numbers of birds colliding with towers but undetected by observers.

Statistical Analyses

We used the Mann–Whitney *U*-test to test for differences in the fall of 2003, spring of 2005, and fall of 2005 data and the Kruskal–Wallis test combined with Tukey's Honestly Significant Difference (HSD) multiple comparison procedure to test for differences within the spring of 2004 and fall of 2004 data (Zar 1998). Given that observer detection and carcass removal rates were similar among individual towers we used raw data (unadjusted for removal and detection) in all analyses. Raptors occasionally used towers as perch sites; therefore, we removed from further analyses any bird carcasses or feather piles that appeared to be the result of raptor predation.

We used bootstrapping (5,000 iterations) to estimate mean and standard deviation of observer detection rates (Manly 1997, Erickson et al. 2003). We used the mean observer detection rate and carcass removal rate specific for each individual tower to calculate adjustment multipliers by which to correct the observed number of birds killed per tower (W. Erickson, WEST, Inc., personal communication). This adjustment method considered the probability that carcasses not found on 1 day could be found on following days, depending on the rate of carcass removal (W. Erickson, personal communication). We used these two interacting variables (i.e., observer detection rate and carcass removal rate) to determine an average carcass detection probability and the related adjustment multiplier specific to each tower. 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 without the adjustment for carcass removal and detection. We used statistical software SPSS (SPSS, Chicago, IL) for analysis and set $\alpha = 0.05$.

RESULTS

From fall of 2003 to fall of 2005 we detected 677 bird fatalities under communication towers of 78 species. Most carcasses were passeriformes (69%), but our sample also included anseriformes (1%), falconiformes (<1%), galliformes (<1%), charadriiformes (<1%), columbiformes (1%), cuculiformes (<1%), caprimulgiformes (<1%), piciformes (<1%), and the mammalian order chiroptera (<1%). Night-migrating songbirds collided most frequently with communication towers, accounting for about 92% of all carcasses we found (Appendix). Red-eyed vireos (*Vireo olivaceus*) were the most common species found in all study periods except for fall of 2004 when blackpoll warblers (*Dendroica striata*) were the most common tower fatalities.

During the fall of 2003, searches at six medium towers detected 22 birds (Table 1, Appendix), with seven times more bird fatalities at guyed towers than at unguyed towers ($U = 0.00$, $P = 0.037$). In spring of 2004 we found 197 birds (Table 1, Appendix) at 23 towers with differences among tower types ($\chi^2_2 = 16.839$, $P \leq 0.001$). Tall guyed towers were responsible for 56 times more bird fatalities than unguyed medium towers ($P \leq 0.001$) and three times more than guyed ($P \leq 0.001$) medium towers. Similar to fall of 2003, we found seven times more birds under guyed medium towers than unguyed medium towers in ($P = 0.01$). In fall of 2004 we detected 156 birds at 24 towers (Table 1, Appendix), with more than 30 times more bird fatalities at tall guyed towers than at unguyed medium towers ($P \leq 0.001$) and seven times more than at guyed medium towers ($P \leq 0.001$; $\chi^2 = 15.614$, $P \leq 0.001$). Although trends were consistent with spring of 2004, fewer bird fatalities at most medium towers in 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 unguyed towers. In spring of 2005 we detected 169 birds at six towers and again found tall guyed towers were involved in four times the bird collisions than medium guyed towers ($W = 6.0$, $P = 0.040$, Table 1, Appendix). Fatalities in fall of 2005 were not different between tall and medium guyed towers ($W = 7.5$, $P = 0.138$, Table 1, Appendix), likely due to small sample sizes of towers. Although not statistically significant, we found >6 times as many fatalities at tall guyed towers than at medium guyed towers.

The mean observer detection rate (via bootstrapping) was 0.48 (SD = 1.10, $n = 6$) in fall of 2003, 0.40 (SD = 0.03, $n = 28$) in spring of 2004, and 0.27 (SD = 0.03, $n = 28$) in fall of 2004. Technicians studying towers in spring and fall of 2005 had mean observer detection rates of 0.31 (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 fall of 2003, 5.66 days (SD = 2.53, $n = 23$) in spring of 2004, and 6.89 days (SD = 3.07, $n = 24$) in 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 ($\bar{x} = 1.92$, SD = 0.14) in fall of 2003, 1.23 and 2.63 ($\bar{x} = 1.68$, SD = 0.37) in spring of 2004, and 1.24 and 3.41 ($\bar{x} = 2.00$, SD = 0.55) in fall of 2004. In spring 2005, multipliers ranged between 1.18 and 2.83 ($\bar{x} = 1.74$, SD = 0.52), whereas in fall 2005 multipliers ranged between 1.58 and 5.07 ($\bar{x} = 2.45$, SD = 0.87).

DISCUSSION

Although bird collisions with communication towers have been documented since 1949 (Aronoff 1949, Breckenridge 1958, Bernard 1966), studies were not designed in a manner that would permit the testing of hypotheses regarding tower variables including structural characteristics. With our study design we tested and quantified differences between towers of different heights and towers with and without guy wires. We determined that shorter towers without guy wire supports were involved in significantly fewer avian collisions than taller towers supported by guy wires. These data provide managers and regulators with more reliable information to minimize avian collisions than was previously available.

According to our data, bird fatalities may be prevented by 69–100% by constructing unguyed towers instead of guyed towers, consistent with Kruse (1996), who found a significant positive correlation between 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 fall 2004 supported this trend, the lack statistical difference using multiple comparisons may be the result of limited sample sizes and an overall lower tower fatality rate at all medium towers during that season. It is possible that unusually clear weather in September 2004 decreased overall collision rates, as previous research suggests a positive relationship between foggy or cloud-covered nights and increased bird collisions with communication towers (Avery et al. 1976, Larkin 2000, Manville 2007).

Our data indicate that 68–86% fewer fatalities occurred at medium guyed towers than at tall guyed towers. Similarly, a

Table 1. Numbers of bird carcasses we found at Michigan communication towers between 15 September 2003 and 26 September 2005 in a study of avian collisions with tall structures.

		No. of carcasses																			
		Fall 2003 (15 Sep–4 Oct)				Spring 2004 (10–29 May)				Fall 2004 (7–26 Sep)				Spring 2005 (10–29 May)				Fall 2005 (7–26 Sep)			
Tower support	**Ht category above ground level**		*x*	SE	*n*		*x*	SE	*n*		*x*	SE	*n*		*x*	SE	*n*		*x*	SE	*n*
Unguyed	116–146 m	0	0.0	0.0	3	5	0.6	0.2	9	9	1.0	0.3	9								
Guyed	116–146 m	22	7.3	1.2	3	121	11.0	2.6	11	51	4.3	0.7	12	37	12.3	4.8	3	18	6.0	2.7	3
Guyed	≥305 m					71	23.7	11.8	3	93	31.0	5.9	3	132	44.0	11.6	3	120	40.0	18.0	3
						68[a]	34.0	10.0	2												
Total		22				197				153				169				138			
						194[a]															

[a] Data with outlier tall tower removed.

long-term study at a communication tower in Florida detected a significant decrease in bird fatalities after the tower height was decreased from 308 m to 91 m AGL (Crawford and Engstrom 2001). Night-migrating songbirds typically fly between about 91 and 610 m AGL, depending on cloud cover, wind velocity, and other factors (Kerlinger and Moore 1989). It is possible that study towers >305 m AGL impacted more migrants because heights of those towers included a greater portion of the altitude at which migrants fly. Medium towers may have impacted only those birds migrating in the lower ranges of migration altitudes, as supported by the fewer bird mortalities observed at medium guyed study towers.

The comparison of bird fatalities at towers of different heights may be confounded by the difference in tower lighting systems between the two height categories. Gehring et al. (2009) examined the relationship between avian fatalities at communication towers and tower lighting systems and found that towers with non-blinking lights were involved in more avian fatalities than towers with only blinking lights. In our study, both tower height categories were lit with both non-blinking lights and blinking lights; however, tall towers had more non-blinking lights than did medium towers. Given that the lighting systems of towers are determined and regulated by the FAA and Federal Communications Commission (FCC) we were not afforded the opportunity to separate the variable of tower lighting systems from tower heights. Given these regulations, application and management implications of our results remain the same regardless of this potential confounding variable. Future research should address the potential alteration of existing light systems on tall towers to minimize avian collisions.

The broad geographic region encompassed by our study area (circa 153,600 km^2) lends support that our results and conclusions are representative of fatality numbers beyond Michigan. However, given our small sample size of tall towers, additional studies of towers >305 m AGL should be conducted in other geographic settings for valuable replication and potential validation of our results. Our findings are likely to be applicable to towers shorter and taller than those we studied. However, future research on avian collisions with communication towers should examine tower heights between 146 and 305 m AGL, as well as towers shorter and taller than those we studied. Utilization of methodology similar to ours would facilitate comparisons of avian fatality rates based on geographic and tower characteristics.

The diversity of species that collided with communication towers in our study was consistent with other similar research (Shire et al. 2000, FCC 2005, Manville 2007). Shire et al. (2000) compiled documented cases of bird mortalities at about 50 tall guyed communication towers in the United States and tallied about 230 species impacted from these studies. 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, we designed our study to encompass the peak of neotropical songbird migration, thereby potentially missing peak migration periods of species such as short distance migrants that do not overlap with peak of most neotropical migrants.

Few other studies of avian collisions with communication towers have quantified observer detection rates and carcass removal rates (Kerlinger 2000, FCC 2005). However, recent research on avian and bat fatalities at industrial wind turbines provides a source of comparison. When considering birds similar in size to those which typically collide with communication towers (e.g., warblers (parulidae), vireos (vireonidae), and thrushes (turdidae)), Johnson et al. (2002) determined that observers at wind turbines detected a mean of 0.29 of carcasses and that carcasses remained on the ground for a mean of 4.69 days, similar to observer detection and removal rates in our 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. Adjustments for observer detection and scavenging rates would increase all of our estimates of fatalities at the towers we studied. Numbers of fatalities we presented and used in our statistical analyses do not reflect these adjustments because detection rates and carcass removal rates were similar among sites and did not materially change results of the analyses.

MANAGEMENT IMPLICATIONS

Given the increasing number of communication towers in the United States and a growing interest in addressing the bird collision issue, our study is of particular importance (Erickson et al. 2001, FCC 2005, 2006, Manville 2007). Our results show that bird fatalities may be significantly reduced by constructing unguyed towers instead of guyed towers and by constructing shorter towers (116–146 m AGL) instead of taller towers (>305 m AGL). However, taller towers are typically able to broadcast and receive information from a larger area; therefore, more shorter towers may be required to equal the capabilities of one tall tower. Adaptive management should be used when making recommendations for siting communication towers. For example, shorter, unguyed towers may be more appropriate for areas near the Habitat Conservation Areas for endangered songbirds, and some areas may be deemed safer for tall towers. In concert with information on safer FAA obstruction lighting (FAA 2000, Gehring et al. 2009), our research provides quantitative information necessary to the FCC and FAA for compliance with the National Environmental Policy Act (NEPA) under which communication towers are licensed (FCC 2005). This information can be directly applied to future tower design, siting, licensing, and permitting and would substantially reduce the numbers of fatalities of migratory and non-migratory birds resulting from tower collisions. If estimates of 4 million to 5 million bird fatalities per year at communication towers are correct, adherence to our findings in this and Gehring et al. (2009) could result in reducing overall fatalities by millions of birds per year.

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Appendix. Number and percent of total of avian fatalities (by species) at communication towers located throughout Michigan, USA, during September–October 2003 and May and September 2004 and 2005 (20 days each season).

	Fall 2003, 6 towers		Spring 2004, 23 towers		Fall 2004, 24 towers		Spring 2005, 6 towers		Fall 2005, 6 towers		Total	
Bird species[a]	**No.**	**Percent total**	**No.**	**Percent total**	**No.**	**Percent total**	**No.**	**Percent total**	**No.**	**Percent total**	**No.**	**Percent 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 flavipes*)			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 (*Empidonax 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 titmouse (*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 palustris*)							1	<1%			1	<1%
Winter wren (*Troglodytes troglodytes*)							1	<1%			1	<1%
Eastern bluebird (*Sialia sialis*)					1	<1%					1	<1%
American robin (*Turdus migratorius*)			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 (*Dumetella 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 solitarius*)	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 (*Dendroica 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 (*Dendroica 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%

Appendix (*Continued*)

Bird species[a]	Fall 2003, 6 towers		Spring 2004, 23 towers		Fall 2004, 24 towers		Spring 2005, 6 towers		Fall 2005, 6 towers		Total	
	No.	Percent total	No.	Percent total	No.	Percent total	No.	Percent total	No.	Percent total	No.	Percent total
Brown-headed cowbird (*Molothrus ater*)			1	<1%			1	<1%			2	<1%
Baltimore oriole (*Icterus galbula*)							2	1%			2	<1%
Scarlet tanager (*Piranga olivacea*)			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 passerina*)			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[b]			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[b]			14	7%	17	11%	11	7%	8	6%	50	7%
Unknown—warbler/vireo size[b]	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 American Ornithologists' Union Check-list of North American Birds 7th Edition (American Ornithologists' Union 1998).
[b] Bird carcass heavily scavenged preventing identification of species.