# A Summary and Comparison of Bird Mortality from Anthropogenic Causes with an Emphasis on Collisions[1]

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## Abstract

We estimate that from 500 million to possibly over 1 billion birds are killed annually in the United States due to anthropogenic sources including collisions with human-made structures such as vehicles, buildings and windows, power lines, communication towers, and wind turbines; electrocutions; oil spills and other contaminants; pesticides; cat predation; and commercial fishing by-catch. Many of the deaths from these sources would be considered unlawful take under federal laws such as the Endangered Species Act, Migratory Bird Treaty Act, and the Bald and Golden Eagle Protection Act. In this paper, we summarize this literature and provide the basis for the mortality projections for many of the apparent significant sources. Most of the mortality projections are based on small sample sizes, and on studies typically lacking adjustments for scavenging and searcher efficiency biases. Although the estimates for each source often range by an order of magnitude, the cumulative mortality from all these sources continues to be a concern.

*Key Words:* avian mortality, avian fatalities, collisions, communication towers, contaminants, electrocutions, fishing by-catch, power lines, vehicles, wind turbines.

## Introduction

All taxonomic groups of birds are subjected to significant human-caused mortality. Most of the anthropogenic-caused bird mortality would be considered unlawful take under the Migratory Bird Treaty Act, Endangered Species Act, and Bald and Golden Eagle Protection Act. The recently well-publicized prosecution of a utility for Golden Eagle (*Aquila chrysaetos*) electrocutions in Colorado by the United States Fish and Wildlife Service has increased the awareness of these issues (Manville this volume a). Collisions with artificial structures are a significant and well-documented source of bird mortality. Bird collisions with artificial structures and associated fatalities have been documented in the United States (US) since the late 1880s (Crawford and Engstrom 2000). A large amount of published and unpublished literature exists on avian collisions with artificial structures and vehicles. Bird mortality associated with pesticides, oil spills, oil pools, and other contaminant sources have also received significant attention. Domestic and feral cats have also been considered a major source of anthropogenic-caused mortality with estimates near 100 million annual bird deaths. However, calculating accurate numbers of bird fatalities associated with any of these sources is difficult due to limitations in the scope of most mortality studies, as compared to the extensive distribution and extent of these sources. Some individual studies have been well designed to obtain accurate fatality estimates for the particular structure(s) investigated (e.g., Kemper 1996, Johnson et al. 2002); however, most studies that are available for making these estimates lack standardized methods for searching, and often do not consider sources of bias, such as scavenging and searcher efficiency.

Many of the studies are limited to documenting avian collisions at a particular season or location. For example, many of the studies are limited to fall migration periods. Furthermore, many of the studies were conducted in response to suspected or actual large mortality events, and focus on areas where the number of fatalities may be unusually high. For example, many power line studies involved monitoring fatalities associated with lines near wetlands with high waterfowl use. In many cases, fatality estimates derived from data reported in the available literature would most likely be an over-estimate of the true mortality. Estimating the annual fatality rate for any of these sources requires a random or at least representative sample of experimental units (e.g., buildings, communication towers, miles of road, number of agricultural fields) with information replicated across time, but due to obvious logistical and financial constraints, a large representative sample of experimental units for each source has not been studied.

We did not attempt to develop our own estimates of avian mortality from sources other than wind turbines

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due to the lack of standardized information. We feel that the available data cannot be used to make projections based on averages of individual estimates. Instead, we have updated previous estimates provided in the literature based on increases in the number (e.g., buildings) or extent of collision sources. Although the many difficulties in making fatality projections is widely recognized, the shear magnitude of these projections should continue to bring an awareness and concern to anthropogenic-caused bird mortality.

## Sources of Biases in Estimating Fatality Rates

Determining the extent of wildlife mortality due to environmental perturbations such as oil spills or due to collisions with structures such as power lines, buildings, communication towers, or wind plants is a difficult sampling and estimation problem (Erickson et al. 2000a, 2001). Biases associated with observer detection and scavenging rates can lead to biased mortality estimates (Morrison 2002). Observers conducting searches for carcasses often may not detect some of the carcasses for various reasons including dense vegetative cover, size of carcass and cryptic coloration of the carcasses. During fatality studies at the Buffalo Ridge wind plant in southwest Minnesota, the proportion of carcasses detected by observers, (i.e., searcher efficiency rates) for small birds (e.g., most passerines) was estimated at 30 percent when averaged across several habitat types (e.g., plowed field, corn, wetland, CRP/grassland) and across spring, summer and fall seasons (Johnson et al. 2002). In contrast, searcher efficiency rates for small birds at the Foote Creek Rim wind plant, Wyoming in short grass prairie habitat was 57 percent (Young et al. 2003). Searcher efficiency rates for large birds (e.g., waterfowl and raptors) were 49 percent on average at Buffalo Ridge, but over 90 percent at Foote Creek Rim. Similar protocols for searching (transect widths, etc.) were used at both sites. Comparisons of fatality rates at Foote Creek Rim and Buffalo Ridge that unadjusted for searcher efficiency would be very misleading.

Estimated disappearance or scavenger removal rates vary significantly in the literature. Nearly 80 percent (79.2) of the chicks placed in a mixed grazed pasture were removed within 24 hr of being placed (Wobeser and Wobeser 1992). In Maryland, approximately 75 percent of 78 trial carcasses placed in agricultural fields were removed in the first 24 hr (Balcomb 1986). During a study at a TV tower in Florida, 93 percent of 157 birds purposely placed underneath the tower at dusk to monitor predation were partially or completely removed by the next morning (Crawford 1971). In France, Pain (1991) estimated duck carcasses lasted an average of 1.5 d in open habitats, whereas those concealed by vegetation or those in water lasted between 3.3 and 7.6 d. In one orchard during this study, scavengers removed all 25 of the placed carcasses within 24 hr, with lower rates in the other orchards studied. At the Vansycle wind plant in Oregon, small carcasses or evidence of the carcass (e.g., feather spot) lasted an average of 15.0 d, and large carcasses lasted on average longer than 28 d (Erickson et al. 2000b). At the Buffalo Ridge wind plant, small carcasses persisted an average of 4.7 d, whereas small birds at Foote Creek Rim persisted 12.2 d. Disappearance rates also likely vary by species or avian group. For example, it is speculated that raptor carcasses last longer than other large bird carcasses such as game birds and waterfowl, although limited empirical data exist to test this hypothesis.

Carcass detection rates and scavenging rates do vary among sites, habitats, seasons and sizes of birds. Comparison of fatality rates that are not adjusted for these two primary sources of bias can be very misleading. Differences in observed fatality rates may only reflect true differences in scavenger densities or carcass detection rates. Many, if not most of the studies of bird mortality we present below, do not account for the biases described above. The following sections provide a review of studies of mortality for collision sources such as power lines, buildings and windows, communication towers and wind turbines.

## Collision Mortality

### *Avian Mortality Due to Collisions with Automobiles, Trains, and Airplanes*

#### Study examples

Although several studies have been conducted in Europe (e.g., Finnis 1960, Hodson 1962, Dunthorn and Errington 1964, Hodson and Snow 1965, Hugues 1996), we found relatively few documents that reported vehicle-related avian mortality in the United States. In Illinois, Decker (1987) traversed a 4.4-mile (7 km) stretch of road daily and estimated mortality at 33 birds per mile per year (21 birds/km/year). The most common fatalities were passerines or other small birds, including Yellow-billed Cuckoo (*Coccyzus americanus*), Blue Jay (*Cyanocitta cristata*), Red-winged Blackbird (*Agelaius phoeniceus*), and Indigo Bunting (*Passerina cyanea*). In Ontario, Canada, Ashley and Robinson (1996) searched a 2.2 mile (3.6 km) stretch of road located near wetlands three days a week and calculated that 223 birds were killed per mile per year (139 birds/km/year), most of which were passerines. No adjustments were made for searcher efficiency or scavenger removal in either of these studies.

From 1969 to 1975, Case (1978) searched the entire length of Interstate 80 in Nebraska (458 miles, 732 km) and documented a total of 7,195 Ring-necked Pheasant (*Phasianus colchicus*) vehicle collision fatalities. Based on finding 562 dead ducks over a 10-year period, Sargeant (1981) estimated that vehicles killed an average of 13,500 ducks each year in the prairie pothole regions of North and South Dakota. Mean annual mortality of ducks was estimated to be 0.250 ducks per mile (0.156 ducks/km) of interstate, 0.008 ducks per mile (0.005 ducks/km) of unsurfaced roads, and 0.042 ducks per mile (0.026 ducks/km) for all road types combined. Although the number of fatalities appears high, it was estimated to represent less than 0.2 percent of the breeding population in the study area. Much lower mortality was documented during other studies. McClure (1951) documented only four road-killed ducks while driving 76,250 miles (122,000 km) of road in Nebraska. In Minnesota, Sargeant and Forbes (1973) found only three road-killed ducks along 17 miles (27 km) of roads driven almost daily for an 18-month period. Raptors also appear susceptible to vehicle collisions in some areas. Based on driving surveys over a 10-year period in New Jersey, Loos and Kerlinger (1993) estimated that 25 raptors were killed per year within a 90-mile (145 km) survey route. Most of the fatalities were owls; however, six species of hawks were also found among road fatalities.

#### Annual mortality predictions

Banks (1979) summarized several studies and reported estimates of avian fatality rates ranging from 2.7 to 6.1 deaths per mile of road per year to 60 to 144 bird fatalities per mile per year. From U.S. studies reported in Banks (1979), use of the minimum (2.7) and maximum (96.25) reported values for bird deaths per mile yields estimates of 10.7 million to 380 million annual bird deaths on U.S. roads. Banks (1979) estimated total annual avian road mortality to be 57.2 million. This figure was derived from the estimate of 15.1 bird fatalities per mile reported by Hodson and Snow (1965), who conducted a fairly extensive study in England, although no scavenging or searcher efficiency bias was considered which would result in an underestimate of true fatality rates. The U.S. Census Bureau (Statistical Abstract of the United States 1999) estimated 3,944,597 miles of road in the US in 1997. Using this number to update Banks' estimate yields a 1997 estimate of approximately 60 million avian fatalities on U.S. roadways annually. The number of registered vehicles has increased 35 percent from 1980 to 1998 alone, so an alternative estimate would be 1.35 times 60 million, or approximately 80 million avian fatalities. It is believed that some of the mortality observed along roads is actually caused by collisions with adjacent power and telephone lines (C.J. Ralph, pers. comm.).

Although most avian fatalities caused by vehicles occur on roadways, avian collisions also occur with trains (Spencer 1965) and airplanes. Avian collisions with airplanes present a significant hazard to both military and commercial aircraft. The Federal Aviation Administration (FAA) keeps records of avian collision strikes involving aircraft in the US. In 1998, the U.S. Air Force reported over 3,500 bird strikes by planes, and it is estimated that civil aircraft strike over 25,000 birds per year. Data collected from 1990 to 1999 indicate that gulls (31 percent), waterfowl (31 percent) and raptors (15 percent) comprised 77 percent of the reported bird strikes causing damage (Bird Strike Committee USA 2000). No estimates for train-caused avian mortality were found in the literature. It is likely that train collisions also result in several thousand bird deaths annually in the United States.

### *Avian Mortality Due to Collisions with Buildings and Windows*

#### Study examples

Numerous studies have documented extensive avian collision mortality associated with buildings and similar structures such as smokestacks or monuments. Fatalities associated with buildings are usually the result of collisions with tall buildings and collisions with windows at residential houses. Studies may be divided into two categories, studies of short-term or episodic mortality events, and longer-term studies. Some mortality events at tall buildings have involved extensive numbers of birds. At one oil flare stack in Alberta, 1,393 dead birds comprised of 24 species of passerines were found over a 2-day period in May 1980 (Bjorge 1987). Over a 3-day period in October 1964, Case et al. (1965) searched several buildings in Florida and recovered 4,707 dead birds, most of which were passerines. Also in Florida, Maehr et al. (1983) searched the base of four smokestacks over a 2-day period in September and recovered 1,265 dead passerines. The authors estimated that 5,000 birds might have collided with the structures during this period. In the fall of 1970, 707 dead birds were documented below the Empire State Building in New York (Bagg 1971). Extensive numbers of nocturnal migrant fatalities have also been documented at the Washington Monument in Washington, D.C. (Overing 1936). From October 5-8, 1954, 9,495 dead birds (mostly passerines) were found at 25 tall buildings in the eastern and southern US following a cold front during fall migration, and it was estimated that 106,804 birds were actually killed (Johnston and Haines 1957).

Several long-term studies have documented the chronic nature of collision mortality associated with some buildings (Erickson et al. 2001). Over a 3-year period in Toronto, Ontario, Ogden (1996) counted 5,454 dead birds at 54 tall glass buildings and estimated that 733 birds (mostly passerines) were killed per building per year. Following nights with inclement weather conditions, Taylor and Kershner (1986) searched one building in Florida from 1970 to 1981 and documented 5,046 avian fatalities comprised of 62 species, the majority of which were passerines. Two smokestacks in Citrus County, Florida were searched five times per week from 1982 to 1986, and 2,301 dead birds were found (Maehr and Smith 1988). From this, the authors estimated that 541.4 birds were killed per year. Fatalities included 50 species, most of which were neotropical migrant passerines. Daily searches of two smokestacks in Ontario, Canada over a 4-year period yielded 8,531 dead birds. Again, most of these were passerines (Weir 1976).

Klem (1990) searched two houses in Illinois and New York daily from 1974 to 1986. A total of 100 dead birds were found at the houses, and the author estimated that 55 percent of window collisions result in death. Over the 1989-1990 winter, 5,500 residential houses in the U.S. were searched for dead birds using a standardized procedure, and a total of 995 dead birds were found (Dunn 1993). The author estimated that an average of 0.85 birds are killed per house each winter based on actual mortality ranging from 0.65 to 7.7 birds per house per year. The fatalities were comprised of 66 species, most of which were passerines commonly found at feeders during the winter.

#### Annual mortality predictions

In 1995 there were an estimated 4,579,000 commercial buildings (warehouse, religious/worship, public assembly, offices, mercantile/services, lodging, health care, food sales, education) in the United States (Statistical Abstract of the United States 1999). Klem (1990) reported there were 93.5 million residential houses in 1986. Due to the large number of structures in this class, and only a few good studies, it is difficult to obtain very accurate fatality estimates for the US. Most of the building and window collision data come from studies of known or suspected problem structures. Accurately predicting the number of building-related avian fatalities would require random selection of numerous buildings of all types and sizes, followed by long-term standardized and systematic searches for dead birds.

Banks (1979) acknowledged a lack of information on building and window collision mortality, and estimated 3.5 million avian fatalities per year based on an arbitrary estimate of 1 bird fatality per square mile in the US. An estimate of 97.6 to 976 million bird deaths per year in the U.S. due to collisions with windows was based on an estimated 1 to 10 bird deaths per structure per year from a fatality study in New York (Klem 1990).

### *Avian Mortality Due to Collisions with High Tension Lines*

#### Study examples

Concern over avian collisions with high-tension lines has existed at least since 1876, when Coues (1876) counted approximately 100 avian carcasses (primarily Horned Larks (*Eremophila alpestris*) beneath a 3-mile long (4.8 km) section of telegraph wire between Denver, Colorado, and Cheyenne, Wyoming. Since then, there have been numerous studies of power line collisions involving birds. Faanes (1987) searched 6 miles (9.6 km) of power lines in North Dakota in the spring and fall of 1977 and 1978. Based on a total of 633 dead birds found, he estimated that 200 avian fatalities per mile per year (125 birds/km/yr) were occurring at those sites. The power lines included in the study were located near wetlands or lakes and most of the fatalities consisted of waterbirds (46 percent) and waterfowl (26 percent), followed by shorebirds (8 percent), and passerines (5 percent).

For some types of birds, power line collisions appear to be a significant source of mortality. Waterfowl band recovery data collected prior to 1967 indicated that powerline strikes were responsible for 65 percent of the collision fatalities involving 3,015 banded birds (Stout 1967). Of 75 Trumpeter Swan (*Cygnus buccinator*) deaths recorded from 1958 to 1973, 19 percent of the fatalities were due to powerline collisions (Weaver and St. Ores 1974). During a 2-year study of Mute Swans (*C. olor*) in Rhode Island, Willey (1968) found that 26.7 percent of adult fatalities were due to collisions, mostly with powerlines.

#### Annual mortality predictions

The U.S. electrical energy system includes more than 500,000 miles (800,000 km) of bulk transmission lines (Edison Electric Institute 2000). Estimates for the total length of distribution lines (power lines to residences and businesses) in the US could not be found in the literature, but are far greater than for bulk transmission lines. Estimates of avian fatalities due to collisions with high-tension lines are lacking due to minimal monitoring efforts on a large-scale basis. As with most other sources of collision mortality, most monitoring and/or studies are conducted in response to a known or perceived problem, and few data have been collected at randomly-chosen sites. Based on the limited studies, waterfowl including ducks, geese, swans, cranes, and shorebirds appear to be most susceptible to collisions when powerlines are located near wetlands. In upland habitats away from wetlands, raptors and passerines appear most susceptible to collision.

In the Netherlands, where approximately 2,875 miles (4,600 km) of high-tension lines are present, Koops (1987) estimated that approximately 750,000 to 1 million birds are killed annually by collisions based on variation in extrapolation made in three other Netherlands studies. Estimates in all three studies were in the same order of magnitude. The latter study estimated (unadjusted for scavenging and searcher efficiency) 113 fatalities per km of high tension line in grasslands, 58 fatalities per km of high tension line in agricultural lands, and 489 fatalities per km of high tension line near river crossings. We use the mean estimate (adjusted for scavenging and searcher efficiency bias) of 750,000/2,875 = 261/mile of high tension line. Extrapolating the mid-range of this estimate to the 500,000 miles (800,000 km) of bulk transmission lines in the United States would lead to a fatality estimate of approximately 130 million birds per year. Given the large, but unknown number of miles of power and other high tension lines in the U.S., and the lack of standardized data in the U.S., this estimate may be off by an order of magnitude or more.

## *Avian Mortality Due to Collisions with Communication Towers*

### Study examples

Substantial concern over the recent proliferation of communication towers in the U.S. has arisen in response to large fatality events, such as an estimated kill of 5,000 to 10,000 birds, mostly Lapland Longspurs (*Calcarius lapponicus*), at 3 associated communication towers and a natural gas pumping facility in western Kansas on the night of January 22, 1998 (Evans 1998). Large, single-night fatality events are not new. Kemper (1996) counted and identified species for over 12,000 birds killed one night in 1963 at a television tower in Wisconsin. As a result of this concern, avian collision mortality associated with communication towers has received more study and review than other sources of collision mortality, with the possible exception of wind turbines. During our review we located numerous studies covering avian collision mortality with communication towers in 25 states. The vast majority of the studies were one-day searches at single towers following nights of substantial avian mortality. Most avian fatalities at communication towers involve nocturnal migrant passerines, especially warblers, vireos, and thrushes.

Erickson et al. (2001) reported on 17 studies where collision mortality was measured for periods of time ranging from one to 38 years. For studies conducted over a period of at least two years, with searches conducted on a daily or almost daily basis, the estimated mean number of annual collisions per tower ranged from approximately 82 birds per year at an 825-ft (250-m) tall television tower in Alabama (Bierly 1968, 1969, 1972; Remy 1974, 1975; Cooley 1977) to 3,199 birds per year at a 1,000-ft (305-m) tower in Eau Claire, Wisconsin (Kemper 1996). Very few of these studies measured scavenger removal and searcher efficiency. The research at Eau Claire, Wisconsin, was the longest study conducted at any one tower and covered the period from 1957 to 1994 (38 years). Two other continuous studies at individual communication towers include a study from 1960 to 1997 (37 years) at a 1,368-ft (417-m) tower in Nashville, Tennessee (Nehring 2000), and another study that took place at a 1,010-ft (308-m) tower from October 1955 to December 1983 (28 years) at Tall Timbers Research Station in Tallahassee, Florida (Crawford and Engstrom 2000). At the Tennessee tower, 19,880 fatalities were recovered over the 37-year period. At the Florida tower, 1,517 birds on average were killed per year.

### Annual mortality predictions

Based on the July 2002 statistics from the Federal Communication Commission's (FCC) Antenna Structure Registry Database (FCC 2002), more than 138,000 towers were listed with the Commission, of which some 106,000 were lighted. Since an undetermined number of towers are not registered with the FCC, and the number of new towers are increasing at a high rate (Manville this volume a), the total number of communication towers may be as high or higher than 200,000. Numerous types of towers are being built, including radio, television, cellular, microwave, paging, messaging, open video, public safety, wireless data, government dispatch, and emergency broadcast towers (Manville this volume a). Due to the recent proliferation of cellular phones and the advent of digital television, approximately 5,000 to 10,000 new towers are being added each year (6-8 percent increase annually). Some have estimated there will be a total of 600,000 towers in the United States within the next 10 years, creating a potentially catastrophic impact on avian migrants (M. Manville, pers. comm.). Avian mortality appears to increase with tower height. Taller towers also tend to have more guy wires and more lights, often more solid or pulsating red lights, which may increase the potential for collision mortality.

Most lighted towers are lit due to FAA pilot warning regulations. On foggy or low cloud-ceiling nights, these lighted towers appear to attract neotropical nocturnal migrants (Manville 2000, Kerlinger 2000), increasing the risk of collision. Lighting appears to be the single most critical attractant, and preliminary research indicates that solid and pulsating red lights seem to be more attractive to birds at night during inclement weather conditions than are white strobe lights. It is speculated that the birds are attracted to the lighted towers, become disoriented and fly around them in a spiral, colliding with the tower, the guy wires, other birds, or falling to the ground in exhaustion (Larkin and Frase 1988, M. Manville, pers. comm.).

There are very few long-term studies of avian mortality at communication towers, although there are concerted efforts by both the industry and other interested parties to begin collecting standardized data and using standardized metrics following the methods and metrics recommended and used at many wind power plants (Anderson et al. 1999). Currently, much of the published and unpublished information regarding avian fatalities at communication towers is based on single observations of carcasses found at the base of the towers (Erickson et al. 2001). Based on estimates of Banks (1979) and models developed by Tall Timber Research and Bill Evans (M. Manville, pers. comm.), conservative estimates range from 4 million to 5 million avian fatalities per year (Manville this volume a). These estimates could be off by an order of magnitude, especially as the number of towers increases at a high rate each year (Manville this volume a). Further studies are obviously needed to ascertain the true impact.

## *Avian Mortality Due to Collisions with Wind Turbines*

### Study examples

Many of the early studies of bird mortality at wind plants involved examining impacts associated with single, large experimental turbines. The first study took place in Sandusky, Ohio, where a single large turbine was monitored for avian mortality during four migratory seasons. Two dead birds were found during this period (Gauthreaux 1994). Two large experimental turbines and a meteorological tower in Wyoming were monitored for avian mortality in the early 1980s. Twenty-five fatalities were found over a one-year period, most of them involving passerines that had collided with guy wires on the meteorological tower (U.S. Bureau of Reclamation 1984). At a single, 60-m tower wind turbine in Solano County, California, seven fatalities were documented from September 1982 to January 1983, and the total fatality estimate with adjustments for scavenger removal and searcher efficiency was estimated at 54 birds (Byrne 1983, 1985).

Most of the concern over bird mortality from wind turbines began at one of the first large-scale wind energy developments in the US In response to several reported incidents of avian collisions, the California Energy Commission (CEC) obtained data on bird strikes at the Altamont and Tehachapi wind plants in California through interviews and review of unpublished data collected over a 4-year period from 1984 to 1988 (CEC 1989). This study documented 108 raptor fatalities of seven species. Collisions with wind plant structures accounted for most of the avian fatalities (67 percent), including 26 Golden Eagles and 20 Red-tailed Hawks (*Buteo jamaicensis*), while collision and electrocutions associated with power lines comprised the majority of the other fatalities. Several subsequent studies were initiated to further examine fatalities at California wind plants. Many of these studies have been conducted at Altamont Pass, where more than 5,000 turbines exist within the WRA. In general, these studies focused on obtaining raptor fatality estimates with other bird fatalities recorded coincidentally. An early 2-year study documented 182 bird deaths on study plots, 68 percent of which were raptors and 26 percent of which were passerines. The most common raptor fatalities were Red-tailed Hawk (36 percent), American Kestrel (*Falco sparvarius*) (13 percent), and Golden Eagle (11 percent). Causes of raptor mortality included collisions with turbines (55 percent), electrocutions (8 percent), and wire collisions (11 percent) (Orloff and Flannery 1992). Based on the number of dead birds found, the authors estimated that as many as 567 raptors may have died over the 2-year period due to collision with wind turbines. Further investigations at Altamont continued to document levels of raptor mortality sufficient to cause concern among wildlife agencies and others (Orloff and Flannery 1992, 1996; Howell 1997).

Raptor mortality at other older wind plants in California is apparently less that what has been observed at Altamont. Researchers estimated 6,800 birds were killed annually at the San Gorgonio wind facility (more than 3000 turbines) based on 38 dead birds found while monitoring nocturnal migrants at a small sample of turbines. McCrary et al. (1983, 1984) estimated that 69 million birds pass through the Coachella Valley annually during migration; 32 million in the spring and 37 million in the fall. The 38 avian fatalities were comprised of 25 species, including 15 passerines, seven waterfowl, two shorebirds, and one raptor. Considering the high number of passerines migrating through the area relative to the number of passerine fatalities, the authors concluded that this level of mortality was biologically insignificant (McCrary et al. 1986), although the mortality estimates were based on a small sample size. During a more recent study at San Gorgonio, (Anderson, pers. comm.) documented 58 fatalities near wind turbines, including fifteen doves (mostly *Columba livia*), five waterfowl, seven rails (mostly American Coot [*Fulica americana*]), seven passerines, four gulls, three owls, two ravens, one diurnal raptor, one egret, and eleven unidentified birds. The waterfowl, rail and shorebird mortality generally occurred when water was present in the vicinity of the wind resource area, attracting large numbers of waterfowl and shorebirds.

The high levels of raptor mortality associated with the Altamont wind plant has not been documented at newer wind plants constructed in other states (*table 1*). We discuss three wind resource areas that have been monitored for mortality and have included adjustments for scavenging and searcher efficiency bias (Osborn et al. 2000, Johnson et al. 2002, Young et al. 2003, Erickson et al. 2000b), although other studies listed in *table 1* include Erickson et al. 2003a and 2003b, Howe et al. 2002, Nicholson 2003 and Johnson et al. 2002.

Several studies have been conducted at the Buffalo Ridge wind resource area, which is located an agricultural landscape in southwestern Minnesota. At the 73-turbine Phase I wind plant, eight collision fatalities were documented during the initial two-year period of operation (Osborn et al. 2000). The fatalities consisted of one Ruddy Duck (*Oxyura jamaicensis*), one Franklin's Gull (*Larus pipixcan*), one Yellow-bellied Sapsucker (*Sphyrapicus varius*), and four passerines. The estimated total number of annual fatalities for the entire wind plant was 36, equivalent to an annual mean of 0.49 collisions per turbine per year. A more extensive study of this wind plant plus two additional wind plants on Buffalo Ridge totaling over 350 turbines was conducted from 1996 through 1999. Total annual mortality was estimated to average 2.8 birds per turbine based on the 55 fatalities found during the study. Only one raptor, a red-tailed hawk, was found during the 4-year monitoring period. Most of the fatalities were passerines (76.4 percent), followed by waterfowl (9.1 percent), waterbirds and upland gamebirds (5.5 percent each). Many of the fatalities documented were nocturnal migrants (Johnson et al. 2002). Radar studies at Buffalo Ridge (Hawrot and Hanowski 1997) indicate that as many as 3.5 million birds per year may migrate over the wind development area (Johnson et al. 2002). The two largest single mortality events reported at a

**Table 1–***Estimates of avian collision mortality by wind projects.*

| Location of study[1] | No. turbines | No. MW | No. birds/ turbine/year | No. birds/ MW/year | No. raptors /turbine/year | No. raptors /MW/year |
|---|---|---|---|---|---|---|
| West (excluding California) | | | | | | |
| Stateline, Oregon/Washington | 454 | 300 | 1.69 | 2.56 | 0.053 | 0.080 |
| Vansycle, Oregon | 38 | 25 | 0.63 | 0.96 | 0.000 | 0.000 |
| Klondike, Oregon | 16 | 24 | 1.42 | 0.95 | 0.000 | 0.000 |
| Nine Canyon, Washington | 37 | 48 | 3.59 | 2.76 | 0.065 | 0.050 |
| Foote Creek Rim, Wyoming | 105 | 68 | 1.50 | 2.34 | 0.035 | 0.053 |
| Subtotal | 650 | 465 | 1.71 | 2.40 | 0.044 | 0.068 |
| Upper Midwest | | | | | | |
| Wisconsin (MG&E and PSC) | 31 | 20 | 1.30 | 1.97 | 0.000 | 0.000 |
| Buffalo Ridge, Minnesota | 354 | 233 | 2.86 | 4.21 | 0.002 | 0.008 |
| Subtotal | 386 | 254 | 2.73 | 4.03 | 0.002 | 0.008 |
| East | | | | | | |
| Buffalo Mountain, Tennessee | 3 | 2 | 7.70 | 11.67 | 0.000 | 0.000 |
| Grand Total | 1039 | 721 | 2.11 | 3.04 | 0.029 | 0.045 |
| California (older projects) | | | | | | |
| Altamont, California | ~5400 | 548 | na[2] | na | 0.100 | na |
| Montezuma Hills, California | 600 | 60 | na | na | 0.048 | na |
| San Gorgonio, California | ~2900 | 300 | 2.31 | na | 0.010 | na |
| Subtotal | ~8900 | 878 | na | na | 0.067 | na |

| Total fatality projections | Overall | Outside California |
|---|---|---|
| Projected annual bird fatalities[3] | 20,000-37,000 | 9200 |
| Raptors[4] | 933 | 195 |

[1]We excluded studies of 4 small project sites in Vermont, Pennsylvania, Colorado, and Iowa that were conducted short-term and/or did not include adjustments for scavenging and searcher efficiency bias.
[2]Not available; data on scavenging or searcher efficiency or average MW of study turbines not available
[3]The per turbine/year and per MW/year estimates applied to the number of MW in U.S. at the end of 2003
[4]Based on the per turbine estimate in California (11,500 turbines) and the per MW basis outside California

U.S. wind plant were fourteen spring migrant passerines at two turbines at the Buffalo Ridge, Minnesota wind plant on one night and approximately 30 spring migrant passerines at a floodlit substation and nearby turbines in West Virginia on one night.

At the Foote Creek Rim wind plant located in Carbon County, Wyoming within native grassland-steppe and shrub-steppe habitats, total mortality associated with the 69 turbines and 5 meteorological towers was estimated to be approximately 143 birds per year, based on the 122 collision fatalities actually found during the first three years of operation (Young et al. 2003). Mean annual mortality was estimated to be 1.5 birds per turbine and 0.03 raptors per turbine per year. Of the 122 fatalities found during the study, raptors comprised only 4.0 percent, whereas passerines comprised 90.2 percent. Furthermore, while many of the fatalities at this location were nocturnal migrant passerines, the largest number of carcasses detected at a turbine during one search was two, suggesting no large mortality events of nocturnal migrants have occurred at this site.

At a 38-turbine wind plant completed on Vansycle Ridge, Oregon, which is located in an agricultural landscape, 12 avian fatalities were located during the first year of operation (Erickson et al. 2000b). The casualties were comprised of at least six species, and most of the fatalities (58 percent) were passerines. Total estimated mortality adjusted for scavenging and observer detection rate estimates, was 24 birds per year, or 0.63 birds per turbine per year. No raptors were among the fatalities (Erickson et al. 2000b).

We are unaware of any studies that directly compare communication tower mortality to wind turbine mortality; although, we do have limited information on guyed meteorological tower mortality compared with wind turbine mortality at the Foote Creek Rim, Wyoming wind plant. At this site searches of both wind turbines (600-kW, approximately 200-ft (60-m) towers) were conducted and guyed met towers (200 ft (60 m) in height) once every 28-d during the study. During this period of study, the met towers had estimates of 8.1 bird fatalities per tower per year, whereas the turbines had estimates of 1.5 bird fatalities per turbine per year (Young et al. 2003).

### Annual mortality predictions

The average number of avian collision fatalities per turbine and per MW (Megawatt) are 2.11 and 3.04 per year, respectively. There were approximately 17,500 turbines and 6,374 MW of installed wind generation capacity at the end of 2003 in the United States, with approximately 6,000 turbines and 4,331 MW outside California. Therefore, on average, we calculate approximately 20,000 (3.04 times 6374 MW) to 37,000 (2.11 times 17,500 turbines) die annually from collisions with wind turbines in the United States. We estimate approximately 9,200 birds will die annually outside California from the 4331 MW of installed wind generation capacity (2003). This extrapolation assumes fatality rates observed at wind projects that have been studied are representative of rates at wind projects not studied. Fatality estimates for all birds are generally not available at most old projects in California, and for all birds and raptors from Texas and Iowa, two states with significant wind development.

Because much attention has been given to the issue of raptor/wind power interaction, we also developed separate fatality estimates for raptors. Estimates of raptor fatalities per turbine per year from individual studies through 2001 (Erickson et al. 2001) ranged from 0 at the Vansycle, Oregon; Searsburg, Vermont; Ponnequin, Colorado; Somerset County, Pennsylvania; and Buffalo Ridge, Minnesota, Phase II and Phase III sites, to 0.10 per turbine per year at the Altamont, California site (C. Thelander, pers. comm.). Based on these statistics, we estimate 933 raptors are killed annually (2003) by turbines in the United States, with approximately 80 percent of the raptor mortality occurring at the older projects in California. We project raptor mortality at wind plants outside California to be 195 per year (2003) based on relatively small number of raptors found at Buffalo Ridge Minnesota (Johnson et al. 2002), Foote Creek Rim Wyoming (Young et al. 2003), Stateline Oregon and Washington (Erickson et al. 2003a), and Nine Canyon Washington (Erickson et al. 2003b).

## Other Non-collision Related Sources of Bird Mortality

The previous sections have focused on collision-related sources of bird mortality. We will now discuss in much less detail other significant sources of bird mortality which include oil spills, oil pools, cat predation, pesticides and other contaminants, electrocutions and fishing by-catch. The latter two sources are covered in more detail in Manville (this volume a, this volume b). Hunting is another obvious source of bird mortality, but since it is a permitted source, we do not discuss it.

### *Pesticides*

Pesticides are a significant source of bird mortality in the US as well as other countries (Pimentel et al. 1991; Mineau, this volume). Large die-offs of Swainson's Hawks (*Buteo swainsoni*) were observed in Argentina due to exposure to the pesticide monocrotophos in 1996 (Di Silvestro 1996). Approximately 160 million acres of cropland are treated with pesticides each year in the US (Pimentel et al. 1991) using data collected in the 1980s and 1990s. It has been estimated that approximately 67 million birds die annually in the US due to pesticides (Pimental et al. 1991). This estimate is based on the assumption that 10 percent of the estimated 672 million birds exposed to pesticides die each year. This estimate may be conservative, since the empirical data on bird mortality at crop fields is reported as 0.1 to 3.6 per acre (Mineau 1988). Lawn, turf, golf course and other pesticide uses were not included in this estimate.

### *Oil Spills*

Oil spills can be a significant source of bird mortality, but the occurrence of spills and the effect and are obviously difficult to predict. Over 30,000 bird carcasses were recovered, including 250 Bald Eagles (*Haliaeetus leucocephalus*) following the 1989 Exxon Valdez oil spill in Prince William Sound Alaska, but between 100,000 and 300,000 birds of all species were estimated to have died (Piatt et al. 1990). Flint et al. (1999) conservatively estimated over 1750 birds died as the result of the M/V Citrus spill near St. Paul Island, Alaska. Small spills or chronic oiling is much less publicized, yet possibly a significant source of seabird mortality (Burger 1993). Estimates of annual mortality based on counting oiled corpses on beaches from small or chronic oiling have ranged from less than 0.01 per km of shoreline to 3.68 per km. Many oiled birds which die at sea are never found on beaches. Considering the US, including the island territories, has approximately 90,000 miles of marine tidal shoreline, annual bird mortality from chronic oiling may easily be in the 10,000 to 100,000 range.

### *Oil Pits*

Man-made pits associated with oil and gas development are another well-documented source of bird mortality. Esmoil (1995) found 282 dead birds during weekly sampling of 35 oil pits in 1989, and 334 dead birds during weekly sampling of 53 pits in 1990. The largest affected taxonomic group was passerines (41 percent). Banks (1979), based on estimates made for the San Joaquin Valley in the early 1970s, conservatively estimated 1.5 million birds die annually due to these pits.

### *Cat Predation*

Domestic and feral cats might also be considered an anthropogenic source of bird mortality. 1990 U.S. census data report 60 million cats claimed as pets by owners, and an unknown number of unclaimed feral cats. Coleman and Temple (1996) estimated that between 8-219 million birds are killed by free-ranging cats in Wisconsin alone. These figures are derived from estimates that there are 1.4 - 2 million free-ranging cats in rural Wisconsin, that each cat on average kills between 28 and 365 animals per year, and that on average 20 to 30 percent of the animals killed by cats are birds (5 -100 birds/cat/year). We use the estimate of 100 million birds killed by cats on an annual basis, but this estimate is likely conservative. If the Wisconsin estimates are representative of the averages nationwide, this estimate is highly conservative given that there are 50 states and because it only accounts for cats claimed as pets by owners.

### *Electrocutions*

Recent prosecution of the Moon Lake Utility for violations of the Bald and Golden Eagle Act and the Migratory Bird Treaty Act (Manville this volume a) has brought more attention to the continued problem of electrocutions of raptors from powerlines. It appears that nation wide mortality estimates from electrocutions are not available. Most data available were not collected in a systematic fashion, and do not attempt to adjust for scavenging and searcher efficiency biases.

In a review of mortality reports from utilities, wildlife rehabilitators and falconers between 1986 and 1996, 1450 raptor electrocutions representing 16 species were confirmed, with Golden Eagles accounting for the largest percentage of fatalities (Harness and Wilson 2001).

### *Fishing By-catch*

Many groups of seabirds have been reported drowned by fishing nets and gear (Atkins and Heneman 1987) and yearly mortality may reach hundreds of thousands (Manville this volume b). Quality studies on the impacts from commercial fishing are absent except for a few studies (e.g., Brothers 1991), and most mortality reports are largely anecdotal.

## Cumulative Mortality

Based on the estimates derived or reviewed in this paper, annual bird mortality from anthropogenic sources may easily approach 1 billion birds a year in the US alone (*table 2*). Buildings, power lines and cats are estimated to comprise approximately 82 percent of the mortality, vehicles 8 percent, pesticides 7 percent, communication towers 0.5 percent, and wind turbines 0.003 percent. Other sources such as mortality from electrocution, oil spills and fishing by-catch are also contributors but estimates were not made and we have not even considered the impacts from loss of habitat which could also be considered anthropogenic.

## Discussion

Based on existing projections and projections made in this paper, annual avian mortality from anthropogenic causes may be near 1 billion. Given the uncertainty in the estimates, the true avian mortality, especially for communication towers, buildings and windows, vehicles, powerlines, pesticides, oil spills, fishing by-catch, cats, and vehicles could easily be different by an order of magnitude. In general, these sources of mortality continue to grow as our population grows (e.g., buildings and houses), and demand for efficient communications (e.g., cellular telephones), electricity (e.g., wind turbines and powerlines), fuel and other comforts of life grow as well. Although there is high variability in the estimated magnitude of total bird mortality for the different sources, there is also high variability in the types of birds (nocturnal migrants versus residents) and species that individual sources impact. Therefore, the significance on any one source or a particular location of a unit (e.g., a communication tower) may vary greatly depending on the species or groups of birds that may be impacted.

Many of the collision mortality studies have been conducted in response to a known or perceived risk, and therefore are probably not appropriate for extrapolation in the same manner we extrapolated for wind turbines. However, it has been argued by several researchers making mortality projections that their estimates are probably conservative (underestimates), given that scavenging and searcher efficiency biases have generally not been incorporated into the estimates. For example, Banks' (1979) estimate of vehicle mortality was based on the Hodson and Snow (1965) estimate of 15.1 birds per mile (9.4 bird/km), which was based on weekly surveys that did not adjust for scavenging and searcher efficiency.

The large uncertainties associated with estimates of mortality from one or multiple sources, along with the even larger uncertainties in bird populations (e.g., size, reproduction), makes it extremely difficult to understand the biological significance of human-caused mortality on birds at a population, regional, or even local level (Manville this volume a). Aldrich et al. (1975) estimated there are approximately 10 billion breeding landbirds in the US (excluding Alaska and Hawaii) in the spring, and approximately 20 billion breeding landbirds in the autumn, based on 1973 Breeding Bird Survey data. Based on these estimates and our mortality estimates, approximately 5-10 percent of the populations of breeding landbirds are killed each year from human caused factors. Impacts on individual species may be higher or lower depending on their population levels. The recently published Birds of Conservation Concern (BCC) by the USFWS lists 131 species that may currently have declining population numbers from numerous factors including loss of habitat and human-caused mortality. These are in addition to the 92 species currently listed as Federally threatened or endangered. Very few studies have attempted to determine the significance of human-caused mortality at a population level of an individual species. Based on an intensive radio-telemetry study of a population of Golden Eagles at the Altamont Pass wind plant, it was determined the wind plant was currently not causing a population level decline, but the long-term impact was unknown (Hunt 2002). This study of a relatively small and definable population of eagles was expensive, relatively short-term, and not conclusive.

Rosenberg and Blancher (this volume) discuss a method using Breeding Bird Survey data for better understanding the population status and the impact of human-caused mortality of individual breeding birds. Their approach uses breeding bird survey data, but given the limited and highly variable data on population sizes, survival and reproduction, there are likely huge uncertainties. Until we start to better understand mortality rates and parameters of bird populations, we will not truly understand the biological significance of the mortality. Research and monitoring efforts need to continue and expand so that we can better understand the levels and significance of these mortality sources and we can find better and more effective means for reduction and mitigation of human-caused bird mortality.

There does appear to be a greater awareness of the level of human-caused bird mortality, and there are measures being undertaken to reduce mortality from most, if not all these sources. Programs to reduce night lighting at tall buildings and encourage use of tinted windows appear to be an effective measure to reduce mortality. Marking powerlines with bird flight diverters appears to be an effective and relatively inexpensive way of reducing collision mortality along power lines (Morkill and Anderson 1991, Brown and Drewien 1995). Effective wind project siting, use of underground power lines, unguyed meteorological towers, and reduced lighting within wind projects appears to be an effective way of reducing the collision potential at wind projects (Johnson et al. in press). Programs like Audubon's "Keep Cats Indoors" likely reduce bird mortality from free-ranging cats. The U.S. ban on some granular pesticides know to be highly toxic to birds has presumably reduced cumulative mortality from pesticides. Use of unguyed cell towers and better lighting on communication towers may also be contributing to reduced avian mortality. Guidelines for pole configurations to reduce electrocution mortality (APLIC 1996) have undoubtedly help reduce the electrocution risk from power lines. The use of these measures needs to be expanded and other more effective measures need to

**Table 2**–*Summary of predicted annual avian mortality.*

| Mortality source | Annual mortality estimate | Percent composition |
|---|---|---|
| Buildings[1] | 550 million | 58.2 percent |
| Power lines[2] | 130 million | 13.7 percent |
| Cats[3] | 100 million | 10.6 percent |
| Automobiles[4] | 80 million | 8.5 percent |
| Pesticides[5] | 67 million | 7.1 percent |
| Communications towers[6] | 4.5 million | 0.5 percent |
| Wind turbines[7] | 28.5 thousand | <0.01 percent |
| Airplanes | 25 thousand | <0.01 percent |
| Other sources (oil spills, oil seeps, fishing by-catch, etc.) | not calculated | not calculated |

[1] Mid-range of fatality estimates reported from Klem (1990), 1 – 10 bird fatalities per house, extrapolated to 100 million residences
[2] Based primarily on a study in the Netherlands (Koops 1987), extrapolated to 500,000 miles of bulk transmission line in U.S.
[3] One study in Wisconsin estimated 40 million (Coleman and Temple 1996), there are 60 million cats claimed as pets in the U.S.
[4] Based primarily on one study in England (Hudson 1965, Banks 1979) that estimated 15.1 fatalities/mile of road each year, no searcher efficiency or bias adjustments in that study, updated based on increase in vehicle registrations
[5] Conservative estimate using low range of empirical fatality rate (0.1 to 3.6 birds/acre), studies typically adjusted from searcher efficiency and scavenging
[6] Estimates from models derived by Manville and Evans (M. Manville, pers. comm.).
[7] Mid-range of per turbine and per MW estimates derived from empirical data collected at several wind projects (*table 1*).

be developed to help compensate for the continued growth of human development on the landscape resulting in loss of bird habitat.

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