STATE OF CONNECTICUT

CONNECTICUT SITING COUNCIL

IN RE:	:	
	:	
APPLICATION OF HOMELAND TOWERS, LLC FOR A CERTIFICATE OF ENVIRONMENTAL COMPATIBILITY AND PUBLIC NEED FOR THE CONSTRUCTION, MAINTENANCE AND OPERATION OF A TELECOMMUNICATIONS FACILITY AT 1837 PONUS RIDGE ROAD, NEW CANAAN, CONNECTICUT	: : : : : ::	DOCKET NO. 509
	:	JUNE 21, 2022

RESPONSE OF MARK BUSCHMANN TO SET ONE, CONNECTICUT SITING COUNCIL PRE-HEARING INTERROGATORIES

1. Referring to Mark Buschmann Request for CEPA Intervenor Status, dated May 6, 2022, provide information as to how the Applicant did not properly evaluate the wetlands on the host parcel, including but not limited to, identification and delineation, and wetland characteristics and functions.

   Response: Please see the prefiled testimony of Michael W. Klemens, Ph.D and David S. Ziaks, P.E.

2. Provide information as to how the proposed facility will significantly impact avian populations. Identify the specific state-listed species that would be significantly impacted by the proposed facility.

   Response: Response: Please see the prefiled testimony of Michael W. Klemens, Ph.D and the following exhibits:

   - Exhibit A, Manville, A.M. (2016). Impacts to Birds and Bats Due to Collisions and Electrocutions from Some Tall Structures in the United States: Wires, Towers, Turbines, and Solar Arrays—State of the Art in Addressing the Problems. In: Angelici, F. (eds) Problematic Wildlife. Springer, Cham.

- Exhibit B, Loss, Scott R., Tom Will and Peter P. Marra, (2015) Direct Mortality of Birds from Anthropogenic Causes, Annu. Rev. Ecol. Evol. Syst. 46:99–120
- Exhibit C, Longcore, Travis, Catherine Rich, Pierre Mineauc, Beau MacDonald, Daniel G. Bert, Lauren M. Sullivan, Erin Mutrie, Sidney A. Gauthreaux Jr., Michael L. Avery, Robert L. Crawford, Albert M. Manville II, Emilie R. Travis and David Drake (2013) Avian mortality at communication towers in the United States and Canada: which species, how many, and where? Biological Conservation 58: 110-114

3. Identify and describe Wren Knolls. Is there public access to this feature?

Response: Wren Knolls is a hill 113 meters in elevation located on the west shore of Laurel Reservoir (Latitude:41° 10' 7" N, Longitude:73° 33' 29" W, Lat/Long (dec): 41.16871,-73.55818) which is included in the Centennial Watershed State Forest. Although currently there is no public access to this feature, that may change in the future. Centennial Watershed State Forest was created in 2002 and in many respects is still in the planning stages. There are a number of areas in Centennial Watershed State Forest which have been made accessible to the general public, including trail systems and water bodies, and public access will presumably be extended in the future.

4. What specific areas of Centennial Watershed State Forest would have views of the proposed tower? What analysis was used to determine tower visibility from these areas?

Response: Please see the map attached as Exhibit D produced by the Connecticut Department of Energy and Environmental Protection through a June 13, 2022 FOIA request. With the exception of the southerly end of Laurel Reservoir, where the dam is located, the land along the shore of the Reservoir is included within the Centennial Watershed State Forest, as are the islands located in the Reservoir. The applicants' visibility analyses (Attachment 8 to the Application and Response No. 29 to the Council Interrogatories to Applicants, Set One) confirm that the tower would be visible from these areas, but the Applicants' exhibits do not correctly indicate the location of Centennial Watershed State Forest.

5. Did Mr. Buschmann take photographs of the balloon test conducted by the Applicant on April 7, 2021? If yes, submit the photographs with descriptive captions.

Response: Mr. Buschmann did take photographs of the balloon test conducted by the Applicant on April 7, 2021. Please see Exhibit E to these responses.

6. What alternatives to the currently proposed location are available to the Applicant that would have less of an impact to the natural resources identified by Mr. Buschmann?

Response: Please see the prefiled testimony of Alan Burg, P.E.

EXHIBITS

A. Manville, A.M. (2016). Impacts to Birds and Bats Due to Collisions and Electrocutions from Some Tall Structures in the United States: Wires, Towers, Turbines, and Solar Arrays—State of the Art in Addressing the Problems. In: Angelici, F. (eds) Problematic Wildlife. Springer, Cham. https://doi.org/10.1007/978-3-319-22246-2_20 https://link.springer.com/chapter/10.1007/978-3-319-22246-2_20

B. Loss, Scott R., Tom Will and Peter P. Marra, (2015) Direct Mortality of Birds from Anthropogenic Causes, Annu. Rev. Ecol. Evol. Syst. 46:99–120 https://www.annualreviews.org/doi/10.1146/annurev-ecolsys-112414-054133

C. Longcore, Travis, Catherine Rich, Pierre Mineauc, Beau MacDonald, Daniel G. Bert, Lauren M. Sullivan, Erin Mutrie, Sidney A. Gauthreaux Jr., Michael L. Avery, Robert L. Crawford, Albert M. Manville II, Emilie R. Travis and David Drake (2013) Avian mortality at communication towers in the United States and Canada: which species, how many, and where? Biological Conservation 58,: 110-114 http://dx.doi.org/10.1016/j.biocon.2012.09.019

D. Connecticut Department of Energy and Environmental Protection, June 13, 2022 FOIA Disclosure, Centennial Watershed State Forest Adjacent to Laurel Reservoir

E. Nine photographs taken April 7, 2022

CERTIFICATE OF SERVICE

I hereby certify that a copy of the foregoing document was electronically mailed to the following service list on June 21, 2022.

Lucia Chiocchio, Esq.
Kristen Motel, Esq.
445 Hamilton Avenue, 14th Floor
White Plains, New York 10601
Phone (914) 761-1300
lchiocchio@cuddyfeder.com
kmotel@cuddyfeder.com

Raymond Vergati
Manuel Vicente
Homeland Towers, LLC
9 Harmony Street, 2nd Floor
Danbury, CT 06810
rv@homelandtowers.us
mv@homelandtowers.us

Brian Leyden
Harry Carey
AT&T
84 Deerfield Lane
Meriden, CT 06067
bl5326@att.com
hc3635@att.com

Kenneth C. Baldwin, Esq.
Robinson & Cole LLP
280 Trumbull Street
Hartford, CT 06103-3597
Phone (860) 275-8200
kbaldwin@rc.com

Justin Nishioka
60 Squires Lane
New Canaan, CT 06840
Phone (510) 913-3476
Justin.nishioka@gmailcom

s/ David F. Sherwood
David F. Sherwood
Commissioner of the Superior Court

EXHIBIT A

Chapter 20

Impacts to Birds and Bats Due to Collisions and Electrocutions from Some Tall Structures in the United States: Wires, Towers, Turbines, and Solar Arrays—State of the Art in Addressing the Problems

Albert M. Manville II

Introduction

Air and airspace as habitats are relatively new concepts (Kunz et al. 2008; Diehl 2013) for many individuals, academics, scientists, and agencies, including federal agencies such as the U.S. Fish and Wildlife Service (hereafter FWS); action agencies that implement FWS guidelines, rules and regulations such as the Bureau of Land Management and the U.S. Forest Service; and state agencies. Tall structures such as communication towers, power transmission lines, commercial wind turbines, solar power towers, and buildings extend into the airspace, in some cases to great heights (e.g., 229 m above ground level [AGL; 750 ft] for some wind turbine rotor swept areas, 610 m AGL [2000 ft] for some digital television (DTV) communication towers, and 442 m AGL [1451 ft] for Chicago's Willis high-rise tower). These tall structures can have deleterious direct effects and impacts to flying wildlife, not to mention indirect effects caused by air and facility disturbance from infrasound noise and lighting, barriers, and fragmented habitats. The overall goal for developers of tall structures and the agencies that regulate them should be to do no harm to protected wildlife species and minimize impacts to their habitats such as the U.S. Interior Department's "smart from the start" initiative (2011 doi.gov) for renewable energy development calling for minimal impacts from development. Attention is focused here toward that overall goal. Several industries whose efforts

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A.M. Manville II (✉)
Advanced Academic Programs, Krieger School of Arts and Sciences,
Johns Hopkins University, Washington, DC, USA

Wildlife and Habitat Conservation Solutions LLC, Falls Church, VA, 22043, USA

Division of Migratory Bird Management, U.S. Fish and Wildlife Service,
Arlington, VA, USA
e-mail: whcsllc006@verizon.net

F.M. Angelici (ed.), *Problematic Wildlife*, DOI 10.1007/978-3-319-22246-2_20

have recently been implemented to minimize harm to birds and to a lesser extent to bats are also assessed. These include the electric utility and the communication tower industries. Several other industries that could significantly reduce harm and impact to both bird and bat species and their habitats are discussed, but the majority of companies are not doing so, in major part based on the assessment of this author due to lack of regulations. These include the commercial, land-based wind industry in the U.S. and the industrial solar energy industry, currently in the Southwest U.S.

Status of and Impacts to Avifauna and Bats in North America

Avian Status and Legal Protections

Migratory birds—i.e., by federal legislative definition those that migrate across U.S., Canadian and/or Mexican borders, of which 1027 species are currently protected in the United States (50 Code of Federal Regulations [C.F.R.] 10.13), are a public trust resource, meaning they belong to everyone. Almost all North American continental birds are protected by the Migratory Bird Treaty Act of 1918, as amended (MBTA;16. U.S.C. 703 et seq.), which implements and regulates bilateral protocols with Canada, Mexico, Japan, and Russia. The Act is a strict liability statute; proof of criminal intent in the injury or killing of birds is not required by authorities for cases to be made.

The Statute and its regulations protect migratory birds, their parts, eggs, feathers, and nests from un-permitted "take" (migratory bird nests are protected during the breeding season while eagle nests are protected year-round), although efforts are currently underway by FWS to develop a permit where "take" could be allowed under MBTA. A Federal permit is required to possess a migratory bird and its parts, and the MBTA currently provides no provision for the accidental or incidental "take" (causing injury or death) of a protected migratory bird, even when otherwise normal, legal business practices or personal activities are involved. The U.S. Congress noted the "take" of even one protected migratory bird to be a violation of the Statute, with fines and criminal penalties that can be extensive. For example, Moon Lake Electric Cooperative was fined $100,000 (U.S.) in 1999 for electrocuting migratory birds; and PacifiCorp was fined $10,500,000 (U.S.) for electrocuting birds in 2009 (the final 2014 settlement agreement included $400,000 (U.S.) in fines, $200,000 restitution to the State of Wyoming, and $1,900,000 to the National Fish and Wildlife Foundation for eagle conservation). A Duke Energy Wind Facility was fined $1,000,000 (U.S.) in 2013 for killing protected birds in wind turbine blade collisions. All the cases involved several years probation for the company executives and all required significant improvements and upgrades to facilities. Companies can also be fined under the criminal misdemeanor provisions of MBTA which can occur when steps to avoid or minimize "take" are not implemented and "take" subsequently results. This occurs after field staff and agents from the FWS's Office of

Law Enforcement have advised a proponent of concerns and suggested measures to avoid or minimize "take" and such recommendations have been ignored or only minimally implemented. It is important to note that the vast majority of "take" by industry goes un-investigated let alone unenforced due to lack of funding, staff, and other priorities.

Bald (*Haliaeetus leucocephalus*) and Golden Eagles (*Aquila chrysaetos*) are also protected by the Bald and Golden Eagle Protection Act (BGEPA; 50 C.F.R. 22.3, 22.26 and 22.27). "Take" under BGEPA is more expansive than under MBTA and includes pursuit, shooting, poisoning, capturing, killing, trapping, collecting, molesting, and disturbing both species (50 C.F.R. 22.3). Permits are required for disturbance take and take resulting in mortality (50 C.F.R. 22.26), and for take of nests (50 C.F.R. 22.27).

The overall objective of the FWS is to maintain bird populations at stable or increasing numbers. This is a daunting challenge due to the direct and indirect impacts of all of the structural issues discussed in this chapter, plus many others briefly mentioned below. As a result, there are growing numbers of Birds of Conservation Concern (BCCs; USFWS 2008)—species in decline but not yet ready for federal listing as threatened or endangered. Currently, there are 273 species and subspecies on the national BCC, Service Regional BCC and Bird Conservation Region BCC lists (USFWS 2008), providing an early warning of likely peril unless the population trends are reversed. These BCC lists require periodic reviews and updates under provisions of the Fish and Wildlife Conservation Act (16 U.S.C. 2901–2912).

Federally listed bird species are those designated and protected under the Endangered Species Act (ESA; 7 U.S.C. 136, 16 U.S.C. 1531 et seq.). Listed species include 78 endangered and 15 threatened bird species on the List of Threatened and Endangered Species. An endangered species faces a significant risk of extinction in the near, foreseeable future throughout all or a significant portion of its range. A threatened species is at risk of becoming endangered in the near future. Collectively, BCC and ESA-listed birds represent at least 366 bird species (36 %) in decline, some seriously, with numbers of both listed and BCC species growing (Manville 2013a). Additionally, the FWS is also tasked to maintain stable or increasing breeding populations of Bald and Golden Eagles under implementing regulations of BGEPA and compliance with the National Environmental Protection Act (NEPA, 42 U.S.C. 4321 et seq.).

Birds are critically important to us all. Birds provide key ecosystem services that fuel a multi-billion dollar (U.S.) industry through pollination, insect, and weed-seed control efforts in the agribusiness and forest products industries. Without migratory birds, there would be untold additional problems requiring more pesticide, herbicide, and other chemical use. Feeding, photographing, and watching migratory birds also fuel a $32 billion/year (U.S.) recreation industry in the U.S., representing an estimated 20 % of the U.S. adult population involved in these endeavors. It is asserted that more adults in the U.S. feed, photograph, and watch birds than play golf (Carter 2013; MountainNature.com 2015).

A number of migratory bird species—notably Bald and Golden Eagles, Common Ravens (*Corvus corax*), American Crows (*C. brachyrhynchos*), hawks, falcons, doves, owls, and hummingbirds—are revered by and protected by Tribal law of some Native American Tribes and Canadian First Nations Peoples. Some of these very species are also at considerable risk from habitat disturbance, habitat fragmentation, injury, and death from land-based wind turbine blade collisions (Erickson et al. 2014), communication tower and guy wire collisions (Gehring et al. 2009), and heating/array impacts with solar facilities (Kagan et al. 2013).

Problems and Challenges for Migratory Birds

In an attempt to roughly assess the annual status of breeding bird populations in North America, several FWS biologists estimated a minimum of ten billion breeding landbirds in the United States exclusive of Alaska and Hawaii, and a minimum fall population of 20 billion migratory birds in North America north of Mexico based on Breeding Bird Survey data (Manville 2005, citing Aldrich et al. 1975; Banks 1979; J. Trapp 2001 pers. comm.). It is difficult to reliably quantify the total annual spring and fall breeding landbird populations in North America. The number of imperiled/declining North American birds continues to increase, the number of imperiled populations continues to grow continent-wide, and the numbers of birds on bird conservation, species of concern, watch lists, state-endangered, and federal-endangered species lists are growing in North America—in some cases at troubling, rapidly declining population rates (Manville 2013a).

The large, estimated annual loss of birds is due to a number of factors. Natural mortality can decimate some bird populations (e.g., starvation, disease, predation, parasitism, stress, nutrient deficiencies, and accidents), recognizing that some of these factors can also be human-related. Additionally, the direct and indirect impacts from humans are extensive. According to the theory, natural mortality tends to decrease to compensate for reduced density, but when mortality such as from structures exceeds a threshold, it can become additive to natural mortality, becoming exploitive (Allen et al. 2006). The mortality factors related to our human footprint include collisions with structures (e.g., building windows, power lines, communication towers and guy wires, wind turbine blades, solar power towers and mirrors, monuments, and bridges)—several of which are discussed in this chapter. Birds are also killed or injured by domestic and feral cats, illegal shootings, collisions with vehicles and aircraft, poisoning from pesticides and contaminants, drowning in oil and wastewater pits, impacts from oil and chemical spills, electrocutions at power line infrastructure, entanglement and drowning in fishing gear, drowning in stock tanks, “take” from hunting and crippling loss (i.e., birds injured but not killed by licensed hunters which subsequently die), poaching, poisoning from lead and other metals, direct loss of breeding habitat, and documented impacts to birds from climate change, among others (Manville 2013a, b). Individually and collectively, these impacts may become additive and all should be assessed cumulatively.

Frequently, proponents from one industry sector, concerned citizens, politicians, and conservationists supporting a specific type of industry will compare estimated levels of mortality from their sector of industry to another. For example, building windows are estimated to kill upwards of 1 billion birds/year in the U.S. (Klem and Saenger 2013; Loss et al. 2013b)—probably the greatest single source of structurally caused bird mortality in the U.S. Compare this to the estimated impacts to birds from power line collisions in the U.S., which may number from 8 to 57 million bird deaths annually based on sensitivity analysis and a meta-review of studies (Loss et al. 2014). Electrocutions, meanwhile, may kill from 0.9 to 11.6 million birds annually in the U.S. (Loss et al. 2014). However, collisions with communication towers may "take" *only* 6.8 million birds/year in North America, most of which are in the U.S. (Longcore et al. 2012). Proponents of the communication tower and cellular telephone industries will frequently make these comparisons to favor their own sector from further scrutiny as does the wind generation industry.

A recent estimate by Loss et al. (2013a) suggests a median estimate of 2.4 billion birds killed annually in the U.S. by domestic and feral cats—the largest projected source of human-related mortality to birds yet published in North America. Using this estimate for comparison is misleading since cats tend to concentrate on smaller birds. By comparing mortality from cats to the most recent estimates of mortality caused by commercial land-based wind turbines, the wind energy estimates are several orders of magnitude smaller, resulting in what might at face value be interpreted as insignificant. For several reasons, this comparison is very misleading. Some birds may have evolved adaptions to cat predation (e.g., sparrows and starlings), but behaviors for avoiding rotating blades and structures that appear as water have not evolved (USFWS 2015 pers. comm). Mortality must be cumulatively assessed for all known and projected causes, including for wind generation. Arguing that wind-generation-caused bird mortality is small by comparison may fail to include it among cumulative effects. Some bird species are more vulnerable to "take" which was acknowledged by Erickson et al. (2014) when concerns were raised about the mortality to 13 species of BCC (USFWS 2008) by the wind industry based on available data.

Collisions with land-based, wind energy turbine blades were recently estimated to kill 440,000 birds/year based on a 2008 estimate of some 22,000 operating turbines (Manville 2009) and have more recently been estimated to kill 573,000 birds/year in the U.S., of which an estimated 83,000 are raptors, based on a 2012 estimate of some 34,400 operating monopole and lattice-constructed turbines (Smallwood 2013). Loss et al. (2013c) attempted to estimate bird mortality at monopole-constructed turbines in the U.S., projecting an average of 234,000 bird deaths/year. Erickson et al. (2014) conservatively estimated annual bird mortality in the U.S. and Canada at 368,000 for all bird species killed. In the opinion of this author and some FWS biologists, field staff, wind energy leads, and law enforcement agents (FWS 2014 and 2015 pers. comm., FWS 2014 confidential internal memos), there continues to be a problem with the transparency, reliability, consistency, and rigor of many of the reports evaluated and subsequent mortality estimates published. These concerns are discussed beyond. Loss et al. (2013c) acknowledged the need for the public release of industry reports and a further evaluation of risk to birds before proceeding with a widespread shift to taller and larger turbines. Those recommendations are essentially being ignored. However, as wind generation grows exponentially, impacts to birds and bats are elevated. As of December 31, 2014, 65,879 megawatts (MW) of installed capacity (more than 48,000 utility scale turbines) were operating in the U.S. (DOE WINDExchange 2015, American Wind Energy Association 2015).

From the perspective of commercial, land-based wind energy, there is yet another problem with these mortality comparisons. The relatively low level of estimated wind energy mortality does not account for the current disproportionate take of Golden Eagles (GOEAs) by wind turbines in the Western U.S. Of approximately 67–75 GOEAs killed/year at Altamont Pass Wind Resource Area, California (Smallwood 2013), there are additional records of more than 79 GOEAs and six Bald Eagles (BAEAs) that have been documented killed in the West at other commercial wind energy facilities from 1997 to 2012 (Pagel et al. 2013), contrary to assertions by some wind energy proponents that eagle mortality is only a problem at Altamont Pass, California. These figures represent a substantial underestimation of the number of GOEAs killed at wind facilities in the Western U.S. (Pagel et al. 2013) since records continue to be collected by FWS staff detailing more eagle mortalities (FWS 2014 and 2015 confidential unpublished data). The Pagel et al. (2013) discoveries were not based on any systematic mortality or monitoring surveys. The growing "take" of eagles and the effects to eagle territories and eagle use areas are growing concerns as more wind facilities are built and become operational. Additionally, there is a growing—but still low—level of take of BAEAs nationwide at wind energy facilities, but more records exist of eagle fatalities from both species at wind energy facilities which have not been released by wildlife agencies since the publication of Pagel et al. (2013; FWS 2015 pers. comm., FWS 2014 and 2015 confidential unpublished data).

There is also a disproportionately large but still poorly substantiated level of take of passerines at wind facilities nationwide (Smallwood 2013; Erickson et al. 2014). A proportion of the migratory birds killed at wind facilities which are Birds of Conservation Concern (BCCs; USFWS 2008) continues to grow (Manville 2009, 2013a; Erickson et al. 2014). These BCC species are already in decline and in some cases in significant peril, but not yet listed under the Endangered Species Act. The current status of BCC species is a growing concern and not easily rectified by lack of federal and state agency resources to address these issues. Yet proponents of the wind generation industry will frequently cite other larger estimated sources of mortality to estimated mortality from wind turbines (AWEA 2015) rather than focusing on addressing the problems of wind turbines indiscriminately killing multiple bird species.

The bottom line, when trying to understand the dynamics of bird (and for that matter bat) populations, all impacts of tall structures and alternate energy sources should be assessed through cumulative effects analyses under the National Environmental Policy Act (NEPA). However, not all projects (i.e., from single turbines to large wind facilities) require NEPA review unless proponents want and apply for a BGEPA or ESA "take" permit, are located on public/federal property, or are receiving federal funding (Manville 2013a). Performing a NEPA review can be challenging, especially given data gaps, unknowns, and uncertainties. However, cumulative effects analysis can best be performed by coordination between the project proponent's consultant and the FWS NEPA specialist/coordinator for the FWS Region where the project is being proposed. This will help determine the need for a NEPA Environmental Assessment, an Environmental Impact Statement, or possible categorical exclusion.

In addition to the impacts from causes due to natural mortality, additive mortality, or a continuum between compensatory mortality and additivity (Peron 2013), project proponents should also include cumulative impacts from cats, windows, power lines, wind turbines, solar facilities, lighting, communication towers, and all other anthropogenic structures including bridges and airports. The impacts should be assessed over the lifetime of all the structures and other impact sources. Additionally, the growing effects of climate change should be incorporated in any cumulative effects analysis (Manville 2013a).

The situation makes for a complicated review with many dynamics involved in assessing the status of bird and other populations. The good news: as scientifically validated, peer-reviewed, and published best-management practices, best available technologies, proven conservation measures, and other tools become publicly available, they should be systematically and consistently implemented. This approach makes the best conservation sense, provides the most bang for the buck, and may help reverse declining populations trends.

Status and Impacts to Bats in North America

Among some of the most maligned yet important animals in the world, insectivorous bats (Microchiroptera) play critical roles and provide key ecosystem services to humanity. Unfortunately, the roles bats play are hugely misunderstood by the public. In the U.S., bats alone save billions of dollars each year by protecting the forest products and agricultural industries. The estimated savings range from $4 billion–$53 billion/year (U.S. dollars, averaging $22.9 billion; Boyles et al. 2011). For example, a single big brown bat (*Eptesicus fuscus*) can consume from 3000 to 7000 mosquitoes/night, some of which may be carrying West Nile virus, malaria, and chikungunya virus, among other diseases. A colony of 20 million Mexican free-tailed bats (*Tadarida brasiliensis*) in Central Texas can consume ≥113,398 kg (0.25 million pounds) of insects/night (Cryan et al. 2014). Insectivorous bats consume June beetles (subfamily Melolonthinae), leafhoppers (family Cicadellidae), spotted cucumber beetles (*Diabrotica undecimpunctata*), green stink bugs (*Chinavia hilaris*), corn ear worm larvae (*Helicoverpa zea*), gypsy moths (*Lymantria dispar dispar*), spotted budworms (*Heliothis* spp.), and many other pests.

Of the 45 species of bats found in the contiguous 48 United States, six are federally listed under the ESA (FWS.gov). These include the gray (*Myotis grisescens*), Indiana (*M. sodalis*), Ozark big-eared (*Corynorhinus townsendii ingens*), Virginia big-eared (*C. t. virginianus*), lesser long-nosed (*Leptonycteris yerbabuenae*), and the Mexican long-nosed (*L. navies*) bats. Highly troubling are recent deleterious impacts to cave-dwelling bats, especially those in the genus *Myotis* (e.g., little brown [*M. lucifugus*] and Indiana bat), from the fungal disease known as White-nosed Syndrome (WNS; *Pseudogymnoascus destructans*). To date, WNS is conservatively estimated to have killed more than seven million hibernating bats in 25 U.S. States and six Canadian Provinces. Population declines of >80 % of the bats in the Northeastern United States have recently been reported (Reynolds et al. 2015). All efforts to protect bats and reverse population declines are critically important and any efforts that can reduce or eliminate additional compensatory and/or additive mortality should be employed.

Addressing Problems Through Stressor Management

One approach being used by wildlife agencies, specifically the FWS in addressing direct, indirect, and cumulative impacts to migratory birds—and other fauna including bats—is through stressor management. A stressor is defined as any alteration or addition to the environment that when applied to a resource becomes a threat to the individual bird and/or its population. Stressors can be both anthropogenic and natural. For example, dissecting a project's construction and operational schedule can delineate each stressor. Common avian stressors that impact breeding, foraging, migration, migration corridors, and wintering areas include artificial lighting, noise, human/habitat disturbance, the addition of structures to the landscape, and the removal and manipulation of vegetation. The principle behind stressor management is to focus on the *cause* of the impact (e.g., installation of lighting) rather than its *effect* (e.g., nighttime bird attraction). Previously, managing project effects had focused on fixing the consequences of an action such as marking communication tower guy-support wires with bird deterrent devices to reduce bird collisions—admittedly costly, often difficult, and not necessarily effective. By constructing an un-guyed, monopole, or lattice-support tower, guy wire collisions are avoided. Stressor management today aims to deconstruct a project, providing a more tangible impact analysis by identifying the full spectrum of avian stressors associated with the lifecycle of a project. The stressors produced by each individual activity (e.g., brush clearing, dredging, using heavy machinery, or installing structural lighting), within each phase of a project (i.e., pre-construction, construction, post-construction/operation, and decommissioning), helps the project proponent realistically anticipate the problems that might be associated with their project and identify cost-effective ways to avoid or minimize the individual stressors at their source before they become realized threats to migratory birds (Morris and Kershner 2013; E. Kershner 2013 pers. comm.).

Discussion: Projected Impacts to Birds and Bats from Specific Industry Sectors

Direct and Indirect Effects of Transmission and Distribution Powerline Collisions and Electrocutions

The impacts of transmission and distribution powerlines on migratory birds have not been carefully or systematically monitored, even though dozens of peer-reviewed studies have been published in scientific journals assessing impacts to birds from powerless (e.g., APLIC 2006, 2012). This is in part due to the millions of kilometers (miles; APLIC 2012; Manville 2013a) of distribution lines and nearly 1.207 million km (0.75 M miles; APLIC 2012; Manville 2013a) of transmission lines in the U.S.; lack of adequate utility and agency staff to systematically survey them for dead birds; lack of pressure by the regulatory agencies on the industry; lack of recognition of the problem; and lack of adequate agency funding (Manville 2009, 2011). For purposes of comparison, distribution lines in rural and urban areas generally carry from 2.4 kilovolts (kV) up to 60 kV of electricity, using transformers to step down the voltage going into homes, offices, and other structures. Distribution lines are often placed above ground as undergrounding increases the cost. High voltage transmission lines carry from 60 to >700 kV and are generally located on tall pylon power towers, or other platforms. Transmission lines can be placed underground, but the challenges to maintain them can be significant, plus the costs range from three to 20 times that of above-ground placement, which are significant increases (APLIC 2006; B. Bolin 2013 pers. comm.).

Collisions and electrocutions are both important avian problems, but each has different impacts and rates of mortality vary between species (Manville 2013a). Although different species have different vulnerabilities, other than BAEA, GOEAs, and buteos (i.e., soaring hawks; APLIC 2006), there generally are not enough data to generate a clear quantitative picture of how vulnerable different species are to electrocutions. Vulnerability, time of day/night, weather conditions, visual acuity, disturbance, and issues still not well understood about avian vision all affect collision impacts (Martin 2011, 2014), but all need further quantitative testing, peer review, and publication.

Bird collisions occur primarily with energized transmission wires and the smaller, static (lighting arresting) wires generally located on top of the transmission towers which are not as visible to birds in flight (APLIC 2012). Visual acuity can be critically important since birds must depend on eyesight to see and avoid obstacles such as static wires close-up (Martin 2011, 2014).

Electrocutions, however, occur primarily at distribution lines and their infrastructures, although flashovers (contact between two energized wires, or an energized and grounded structure) have been occasionally documented from raptor "streamers" (streams of liquid fecal waste) which contact energized transmission wires (APLIC 2006). Distribution power lines supplying alternating current are frequently constructed in three, energized (hot) phases, with an additional ground wire separate from them. Because each energized phase is different, electrocutions can occur between them, or between a hot and the ground wire. For birds which touch phased distribution lines placed too close together, electrocutions can result from phase-to-phase line contact (often between fleshy parts of a bird's anatomy, e.g., wrist to foot, or wrist-to-wrist); phase-to-ground contact; or when feathers are wet (resulting in electrocutions and not infrequently power outages). Uninsulated power pole infrastructure can cause bird electrocutions by touching equipment such as exposed wire bushings, bare jumper wires, unprotected fused cutouts, unprotected switches, and by other means. Even small birds such as passerines can be at risk of electrocution (APLIC 2006).

In addition to direct impacts (e.g., Bevanger and Broseth 2004—in an empirical study in Norway), birds, bats, and other fauna are also impacted by the indirect effects of transmission and distribution lines, powerline utility poles, solar power towers and solar mirrors, and their infrastructure. These include the introduction of barriers to movement, habitat fragmentation, site avoidance/abandonment, disturbance, loss of population vigor, behavioral modification, creation of sub-optimal or marginal habitats, loss of refugia, and intraspecific and interspecific competition for resources (Manville 2013a). It is important to note that most of these indirect effects are difficult to quantify, difficult to separate from other impacts, and for the most part have not been quantitatively tested, critically reviewed, and published in refereed journals.

To better understand and address these issues, considerable research has and continues to be conducted on understanding the indirect effects of transmission and distribution lines, among other tall structures. Power lines, wind energy facilities, communication towers, and oil pumping facilities have been suspected of causing negative effects to some bird species, notably some species of grouse (Manville 2004). The imperiled status of many of these species better explains the research focus. For example, the Attwater's Prairie-chicken (*Tympanuchus cupido attwater*) is Federally ESA-listed as endangered, the Gunnison Sage-grouse (*Centrocercus minimus*) is threatened, the Lesser Prairie-chicken (*T. pallidicinctus*) is threatened, and the Greater Prairie-chicken (*T. cupido*) has been petitioned for federal listing. Research on the direct and indirect effects of tall structures on prairie-chickens, sage-grouse, and Sharptail-grouse (*T. phasianellus*) has been extensive (e.g., Connelly et al. 2000; Braun et al. 2002; Hagen 2003; Wolfe et al. 2003a, b; Pitman 2003; Hagen et al. 2004; Patten et al. 2004; Connelly et al. 2004—all summarized in Manville 2004). Research and studies continue with more recent advances discussed in APLIC (2012). Winder et al. (2014) and Winder et al. (2015 in press) empirically tested the recommendation by FWS (Manville 2004) for avoiding development within an 8-km (five mile) buffer from leks by wind energy facilities affecting Greater Prairie-chickens. Both studies showed negative effects on both males and females of this species within eight km, supporting FWS's previous buffer recommendation. Evaluation and proper power line routing continue to be assessed and implemented to address direct and indirect effects on federally endangered Whooping Cranes (*Grus americana*; APLIC 2012).

Bats have been found incidentally in bird mortality searches in both transmission and distribution powerline corridors. While the recommendations from the Avian Power Line Interaction Committee (APLIC 2006, 2012) have been primarily focused on avoiding and minimizing impacts to protected migratory birds, the recommendations and best practices may also benefit bats, especially where bird-wire marking devices are installed. However, until research is conducted on the etiology of bat-wire collisions, the benefits of APLIC recommendations for bats will continue to remain speculative.

Addressing Problems and Attempting to Resolve Impacts to Birds from Powerline Collisions and Electrocutions: An Electric Utility-FWS Partnership

The North American partnership between members of the electric utility industry, including investor-owned utilities, electric cooperatives, electric administrations, several federal agencies, the Edison Electric Institute, Electric Power Research Institute, FWS, and some Canadian (e.g., Canadian Wildlife Service and Environment Canada) and Mexican partners (e.g., Semarnat and the Mexican Institute of Ecology), is noteworthy and deserves closer examination. Called the Avian Power Line Interaction Committee (APLIC), the group's proactive approach in addressing effects from avian impacts as well as dealing with threats associated with electric utility infrastructure has become well-known.

Begun as an ad hoc collaborative in the early 1970s to specifically address Whooping Crane-powerline collisions and GOEA electrocutions at distribution line infrastructure, the APLIC partnership has been significantly expanded and was codified in 1989 with the creation of the committee housed within and managed by the Edison Electric Institute where records are maintained. It has grown to more than 55 members today (www.aplic.org).

While APLIC's initial and early focus centered on avoiding raptor electrocutions and Whooping Crane collisions, its orientation has expanded to all birds, including much more involvement among company members, other stakeholders including vendors, members of academic and research communities, and the interested general public. Similarly, the FWS's involvement with electric utilities—as well as other industries which it regulates—has focused, in descending order of priority, on education, exchange of information, and lastly enforcement—the three "E's" (J. Birchell 2012 pers. comm.). While APLIC has been touted as one of the longest and possibly most productive partnerships FWS has had with any industry sector to date, the partnership between the electric utility industry and FWS has not been without some controversy. FWS law enforcement agents and prosecuting attorneys at the Department of Justice made two criminal cases against the industry, with multi-million dollar (U.S.) penalties, including against the Moon Lake Electric Cooperative in 1999 and PacifiCorp in 2009—previously referenced. While APLIC members are sensitive to the cases and the media surrounding them, in the opinion of this author the cases have served to garner the undivided attention of some of the industry, resulting in more proactive cooperation with FWS and the other regulators. The same cannot be said for the wind generation industry where only one criminal case, previously referenced, has been prosecuted.

APLIC has set the industry standard for a proactive approach to addressing stressors *prior* to wire and infrastructure placement and operation. These include the development and release of APLIC's 2005 *Avian Protection Plan (APP) Guidance* (APLIC 2005), a collaborative effort between APLIC and FWS.[1] The *APP Guidance* lays out 12 principles for companies, cooperatives, public service and utility districts, and electric administrations to follow, while developing and implementing a proactive plan to address potential impacts from wire collisions and electrocutions. By developing and implementing an APP, a utility is ideally focused on the *cause* of a problem (e.g., wire collision and infrastructure electrocution, disturbance to nesting GOEAs due to excessive noise, or removal of vegetation negatively affecting birds) and taking steps to address it proactively, including throughout any new construction. As a result, the APP becomes a business and operational tool and better protects the utility against prosecution from FWS. There are, to date, more than 100 APPs already developed or under development by electric utilities and cooperatives, exclusive of any additional APPs required under court order (e.g., Moon Lake and PacifiCorp).

To proactively deal with stressors as well as deal with existing threats, APLIC periodically publishes best management practices and best operational technologies based primarily on peer-reviewed, published scientific studies to address electrocutions (most recently, *Suggested Practices for Avian Protection on Power Lines: the State of the Art in 2006*)[2] and collisions (most recently, *Reducing Avian Collisions with Power Lines: the State of the Art in 2012*).[3] These documents and their recommendations are designed for use on existing power line infrastructure (e.g., retrofits—focused on addressing threats) and for all new construction (i.e., anticipating and avoiding potential stressors, where possible). Both documents, in part, deconstruct the powerline/infrastructure projects, focusing on the true problems, helping to identify other activities that may produce stressors, and suggesting cost-effective ways to identify and avoid or minimize the stressor component of an activity while still allowing the activity to proceed. Included in the APLIC (2006) document are chapters on regulations and compliance, biological aspects of avian electrocution, power line design and avian safety (in considerable detail), and the development of an APP, among others. Similarly, in APLIC (2012), there are chapters on progress in dealing with collision issues (in North America, internationally, with the need for future research priorities), avian regulations and compliance, understanding bird collisions, minimizing collision risks, powerline marking to reduce collisions, and APPs.

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[1] A document this author helped craft and negotiate.

[2] Coauthored by this author.

[3] Coauthored by this author.

APLIC also teaches short courses and other training modules dealing with avian-wire interactions, funds bird-utility research, and holds bi-annual meetings open to the public—including 1.5-day avian interaction workshops. The work of APLIC and its members has resonated in Canada, Mexico, Europe, Asia, Australia, and elsewhere. Fundamentally, APLIC has set the benchmark for other industries to follow in enabling a means to proactively address two significant threats to birds by identifying, avoiding, and minimizing the primary avian stressors associated with that activity. This still allows the activity to proceed in an effective and efficient way by enhancing reliable electrical energy delivery. In June 2014, APLIC and FWS celebrated their 25th anniversary working collaboratively since the committee was formed, while previously working in an ad hoc capacity since the 1970s (aplic.org).

While Loss et al. (2014) attempted to refine nationwide estimates for wire collisions and electrocutions, they did not attempt to summarize the overall efficacy of APLIC recommendations. Instead, they called for more information on the proportion of utilities implementing new best practices and retrofits, the degree with which these practices are reducing mortality, and the need for a consistent, peer-reviewed monitoring protocol. APLIC has yet to publish a nationwide meta-review of how best practices and suggested mitigation measures have worked to date. However, both APLIC documents (2006, 2012) do summarize empirical findings of mortality reduction based on some specific studies reported in these documents. FWS agents and field biologists routinely request the use of APLIC standards (2006, 2012) as benchmarks for addressing wire collisions and electrocutions, even though the recommendations are voluntary (FWS 2014 pers. comm.). In this author’s opinion, one notable example of success should be credited to Puget Sound Energy, in western Washington. Where collision issues are identified as problems, this company has reduced to near-zero additional distribution wire collisions from Trumpeter Swans (*Cygnus buccinator*) by marking wires with bird diverter devices where birds are feeding at adjacent potato fields and may collide with the lines (M. Walters 2014 pers. comm.; pse.org/environment).

Collisions and Radiation Effects from Communication Towers: Addressing Problems to Birds

Tower Collision Mortality

Communication towers, which vary from short (<61 m AGL [200 ft]) monopole cellular telephone towers and antenna arrays to tall (>610 m AGL [2000 ft]) radio, television, and emergency broadcast towers, have two impacts on migratory birds, and to a lesser extent on bats since mortalities are reported only anecdotally to bird deaths. Information was first published in the late 1940s of a large, single night bird collision with a radio tower in Baltimore, Maryland (Aronoff 1949). More recently, information has been published on the suspected etiology of avian-tower collisions.

Frequently during nighttime migrations, birds are overwhelmed by inclement weather events, forcing bird fall-out, significant reductions in flight heights, and resultant attraction to lighted structures and confusion (Manville 2007, 2009, 2014a). Mortality has previously been conservatively estimated at 4–5 million birds killed in the U.S. annually (Manville 2002, 2005, 2009) based on limited, empirical data, and extrapolation from Banks' (1979) estimate. Current estimates of 6.8 million birds/year in the U.S. and Canada (Longcore et al. 2012) are based on a meta-review of 38 studies for which mortality data were available and corrected for sampling error, searcher efficiency, and scavenging. The vast majority of these bird deaths are in the U.S. (Longcore et al. 2012). In another review, at least 13 species of Birds of Conservation Concern were estimated to suffer annual mortality of 1–9 % of their estimated total population based solely on tower collisions in the U.S. or Canada (Longcore et al. 2013). These include estimated annual mortality of >2 % for the Yellow Rail (*Cocturnicops noveboracensis*), Swainson's Warbler (*Limnothlypis swainsonii*), Pied-bill Grebe (*Podilymbus podiceps*), Bay-breasted Warbler (*Setophaga castanea*), Golden-winged Warbler (*Vermivora* chrysoptera), Worm-eating Warbler (*S. discolor*), Prairie Warbler (*S. discolor*), and Ovenbird (*Seiurus aurocapilla*). Up to 350 species of birds have been documented killed at communication towers (Manville 2007, 2014a).

Radiation Effects

The much less documented but growing concern to birds and other wildlife involves effects of non-thermal, nonionizing microwave (and other) radiation from communication towers on nesting and roosting wild birds, an impact yet unstudied in the U.S. In Europe, impacts have been well-documented. Balmori (2005) found strong negative correlations between levels of tower-emitted microwave radiation and bird breeding, nesting, and roosting in the vicinity of electromagnetic fields in Spain. He documented nest and site abandonment, plumage deterioration, locomotion problems, and death in House Sparrows (*Passer domesticus*), White Storks (*Ciconia ciconia*), Rock Doves (*Columba livia*), Magpies (*Pica pica*), Collared Doves (*Streptopelia decaocto*), and other species. While these species had historically been documented to roost and nest in these areas, Balmori (2005) did not observe these symptoms prior to construction of the cellular phone towers. Balmori and Hallberg (2007) and Everaert and Bauwens (2007) found similar strong negative correlations among male House Sparrows. Under laboratory conditions in the U.S., T. Litovitz (2000 pers. comm.) and DiCarlo et al. (2002) raised troubling concerns about impacts of low-level, non-thermal radiation from the standard 915 MHz cell phone frequency on domestic chicken embryos (*Gallus gallus*)—with lethal results (www.healthandenvironment.org/wg_emf_news/6143). Given the findings of the studies mentioned above, and an extensive meta-review of the published studies by Panagopoulos and Margaritis (2008), field studies should be conducted in North America by third-party, independent research entities with no vested interest in the outcomes to validate potential impacts of communication tower radiation—both direct and indirect—to birds and other animals. However, to date, these have yet to be performed.

Efforts to Reduce Bird Collisions at Communication Towers

The FWS's Division of Migratory Bird Management became actively involved in the avian-tower collision issue in early 1998 with a large, single-night bird kill of up to 10,000 mostly Lapland Longspurs (*Calcarius lapponicus*) at a lighted, gas pumping facility and three surrounding communication towers in western Kansas (Manville 2001). To begin addressing the issue, the FWS published *Voluntary Guidelines for Communication Tower Design, Siting, Construction, Operation, and Decommissioning* in September 2000.[4] It developed and chaired the Communication Tower Working Group, focusing on the science surrounding bird attraction to lights, the dynamics of bird collisions, and efforts focused on dealing with stressors and their threats. The interim, voluntary *Guidelines* published in 2000 were updated in 2013 based on FWS recommendations provided on the record to the Federal Communications Commission (FCC) in 2007, 2011, 2012, and 2013 (Manville 2013a, b, 2014a). Changes in lighting and reductions in tower height and guy-support wires (Manville 2007; Gehring et al. 2009, 2011; Longcore et al. 2012) appear to preliminarily be reducing bird deaths, but a systematic review of these changes is recommended to determine empirically if the FWS guidelines, FCC licensing, and Federal Aviation Administration (FAA) lighting updates are reducing bird mortality. The FAA is finalizing updates to their 2007 lighting circular (FAA 2007), which incorporates new changes to steady-burning, red pilot warning obstruction lights generally placed on tall structures >61 m AGL (200 ft) in height (Manville 2013a; J. Gehring 2015 pers. comm.). Birds are particularly sensitive to the color red at night, especially if the red lights burn continuously rather than flashing or strobed (Gehring et al. 2009).

This development is highly noteworthy given the coordination, research, and work done by J. Gehring (Gehring et al. 2009, 2011). Specifically, new breakthroughs in better understanding the roles of lighting (especially steady-burning, red incandescent L-810 lights), tower height, and the use of guy support wires could—once fully implemented by the FCC and the FAA—reduce bird attraction and collision mortality by more than 50 % based on recent research and meta-reviews (Gehring et al. 2009, 2011; Longcore et al. 2012, 2013). That projected reduction in mortality still needs to be empirically assessed and verified, strongly suggesting the need in the opinion of this author for systematic mortality monitoring based on accepted monitoring protocols (e.g., Gehring et al. 2009).

Meanwhile, the vast majority of the FWS's voluntary recommendations are intended to proactively address the effects of stressors and their threats *before* tower

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[4] Coauthored by this author.

siting and construction occur. These includes recommendations for collocation of antennas, use of a lattice or monopole construction, avoiding wetlands and other important bird areas, building in already degraded sites, eliminating L-810 lighting, keeping towers unlit and unguyed, following APLIC (2006, 2012) recommended standards for wire infrastructure, minimizing habitat footprints, down-shielding security lighting using only motion or heat-sensitive types, decommissioning inactive towers, and other steps (Manville 2013b). The efficacy of each of these recommendations will need, in the opinion of this author, to be systematically monitored and assessed to see how well each is working and modified or adapted as necessary to make them most effective. Since lighting changes will ultimately result in energy cost savings for tower owners and lessees, it is hoped that the majority of communication tower construction projects will comply with the suggested lighting practices and other best practice recommendations, and that re-licensing, existing retrofits, and new construction will collectively result in significant reductions in both "take" and habitat alteration and fragmentation. While no similar partnership like APLIC exists among the communication tower operators and FWS, that industry is represented by a consortium of trade associations. These include CTIA, PCIA, the National Tower Erectors Association, and the National Association of Broadcasters. Members of the consortium are beginning to acknowledge, appreciate, and address the benefits of constructing and maintaining bird-friendly communication towers.

The impacts of tower radiation, especially on nesting birds, are still unstudied in the U.S. Until independent, third-party research can be conducted and results analyzed, no recommendations can yet be provided on this issue—other than to proceed using the precautionary approach and to keep emissions as low as reasonably achievable. The precautionary approach, based in part on Article #15 of the 1992 Rio Conference (unep.org), recommends that where serious harm may result, lack of scientific certainly is not a reason for postponing implementation of cost-effective measures. Aside from the field and laboratory studies referenced above, there remains much uncertainty about effects from nonionizing radiation on migratory birds and other wildlife.

Collisions and Habitat Impacts from Commercial, Land-Based Wind Turbines: Addressing Bird and Bat Impacts

The Effects

Land-based commercial wind energy electrical-generating facilities are relatively new structures on the landscape, only operating in the U.S. since the 1980s at Altamont Pass Wind Resource Area, California (Righter 1996; Smallwood and Thelander 2004). However, from the 1980s to the present, commercial wind generation in the U.S. has grown explosively (DOE 2015). The U.S. Department of

Energy's 2015 WINDExchange (DOE 2015) indicates that 65,879 MW of installed capacity (more than 48,000 utility-scale turbines) were operating by the end of 2014. It is not at all surprising that estimated bird mortality has grown from what was first presented as an average of 34,000 bird deaths/year in 2000 (Erickson et al. 2001, estimating mortality based on a review of only 12 projects). In 2008, as the industry continued to grow exponentially and mortality monitoring protocols by consultants remained inconsistent between nearly every project, Manville (2009) estimated 440,000 bird deaths/year by correcting for six major biases inadequately addressed in then existing project review. These included in decreasing order of bias concern (1) variability in the duration and intensity of carcass searches (including observer bias and lack of credible levels of detection), (2) failure to address carcass searches during some migration and most nesting, (3) effects of inclement weather, (4) size of the search areas, (5) unaccounted crippling loss incidents, and (6) impacts from wind wake and blade wake turbulence. Manville (2009) did not include the formula and actual calculations he used to develop his estimate, in major part due to a lack of space in the peer-reviewed Proceedings. He took the industry's 2008 estimate of 58,000 annual bird deaths, attempting to update it reflective of biases still inadequately addressed by industry consultants. Using conceptual models developed by Huso (2008, later published in 2010), he attempted to address concerns over estimators (Huso 2008), especially where biases remained very large between projects and continued to be unaddressed by many industry consultants. Finally, Manville (2009) weighted the inconsistencies addressed by Huso (2008) in a decreasing order of bias concerns listed above. By selecting decreasingly weighted percentages for the six biases, he roughly calculated a range of annual bird mortality from 440,000 to 690,000, selecting the lowest estimate. Due to the numerous biases in the industry's 2008 cumulative mortality estimate, Manville made no attempt to apply any statistical rigor to his estimate (Manville 2012). By 2012, Smallwood (2013) estimated 573,000 bird deaths, of which some 83,000 were raptors, from wind facilities nationwide based on closer review and analysis. His estimate included a correction for inadequate survey and assessment of passerines killed based on approximately 34,400 then operating turbines across the U.S. in 2012. Loss et al. (2013c) estimated 234,000 birds killed at monopole-constructed wind turbines in the U.S. (excluding lattice turbine structures), while Erickson et al. (2014) estimated 368,000 birds killed at turbines in the U.S. and Canada. There continues to be some disagreement regarding the methodologies and rigor used to assess mortality.

Others (e.g., Sovacool 2009) have published comparisons of bird mortality from wind energy to fossil fuel, nuclear energy, and other sources. While these comparisons can be instructive, the analytical methods used to develop the estimates are often highly variable, duration and intensity of monitoring may differ greatly, scientific peer review may not have been conducted (Ferrer et al. 2012; Smallwood 2013), and reporting mortality in the aggregate (i.e., number of birds estimated killed) fails to detect species-level effects necessary to make conservation assessments and decisions (Longcore et al. 2013).

Impacts especially to Golden Eagles continue to be especially troubling. To date, only the Shiloh IV Wind Project, Solano Country, California, a 102-MW facility, has a pending eagle “take” (50 C.F.R. 22.26) permit to injure and/or kill up to five GOEAs over a 5 year period (http://www.fws.gov/cno/press/release.cfm?rid=628). The pending permit is not without controversy as at least two retired FWS law enforcement agents have spoken out against the project and its permit (Wiegand 2014) as have several environmental groups (Associated Press 2014).

Smallwood (2013) estimated at least 888,000 insectivorous bats killed/year at U.S. commercial wind energy facilities, which was based on 51,630 MW of installed wind capacity in 2012, now at more than 65,879 MW by late December 2014, and growing (DOE 2015). Bats are currently being lost in unprecedented numbers from blade collisions and barotrauma, most susceptible of which are the tree roosting bats including the hoary (*Lasiurus cinereus*), Eastern red (*L. borealis*), and silver-haired bats (*Lasionycteris noctivagans*; Cryan et al. 2014). Why these bats remain more susceptible to collisions with turbine blades, especially at low blade speeds, remains yet unknown. It appears that bat behaviors that evolved at tall trees are now proving maladaptive to flying around turbine blades (Cryan et al. 2014).

Like the impacts from other industry sectors, commercial wind energy projects cause direct and indirect effects on birds and bats. Due, however, to the massive footprint of some of these projects—i.e., hundreds of km^2—effects can be accentuated. The direct effects of turbines and their projects include bird and bat collision mortality, and barotrauma in bats and anecdotally reported in small birds (Manville 2009). Direct habitat loss, creation of barriers, loss of grasslands, direct fragmentation of habitat, increase in habitat edge, increase in nest parasitism and predation, and impacts on water quality can also be problematic (e.g., Sovacool 2009). From the perspective of indirect effects, numerous concerns have also been raised. These include reduced nesting and breeding densities, loss of population vigor and overall densities, habitat and site abandonment, loss of refugia, attraction to modified habitats including suboptimal ones, effects on behavior (e.g., stress, interruption, and modification), displacement, avoidance, and habitat unsuitability (Manville 2004; Gillespie 2013; Winder et al. 2014, 2015 in press). Indirect effects can be incredibly difficult to quantify, with further difficulties teasing out specific effects from others.

Beginning to Address the Problems

The FWS went through a long and detailed, multi-year process (2007–2010), coincident with the process to develop an eagle “take” permit mechanism, working through the Wind Energy Federal Advisory Committee (FAC) to develop and update the FWS’s 2003 interim, voluntary land-based wind energy guidelines. This author served as one of two technical scientific advisors to the FAC. The 2003 document[5]

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[5] Cowritten by this author

was open to 2 years of public comment. The resultant product was the *2012 Service Wind Energy Guidelines* (WEG) available on the FWS's website at www.fws.gov. While the specific guidelines are not prescriptive and only provide recommendations, they do recommend a detailed, tiered process for addressing stressors and their threats—notably Tiers 1, 2, and 3 focused on pre-construction landscape and site review. *If* a wind developer does perform its due diligence and properly sites wind facilities in bird, bat, and habitat-friendly locations, the project is unlikely to impact trust resources including birds in a significant way—i.e., negatively affecting their populations. However, there still is no permitting mechanism for "take" of migratory birds, and the permitting mechanism for eagle "take" requires important data on adult survivorship, territorial and foraging range integrity, adult breeding viability, recruitment, and disturbance to justify proposed levels of "take." The permitting process continues to remain a work in progress within FWS.

However, other than proper site location—i.e., siting turbines in low risk, degraded habitats, developed sites, or other locations where birds and bats will be minimally impacted—options are very limited. These low-risk sites still need to be clearly documented using accepted, scientific protocols that that can tie in low risk to factors that reduce rates of bird collision and minimize impacts from habitat alteration. These efforts continue to be a work in progress. There are no best practices or best available technologies for birds yet available for large-scale, wind energy developers. Such practices and technologies need to be independently peer-reviewed, scientifically validated, and acknowledged by independent experts as accepted tools to avoid or minimize "take" and/or affect habitats. In short, no silver bullet exists. Blade feathering (i.e., changing the pitch of the blades so they no longer cut into the wind), seasonal shutdowns, and electronic monitoring with automated Supervisory Control and Data Acquisition (SCADA) radar systems tied to feathering—which incidentally emit large quantities of radio frequency radiation—have only been reported to show limited success. Additionally, setbacks from ridge edges and turbine alignment have also shown some promise, but only with limited success (e.g., Smallwood and Thelander 2004). SCADA, for example, is very expensive to operate and companies using the system are finding it to be ineffective due to issues of sensitivity, response time to feathering, and verification of approaching targets (FWS 2015 pers. comm.). Mortality data are generally not shared with FWS or other agencies, or made available for third party data collection or independent peer review. This makes the efficacy of mitigation measures unclear, unknown, and difficult to verify (e.g., Wiegand 2014; Associated Press 2014). The smaller and shorter, vertical axis helix, flow-through turbines are far more efficient but more expensive than current technologies. They do have some promise in being more bird- and bat-friendly (FWS 2015 pers. comm.). Economies of scale suggest that higher blade heights with larger rotor swept areas are more efficient, overall less expensive per megawatt produced, but at a growing cost to wildlife and their habitats (Loss et al. 2013c). Rotor-swept areas now exceed 2.8 ha (seven acres) in area, larger than the entire area of three modern 747 jets. This is a situation quite different from what APLIC published through its 2006 and 2012 *Suggested Practices* documents that contain quantified and scientifically validated best practices and best available technologies. Many of these practices have been shown to significantly reduce wire collisions, electrocutions, and habitat alterations.

Hoary, Eastern red, silver-haired, and little brown bats are being heavily impacted by turbine blades. Whether these impacts are compensatory, additive, or represent a continuum between compensation and additivity (Peron 2013) still remains unclear and needs much more assessment. However, for insectivorous bats, there may be a conservation measure that could significantly deter blade collisions. Insectivorous bats tend to forage for insects when wind speeds are low (e.g., ~0.5 to 3.5 m/s) and the insects are present and readily available. Insectivorous bats remain highly susceptible to collisions and even barotrauma at these low wind speeds. By increasing the cut-in speed of turbine blades—i.e., the speed of the wind at which the blades begin to rotate—from ~3.0 to 6.0 or 6.5 m/s, bat mortality in a Pennsylvania study was reduced by up to 93 % (Arnett et al. 2011). While this change results in a loss of only a small fraction of energy production, it could significantly reduce bat mortality and therefore deserves careful consideration (Arnett et al. 2011; Arnett and Baerwald 2013). However, because the recommendation in the FWS's WEG is only voluntary, few companies are currently implementing this or other useful mitigation measure (Williams 2014; Manville 2014b).

Based on public comment, review, and internal assessment, the FWS published its updated, *Eagle Conservation Plan Guidance, Module 1, Land-based Wind Energy, Version 2* (ECPG), in April 2013. Like the WEG, it recommends approaches to avoiding and minimizing eagle "take" and impacts to eagle territories and eagle use areas based on a tiered protocol using the stressor management approach—i.e., identifying the stressors, their threats, and the consequences. While following the ECPG is voluntary, where disturbance "take" and/or "take" resulting in mortality are likely to occur, a permit (50 C.F.R. 22.26 or 22.27) is strongly recommended as un-permitted "take" may have legal consequences (Associated Press 2014). The goal of the ECPG is to ensure that the breeding population of both species of eagles remains stable or increasing. While the FWS published the authorization for the take permits in 2009 (50 C.F.R. 22.26 for eagle "take" and 22.27 for nest "take") along with the required NEPA documentation, the implementation of the regulations and permitting are a work in progress.

Studies are beginning to be published on the indirect effects of commercial wind energy facilities including on grassland bird density, nest survival, bird avoidance and attraction, and bat presence at turbines, turbine pads, and the generation facilities in Iowa (Gillespie 2013). As previously discussed, Winder et al. (2014) and Winder et al. (2015 in press) are validating a FWS recommendation (Manville 2004) of an 8-km (five-mile) buffer between Greater Prairie-Chicken leks and wind facilities. Research into indirect effects continues.

For numerous reasons, it has become increasingly clear that independent, third-party monitoring of wind facilities and site studies, and solar facilities briefly discussed next, must also be implemented. Unfortunately, with FWS's voluntary WEG guidance, that currently seems unlikely. Instances of data falsification and obfuscation of data; data release limitations through confidentiality agreements signed by project biologists, contractors, and cooperators; submission of fraudulent reporting;

and inadequate monitoring have been reported to FWS's Office of Law Enforcement (e.g., Wiegand 2014). Also reported were concerns about vested consultant interests, spotty reporting, proprietary data, and an unwillingness to work with FWS (FWS 2014 and 2015 pers. comm.)—unlike many of the companies in the electric utility industry. As Williams (2014:67) reminds us, "…some wildlife mortality is inevitable with even the best projects. But nothing will do more harm to the industry than excusing or tolerating wildlife-stupid projects that give it a bad name." If the public remains concerned, their voices need to be heard, and in turn, the industry needs to proactively address these concerns.

Beginning to Address Problems to Birds from Collisions and Heat Impacts at Industrial Solar Facilities in the Southwest

Problems to Birds and Other Wildlife

Industrial-scale solar development is relatively new to the U.S. Not until 1979 was the first industrial solar facility installed and operated in the U.S. in the Mojave Desert, which used a heliostat-power tower-solar receiver boiler generation system. Named Solar One, it had a tower of 86 m AGL (282 ft) in height, and a heliostat field of 765 m (2510 ft) in diameter—small by current power tower standards. At Solar One, McCrary et al. (1986) collected and reported 70 bird fatalities involving 26 species, 57 birds of which died from collisions while 13 died from burning. More recently, Leitner (2009) raised additional concerns and made suggestions for the proper selection of solar sites, including more research and mitigation. However, based on preliminary discoveries, a recent publication with troubling results (Kagan et al. 2013), and specific new recommendations by researchers, the environmental project review for the current solar technologies continues to be sorely inadequate.

There are three types of solar-generating facilities: (1) photovoltaic systems, (2) trough systems, and (3) solar power towers.

(1) Photovoltaics directly convert sunlight into energy (e.g., Desert Sunlight—at 1619+ ha [4000+ acres], with more than eight million panels, is probably the largest solar facility in the world). These flat panel systems can each cover enormous areas, displacing foraging habitats for GOEAs (a species of concern for FWS), their prey, and other species. In California's Imperial County alone, 91 km^2 (35 mi^2) of flat panel photovoltaics have already been and are being proposed for development. In a recent 2013 opportunistic survey conducted by staff of FWS and reported by the National Fish and Wildlife Forensics Laboratory (NFWFL; Kagan et al. 2013), where no pre-determined carcass sampling protocol was used, 61 bird carcasses retrieved from Desert Sunlight were transported to NFWFL to determine cause of death. Birds apparently mistook the shiny mirrored surfaces of the cells for water, resulting in blunt force trauma, predation, and unknown causes. Bird carcasses have

also incidentally been found at other flat panel projects in California's Central Valley, Imperial Valley, and in Nevada. These reports are only incidental to facility operations, not based on systematic surveys—which is a quandary.

(2) Trough systems consist of parabolic mirrors which are about 9m (30 ft) tall and can be hundreds of meters long. They focus sunlight onto tubes which convert heat to electricity (e.g., Genesis Solar Energy). From the Genesis site, 31 bird carcasses were opportunistically evaluated by NFWFL for cause of death. The results included impact trauma, predation, and unknown causes (Kagan et al. 2013). It is important to note that the number of carcasses found to date far outnumber the 31 reported several years ago by Kagan et al. (2013; FWS 2015 pers. comm.). These carcasses were found opportunistically, with no research study design, based on no third-party monitoring.

(3) Solar power towers are by far the most complex of industrial solar generation and also the most deadly to both birds and bats—based on the preliminary evidence. They consist of thousands of mirrors (e.g., Ivanpah with more than 300,000—the largest industrial solar steam generating system in the world). The mirrors intensely reflect solar energy to a power-generating tower (for Ivanpah, 140 m AGL [459 ft]), producing steam at temperatures of up to 427 °C (800 °F). This, in turn, runs a turbine and has an air-cooled condenser. Ivanpah has been characterized as a "mega-trap" for wildlife by the NFWFL (Kagan et al. 2013). In addition to significant bat and monarch butterfly (*Danaus plexippus*) mortality, the facility has attracted other insects, which in turn have attracted insect-eating birds, which were incapacitated by the solar energy flux, in turn attracting avian and mammalian predators. This has created an entire food chain vulnerable to injury and death. Carcasses collected opportunistically at Ivanpah included 141 birds which died from solar flux ($N=47$), impact trauma ($N=24$), predation ($N=5$), undetermined trauma ($N=14$), and "unknown" ($N=46$; Kagan et al. 2013). Even more troubling is a very recent, preliminary report (FWS 2015 unpublished data) by third-party monitors of 130 birds killed during a 4-h observation period at Crescent Dunes solar steam power project, Nye County, Nevada. Virtually all the birds were vaporized (FWS 2015 pers. comm.).

If just three commercial solar energy facilities are killing $N=233$ protected migratory birds based only on opportunistic and incidental monitoring during a few visits—i.e., information not gathered via pre-determined, robust, and peer-reviewed protocols for mortality monitoring—then how many birds, bats, and imperiled insects (e.g., monarchs) are actually being killed/year? It must be emphasized that the $N=233$ number represents only what FWS opportunistic visits discovered several years ago. Current FWS Special Purpose-Utility (Avian Take Monitoring) Annual Reports (SPUT; FWS Form 3-202-17) indicate that for Desert Sunlight, Genesis, and Ivanpah alone, more than 1000 birds killed representing almost 160 different species have been reported to FWS (2015 unpublished FWS data; also reported on www.kcet.org). This is far greater than the Kagan et al. (2013) preliminary reporting. While no GOEA carcasses have yet been found, solar facilities are displacing thousands of hectares of breeding and foraging habitat. One estimate suggests that up to 28,000 birds, including rapidly declining populations of Western Grebes (*Aechmophorus occidentals*; a BCC species), Common Loons (*Gavia mimer*), Peregrine Falcons (*Falco peregrinus*), Burrowing Owls (*Athene cunicularia*), Short-eared Owls (*Asio flames*), and others, are being killed each year in commercial solar arrays now operating only in Southern California, with a focus on Ivanpah (Center Biological Diversity 2014). However, until reporting is consistent, systematic, robust, and scientifically credible, the direct, indirect, and cumulative effects of industrial solar development on resident and wintering/migrant birds will remain uncertain. The lack of peer-reviewed data and a push by the current administration to fast-track renewable energy only complicates the situation.

These developments clearly do not bode well for industrial solar development. Apparently a number of FWS biologists raised major concerns before projects were even approved, let alone constructed, but their concerns did not resonate (FWS 2014 and 2015 pers. comm. and internal communications).

Beginning to Address the Problems

It is time to go back to the basics, using sound science and accepted protocols for monitoring as the drivers for developing industrial solar energy. These protocols should be scientifically credible, sufficiently robust, field tested, peer-reviewed, and accepted as valid by the scientific community—e.g., Gehring et al. 2009, as modified to apply to solar monitoring. Agencies need to maintain the leadership willing to stand up to the powerful industries and not be swayed by “green washing” (i.e., industry touting its actions as environmentally friendly and responsible, when in fact they can be very impactful). Because it is so challenging, enacting change within the agencies can be incredibly difficult. For example, on Bureau of Land Management public lands where the focus is on the development of solar facilities, thorough pre-construction risk assessment must be implemented, along with a full NEPA review of proposed projects, including citizen participation in the process (e.g. testimony, peer review, and litigation). Meanwhile, here is a preliminary list of some suggested mitigation for wildlife impacts at industrial solar facilities—which is far from exhaustive. All should be further tested using empirical field studies and published in refereed scientific journals, indicating which techniques are most effective. Bird and bat mortality can be reduced through fencing, nets, perch deterrents, exclusionary measures, UV-reflective glass, suspended operations during peak bird presence, use of video cameras and trained dogs for detection of carcasses, at least 2 years of daily bird and bat mortality searches—adjusting for scavenger removal including by Common Ravens, and addressing observer bias—and other measures as suggested by Kagan et al. (2013). Independent peer review of the agencies and contractors’ statistics is also critical. How these projects were approved without sufficient oversight is very troubling. In this author’s opinion, this same concern also applies to land-based wind development.

Conclusion

The issues discussed above present huge challenges, especially since we still know so little about the overall, cumulative impacts of powerlines, communication towers, commercial wind projects, and commercial solar arrays on birds, bats, and their habitats. If electric transmission, electronic communication, and renewable energy development are to be bird-, bat-, and habitat-friendly, changes must take place. This suggests a complete paradigm shift in assessing sites, adequately predicting pre-construction risks, validating risks during post-construction monitoring and assessment, and reversing ongoing very troubling trends.

To begin making this shift, this author recommends the development of an accepted monitoring protocol for each industry sector. Each protocol should be empirically based, scientifically valid, sufficiently robust—of the appropriate duration and intensity, with a consistent study design, field tested, peer-reviewed, and published in a refereed scientific journal. Post-construction monitoring should ideally include empirically driven, field-tested, and validated conservation and mitigation measures. Where such measures currently do not exist (e.g., industrial solar arrays and wind energy projects), research should continue to try to find them. Mitigation replacement/compensation measures for "take" and impacts to wildlife habitats should also be developed, empirically evaluated, peer-reviewed, published, and adopted, where most effective.

The guidelines for avoiding or minimizing impacts to migratory birds at communication towers, electric utilities, and commercial wind turbines have, for the most part, been voluntary—generally left up to the discretion of the industry proponents. This has often resulted in huge inconsistencies in monitoring (e.g., this author recounts a consultant providing four days of bird monitoring data at a proposed wind energy site to represent an entire migratory season of three months). As a result, a regulatory (e.g., implemented through the U.S. Code of Federal Regulations) versus voluntary approach has been suggested, including by this author, but under the current political climate in the U.S., that is highly unlikely. If regulations were developed, the suggested, empirically based monitoring protocols mentioned above should be incorporated as part of them. Also important, the agencies required by law and statute to manage wildlife and wildlife habitats need to acknowledge and implement their trust and statutory responsibilities regarding the wildlife they are entrusted to protect and conserve. Based on this author's experiences, politics rather than sound science seem to drive many current decisions. The Department of Interior and Department of Energy might be good places to begin the shift.

Based on the experiences of this author, there is some good news. With collaborative efforts such as those of APLIC long in place—and generally working well—the bar has been set high for other industries and agencies to follow. Where companies and their consultants are working with FWS, other agencies, and the public to better understand and minimize the impacts from human structures, their efforts should be applauded. This is a very good, but still too rare a thing.

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EXHIBIT B

Direct Mortality of Birds from Anthropogenic Causes

Scott R. Loss,[1] Tom Will,[2] and Peter P. Marra[3]

[1]Department of Natural Resource Ecology and Management, Oklahoma State University, Stillwater, Oklahoma 74078; email: scott.loss@okstate.edu

[2]Division of Migratory Birds, Midwest Regional Office, US Fish and Wildlife Service, Bloomington, Minnesota 55437-1458; email: tom_will@fws.gov

[3]Migratory Bird Center, National Zoological Park, Smithsonian Conservation Biology Institute, Washington, DC 20013; email: marrap@si.edu

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Keywords

anthropogenic mortality, avian ecology, conservation biology, incidental take, population ecology

Abstract

Understanding and reversing the widespread population declines of birds require estimating the magnitude of all mortality sources. Numerous anthropogenic mortality sources directly kill birds. Cause-specific annual mortality in the United States varies from billions (cat predation) to hundreds of millions (building and automobile collisions), tens of millions (power line collisions), millions (power line electrocutions, communication tower collisions), and hundreds of thousands (wind turbine collisions). However, great uncertainty exists about the independent and cumulative impacts of this mortality on avian populations. To facilitate this understanding, additional research is needed to estimate mortality for individual bird species and affected populations, to sample mortality throughout the annual cycle to inform full life-cycle population models, and to develop models that clarify the degree to which multiple mortality sources are additive or compensatory. We review sources of direct anthropogenic mortality in relation to the fundamental ecological objective of disentangling how mortality sources affect animal populations.

INTRODUCTION

The novel human-driven changes that characterize the Anthropocene have increased the number of mortality sources that affect wildlife populations. Birds in particular are experiencing precipitous population declines across the globe as a result of multiple anthropogenic stressors (Sekercioglu et al. 2004, IUCN 2014). In the United States, 100 bird species and subspecies are listed as federally threatened or endangered (USFWS 2014). Without further conservation action, nearly 200 additional species will likely become candidates for listing (USFWS 2008). Species population declines and extinctions can lead to a breakdown of ecosystem processes and services (Wardle et al. 2011, Valiente-Banuet & Verdu 2013), can cost millions of dollars in recovery efforts (USFWS 2013a), and can have implications for human societies (Cardinale et al. 2012). It is therefore essential to disentangle how mortality threats, individually and cumulatively, affect bird populations.

Habitat loss, climate change, and other stressors indirectly cause animal mortality through one or more intermediate mechanisms. However, there exist several anthropogenic stressors that directly kill billions of birds each year (**Figure 1**). Most of these direct mortality sources—including collisions with vehicles and manmade structures, poisoning with toxins, and predation by free-ranging pets—affect hundreds of bird species (Calvert et al. 2013; Loss et al. 2013a,b, 2014a). These mortality sources can cause large die-offs (e.g., poisoning events in agricultural areas and collision events at tall, lighted structures; Longcore et al. 2012, Mineau & Whiteside 2013) or they can kill birds in millions to billions of individual events each year (e.g., free-ranging cats

Figure 1

Major sources of direct anthropogenic mortality include (clockwise from upper left): collisions with automobiles (Northern Cardinal, *Cardinalis cardinalis*, Washington, DC), collisions with building windows (Clay-colored Sparrow, *Spizella pallida*, Oklahoma), predation by domestic cats (Ovenbird, *Seiurus aurocapilla*, North America), collisions with communication towers (Hawfinch, *Coccothraustes coccothraustes*, Slovenia), collisions with wind turbines (White-tailed Eagle, *Haliaeetus albicilla*, Norway), and electrocution at power lines (Crow, *Corvus* spp., UK). Photos used with permission from: upper left and upper middle, Scott R. Loss; upper right, Creative Commons, A. Currie; lower left, Wikimedia Commons, T. Jančar; lower middle, Wikimedia Commons, J. Ferenc; and lower right, Creative Commons, N. Mykura.

and collisions at residential buildings; see Blancher 2013; Loss et al. 2013b, 2014a), resulting in mortality that far exceeds more visible die-offs.

When compared with indirect stressors, direct mortality sources are characterized by relative clarity of cause and effect. The study of direct anthropogenic mortality therefore has the potential to lead to mitigation measures that target the cause and substantially reduce bird mortality. Recent syntheses of the growing number of quantitative mortality studies have led to improved estimates of national bird mortality for the United States and Canada (Calvert et al. 2013; Loss et al. 2013a,b, 2014a–c) (all estimates appear in **Table 1**, and the top mortality sources are summarized in **Figure 2**). Research has also identified correlates of mortality rates (Longcore et al. 2012, Loss et al. 2013a) and disproportionately vulnerable bird species (Arnold & Zink 2011, Longcore et al. 2013, Loss et al. 2014a). However, relatively little is known about spatiotemporal variation in mortality and the abiotic, ecological, and anthropogenic (e.g., socioeconomic and behavioral) drivers of this variation. This information is critical for understanding avian population responses to mortality (Boyce et al. 1999, Jonzén et al. 2002). Another challenge to clarifying population responses to direct anthropogenic mortality is determining the degree to which mortality is compensatory or additive. With regard to compensatory mortality, at least some of the individuals killed would have died in the absence of the mortality source; more formally, density-dependent population processes compensate for the additional mortality. With regard to additive mortality, the individuals killed would not have otherwise died; more formally, mortality exceeds the compensation ability of density-dependent processes (Sinclair & Pech 1996, Peron 2013). We review the scientific literature on the direct anthropogenic mortality of birds, compare the best available estimates for different mortality sources, identify overarching research needs that must be addressed to understand population responses to mortality, and outline management approaches to reduce bird mortality.

APPROACHES TO STUDYING DIRECT ANTHROPOGENIC MORTALITY

Research on the direct anthropogenic mortality of birds generally falls into the following non-mutually exclusive categories: (*a*) studies that estimate local mortality rates and, in some cases, correlates of mortality; (*b*) population impact assessments, including both local and large-scale studies and both correlative and intensive demographic analyses; (*c*) national estimates of mortality based on extrapolation; and (*d*) systematic syntheses of data across numerous studies.

Studies that use periodic fatality monitoring to quantify variation in mortality rates at local scales comprise most of the research on direct anthropogenic mortality. Most local studies are in the peer-reviewed literature. However, a large proportion of studies on bird collisions with large buildings or wind turbines remain unpublished, are not peer-reviewed, and are not readily available to researchers and the public (Piorkowski et al. 2012, Machtans et al. 2013). Several studies have accounted for factors that contribute negative bias to mortality estimates, including scavenger removal of carcasses and imperfect surveyor detection of carcasses (e.g., for buildings, Hager et al. 2013; for vehicles, Santos et al. 2011; for power lines, Ponce et al. 2010). These biasing factors have been assessed in a relatively large proportion of studies of bird–wind turbine collisions (Smallwood 2013, Zimmerling et al. 2013). Although local mortality estimates form the basis for upscaling analyses, a relatively small proportion of local studies are conducted with the rigor needed for data to be used in regional and national data syntheses (reviewed by Loss et al. 2012, 2014b,c).

Several local-, regional-, and national-scale studies have assessed population-level impacts of direct mortality sources. At local scales, intensive population modeling—based on field collection of mortality data and locally collected or literature-derived demographic data—has indicated that

Table 1 Systematic, data-driven estimates of national bird mortality from direct anthropogenic stressors

Mortality source	Country	Estimate[a]			Estimate type	Source
		Central	Lower	Upper		
Cats (all)	Canada	204,000,000	105,000,000	348,000,000	Median, 95% CI	Blancher 2013
	United States	2,407,000,000	1,306,000,000	3,992,000,000	Median, 95% CI	Loss et al. 2013b
Cats (unowned, feral)	Canada	116,000,000	49,000,000	232,000,000	Median, 95% CI	Blancher 2013
	United States	1,652,000,000	803,000,000	2,955,000,000	Median, 95% CI	Loss et al. 2013b
Cats (owned, free-ranging)	Canada	80,000,000	27,000,000	186,000,000	Median, 95% CI	Blancher 2013
	United States	684,000,000	221,000,000	1,682,000,000	Median, 95% CI	Loss et al. 2013b
Buildings (all)	Canada	24,900,000	16,100,000	42,200,000	Mean, range	Machtans et al. 2013
	United States	599,000,000	365,000,000	988,000,000	Median, 95% CI	Loss et al. 2014a
Buildings (low-rises)	Canada	2,400,000	300,000	11,400,000	Mean, range	Machtans et al. 2013
	United States	339,000,000	136,000,000	715,000,000	Median, 95% CI	Loss et al. 2014a
Buildings (residences)	Canada	22,400,000	15,800,000	30,500,000	Mean, range	Machtans et al. 2013
	United States	253,000,000	159,000,000	378,000,000	Median, 95% CI	Loss et al. 2014a
Buildings (high-rises)	Canada	64,000	13,000	149,000	Mean, range	Machtans et al. 2013
	United States	508,000	104,000	1,600,000	Median, 95% CI	Loss et al. 2014a
Automobiles	Canada	13,810,906	8,914,341	18,707,470	Mean, 95% CI	Bishop & Brogan 2013
	United States	199,600,000	88,700,000	339,800,000	Median, 95% CI	Loss et al. 2014b
Power line collisions	Canada	25,600,000	10,100,000	41,200,000	Mean, 95% CI	Rioux et al. 2013
	United States	22,800,000	7,700,000	57,300,000	Median, 95% CI	Loss et al. 2014c
Communication towers	Canada	220,650	NA[b]	NA[b]	Mean	Longcore et al. 2012
	United States	6,581,945	NA[b]	NA[b]	Mean	Longcore et al. 2012
Power line electrocutions	Canada	481,399	160,836	801,962	Mean, range	Calvert et al. 2013
	United States	5,630,000	920,000	11,550,000	Median, 95% CI	Loss et al. 2014c
Wind turbines (all)	Canada	16,700	13,330	21,600	Mean, 95% CI	Zimmerling et al. 2013
	United States	573,093	467,097	679,089	Mean, 90% CI	Smallwood 2013
Wind turbines (monopole)	United States	234,000	140,000	328,000	Mean, 95% CI	Loss et al. 2013a
Agricultural pesticides	Canada	2,695,415	960,011	4,430,819	Mean, range	Calvert et al. 2013
Fisheries: marine gill nets	Canada	20,612	2,185	41,528	Mean, range	Ellis et al. 2013
Marine oil and gas activities	Canada	2,244	188	4,494	Median, range	Van Wilgenburg et al. 2013
Fisheries: marine longlines/trawls	Canada	1,999	494	4,058	Mean, range	Ellis et al. 2013

[a] Estimates are for independent birds only (i.e., estimates of destroyed nests, eggs, and nestlings are excluded; see Calvert et al. 2013), and systematic, data-driven estimates that apply to only one or a few species are excluded.

[b] No range of uncertainty produced in original study.

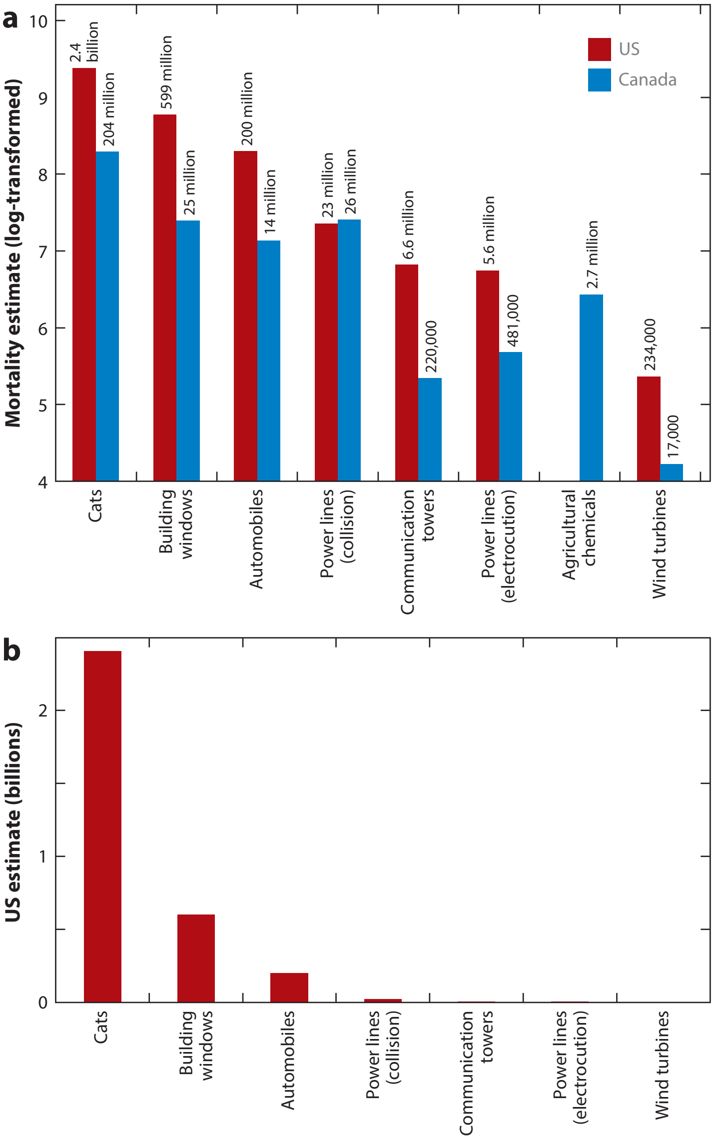

Figure 2

Comparison of major sources of direct anthropogenic bird mortality for the United States and Canada. Note the logarithmic scale for panel *a* and the absolute scale for panel *b* (estimate sources: Longcore et al. 2012, Calvert et al. 2013, Loss et al. 2013a,b, 2014a–c).

cat predation increases the probability of population extinction or decline for some bird species (van Heezik et al. 2010, Balogh et al. 2011). In addition, relatively low mortality rates for some sources can lead to significant population declines [e.g., vehicle collisions for owls in Portugal (Borda-de-Agua et al. 2014), wind turbine collisions for vultures in Spain (Carrete et al. 2009) and eagles in Norway (Dahl et al. 2012)].

At regional and national scales, population impacts have been indirectly assessed by dividing estimated mortality by estimated population abundance (Calvert et al. 2013, Longcore et al. 2013) or by correlating population abundance or trends with exposure or vulnerability indices (Arnold & Zink 2011, Mineau & Whiteside 2013). Significant population declines in birds have been associated with agricultural pesticide use in the United States and the Netherlands (Mineau & Whiteside 2013, Hallmann et al. 2014). Such correlative analyses may be useful for highlighting the broad conservation importance of a mortality source, but they do not identify particular species and locations experiencing population-level impacts. Two quantitative approaches hold promise for clarifying how populations respond to direct sources of mortality: integrated population models (IPMs; Hoyle & Maunder 2004, Schaub et al. 2007) and potential biological removal (PBR) models (Wade 1998). Both approaches allow for uncertainty in model inputs to be propagated into estimates of population responses. IPMs allow the combination of multiple data types (e.g., census and mark-recapture data) to jointly estimate population responses (Rhodes et al. 2011). PBR models allow shortcuts for difficult-to-estimate parameters (e.g., substituting intrinsic population growth rate with generation time or adult survival and age of first reproduction; Niel & Lebreton 2005, Dillingham & Fletcher 2011). These shortcuts allow population analyses to be conducted for far more bird species than would be possible using more complex demographic models.

Data-driven estimates of mortality at regional, national, and continental scales are needed to understand impacts of mortality sources on bird populations and to provide an evidence base for policy and management decisions (Longcore & Smith 2013, Machtans & Thogmartin 2014). Large-scale estimates of direct anthropogenic bird mortality have traditionally been based on nonsystematic analyses and extrapolation of mortality rates from one or a few studies to entire regions or countries. Authors of these studies have been careful to qualify limitations of the estimates (Banks 1979, Klem 1990, Erickson et al. 2005); however, the figures are often cited in the scientific literature and popular media without the original qualifications. Recently, several quantitative, data-driven reviews have been conducted for the United States and Canada with the objectives of updating nonsystematic estimates, systematically identifying sources of estimate uncertainty, and assessing spatiotemporal and taxonomic patterns of mortality. We highlight major findings of these studies throughout this article. Although numerous studies of direct, anthropogenic bird mortality have been conducted throughout the world, we are not aware of systematic reviews of direct anthropogenic mortality outside of North America.

MAJOR SOURCES OF DIRECT ANTHROPOGENIC BIRD MORTALITY

Predation by Free-Ranging Domestic Cats

Predation by domestic cats (*Felis catus*) has caused the decline and extinction of numerous bird populations on small islands (Nogales et al. 2013). Impacts of free-ranging pet cats and unowned feral cats in mainland areas are less clear, despite evidence that predation impacts local population processes (van Heezik et al. 2010, Balogh et al. 2011). A recent quantitative review incorporating data from 17 studies generated the first data-driven national estimate of cat predation mortality (Loss et al. 2013b). The estimate of between 1.4 and 4.0 billion birds killed annually by cats in the United States was higher than previous speculative estimates and higher than estimates for any other source of direct anthropogenic mortality. A similar analysis for Canada, where the total population of free-ranging cats is estimated to be far lower than in the United States, estimated that between 100 and 350 million birds are killed annually (Blancher 2013). In both studies, the greatest sources of estimate uncertainty—which can be interpreted to indicate major research needs—included estimates of population size and predation rate for unowned feral cats. Both studies also highlighted the scarcity of information about which bird species are most frequently killed, indicating a pressing need for research into species-specific mortality. This information will facilitate increased precision of mortality estimates and modeling of population impacts of cat predation. Recent research has begun to fill these information gaps, including studies that have (*a*) assessed fine-scale habitat selection of cats with satellite tracking technology (Recio et al. 2014); (*b*) documented cat predation events, including the species killed, using cat-mounted cameras (Loyd et al. 2013); and (*c*) identified bird species that face a high risk of extinction from predation (Bonnaud et al. 2012).

The primary management approach to reduce predation by cats is to prevent or limit their outdoor access. In theory, this approach should be easy to implement for pet cats, given that it is widely accepted and advocated for by conservation and wildlife management groups (e.g., the American Bird Conservancy, National Audubon Society) and most pet owner and animal welfare organizations (e.g., People for the Ethical Treatment of Animals, The Humane Society of the United States). Nonetheless, tens of millions of pet cats remain outdoors in the United States alone (Lepczyk et al. 2010, Loss et al. 2013b), largely as a result of pet ownership behaviors and, in many municipalities, ineffective programs to license pet cats.

Reducing predation by unowned feral cats necessitates reducing feral cat populations. Approaches for achieving this objective are highly controversial (Longcore et al. 2009, Lepczyk et al. 2010) and range from lethal control (by poisoning, lethal injection, and/or legalized hunting) to trap, neuter, and release (TNR) programs (McCarthy et al. 2012, Lohr & Lepczyk 2014). Reducing feral cat populations is further complicated by outdoor feral cat feeding stations, which subsidize abandoned, stray, or semiferal cat populations. These feeding stations range from informal and small scale (e.g., plates of cat food placed in parks or private yards) to large scale (e.g., the extensive feeding and sheltering operations in many US public parks). Central to identifying effective and acceptable solutions for reducing feral cat populations are scientifically sound and consistent regulation and the monitoring of TNR and cat feeding programs. Although TNR programs are widely implemented, little formalized monitoring of the success and impact of these programs exists. Claims that TNR programs consistently reduce cat population sizes are not based on carefully collected scientific evidence (Longcore et al. 2009). Furthermore, the numerous informal cat feeding operations that do not undertake sterilization and adoption programs are likely to escape scrutiny and potentially counteract any positive effects of more official management efforts. Although lethal control options are often portrayed as unacceptable to the public, a survey in Hawaii indicated that most residents favor lethal control over TNR programs (Lohr & Lepczyk 2014). Studies that assess the acceptability of alternative management strategies will lead to more effective and acceptable solutions for managing feral cat populations.

Collisions with Buildings

Klem (1990) called attention to the issue of bird collisions with buildings and with windows in particular. However, relatively few peer-reviewed studies of this topic have been conducted. Three recent quantitative reviews have generated national estimates of bird-building collision mortality and/or species vulnerability. Arnold & Zink (2011) used bird mortality data from three cities in eastern North America to identify supercolliders (i.e., species found dead disproportionate to their abundance). They found that most supercolliders are migratory species and that most urban-adapted species are not vulnerable to collisions. For Canada, Machtans et al. (2013) estimate that between 16 and 42 million birds are killed annually by building collisions. Based on 10 different data sources, they demonstrate that skyscrapers and other large buildings kill the most birds on a per building basis, but individual residences cumulatively kill the most birds. The most extensive review to date—based on 26 studies, including citizen science programs in 13 cities and more than 90,000 fatality records—estimates US building collision mortality at between 365 and 988 million birds (Loss et al. 2014a). This study corroborates the finding of the Canadian study regarding the large amount of mortality at residences, supports the conclusion that the most vulnerable species are long-distance migrants, and identifies additional supercolliders, including several US Birds of Conservation Concern (USFWS 2008) [e.g., the Painted Bunting (*Passerina ciris*) and the Golden-winged Warbler (*Vermivora chrysoptera*)].

Loss et al. (2014a) summarize the need for further research to better understand the population impacts of bird-building collisions, including studies that (*a*) quantify collision rates for different building types throughout the year and in diverse geographic and ecological settings, (*b*) assess survey-related biases that cause underestimation of mortality (e.g., scavenger removal, imperfect carcass detection), and (*c*) determine best approaches for reducing mortality. Researchers have begun to account for the above biases, to identify correlates of collision rates (e.g., window area, vegetation cover; Klem et al. 2009, Hager et al. 2013), and to take a large-scale approach (Bayne et al. 2012, Hager & Cosentino 2014). Systematic testing of window collision mitigation measures remains limited. Nonetheless, approaches that are likely to reduce collision rates include turning off lights in large buildings during migration, using bird-friendly design elements (e.g., reducing the amount of reflective surface, limiting trapping mechanisms such as deep alcoves, and minimizing features that allow birds to see through to the interior or opposite side of a building), and developing and implementing deterrence techniques (e.g., reflective adhesives keyed to avian visual perception) (Sheppard 2011, Klem & Saenger 2013, Fernandez-Juricic 2015). Tests of window treatments have been based on two approaches: (*a*) tunnel tests, whereby birds are released at one end of a tunnel and choose between two lighted openings, each covered by a different glass treatment, and (*b*) field tests, whereby window frames are placed in the field to mimic building windows (Klem & Saenger 2013). Such tests have illustrated that collisions can be reduced by covering glass with UV-reflecting surfaces (with reflectance of 20–40% of the 300–400 nm wavelength), hanging objects in front of windows, or placing objects or patterns on the glass exterior (with 10-cm and 5-cm separation between vertical and horizontal objects, respectively) (Klem 1990, Klem & Saenger 2013).

Collisions with Communication Towers

Collisions with communication towers are a major source of mortality for birds, with several reports of single-night, single-tower casualty events of hundreds to thousands of individuals. Birds are attracted to lights on towers during nighttime migration periods, especially during foggy and otherwise inclement weather. Most fatalities occur when birds collide with towers or their guy wires (Shire et al. 2000). A continental-scale quantitative review estimated that towers kill 6.6 million birds annually in the United States and 220,000 birds in Canada (Longcore et al. 2012). As with buildings, the species most vulnerable to tower collisions are migratory songbirds (e.g., warblers, vireos, thrushes, and sparrows). By combining estimates of species-specific mortality with estimates of total North American population abundance, Longcore et al. (2013) conclude that 29 bird species could experience annual mortality from communication towers greater than 1% of their entire population. Such species include the Yellow Rail (*Coturnicops noveboracensis*), the Pied-billed Grebe (*Podilymbus podiceps*), and 19 warbler species.

Management recommendations for reducing bird collisions with communication towers are based on studies that compare bird mortality rates among towers with varying structural and lighting characteristics. Research on more than 20 towers in Michigan showed that replacing steady-burning lights with either red or white flashing lights can reduce mortality by 51–70% (Gehring et al. 2009) and that towers 116–146 m tall without guy wires cause 16 times less mortality than comparably sized guyed towers (Gehring et al. 2011). Furthermore, taller towers kill more birds, likely as a combined result of their taller central tower structure and their longer total guy wire length. Gehring et al. (2011) found that guyed tall towers (those >305 m in height) cause roughly five times more mortality than medium-sized guyed towers and 70 times more mortality than medium-sized unguyed towers. A meta-analysis of 26 towers in the United States documented a strong positive relationship between tower height and mortality, even when controlling for the effect of lighting (Longcore et al. 2008). Additional approaches that could reduce bird mortality at communication towers include visually marking guy wires and placing new towers near existing ones rather than in undisturbed locations (USFWS 2013c).

Collisions with Wind Turbines

The impact of wind energy development on birds has become a major conservation focus (Kuvlesky et al. 2007). Numerous studies have assessed indirect impacts of wind facilities on bird abundance (Pearce-Higgins et al. 2012), breeding ecology (LeBeau et al. 2014, McNew et al. 2014), and habitat use in relation to the risks of constructing new facilities (Belaire et al. 2014, Loring et al. 2014). However, most studies of bird–wind turbine collisions are unpublished and not peer reviewed (but see, e.g., Johnson et al. 2002, Smallwood & Karas 2009).

Recent quantitative reviews have provided a large-scale perspective on bird-turbine collisions. A review of data from 71 wind facilities estimated annual US mortality—including mortality from old-generation lattice turbines and new-generation monopole turbines (see **Figure 3** for examples

Figure 3

A wind facility in California with several models of monopole wind turbines (those with solid towers) as well as lattice wind turbines (those with hollow, cage-like towers). Photo used with permission from Scott R. Loss.

of each turbine type)—at between 420,000 and 644,000 birds (Smallwood 2013). Another study based on data from 67 facilities estimated US mortality from monopole turbines at between 140,000 and 328,000 birds (Loss et al. 2013a). The latter study showed that, as for communication towers, mortality rates at monopole turbines increase with height. However, Loss et al. (2013a) and others have been unable to disentangle turbine height from other strongly correlated metrics of turbine size (e.g., rotor diameter). Nonetheless, increased mortality likely occurs because large turbines both reach into altitudes through which large numbers of birds fly and have rotors that affect a larger volume of airspace.

Turbine placement appears to be a major determinant of collision risk, with high mortality rates documented for broad regions (e.g., California and eastern mountains in the United States; Loss et al. 2013a) and particular areas within wind facilities (e.g., ridgelines at California wind facilities; Smallwood & Thelander 2008). Although evidence is currently insufficient to infer the population impacts of wind turbine collisions (Stewart et al. 2007), some raptor species may experience population declines from even a small amount of turbine collision mortality (Carrete et al. 2009, Dahl et al. 2012) or as a result of particular turbine arrays (Schaub 2012). Further research is needed to clarify the factors driving collision rates and to inform decisions about where to install wind farms and individual turbines. In many regions, systematic analyses are needed to assess the accuracy with which preconstruction surveys predict mortality. Most preconstruction studies currently assess entire wind facilities and consider birds as an undifferentiated group. However, an analysis of data from 20 wind facilities in Spain illustrated that preconstruction designations of mortality risk (based on visual observations of birds) were unrelated to total bird mortality following facility construction (Ferrer et al. 2012). The authors concluded that increased accuracy of preconstruction assessments requires a shift to focusing on individual proposed wind turbines and individual bird species.

Current estimates of bird mortality at wind facilities are low compared with many other mortality sources. However, rapid expansion of wind energy along with a projected increase in turbine size could lead to substantially greater mortality (Loss et al. 2013a). Current projections estimate as much as a fourfold increase in the amount of US wind energy generation by 2040 (USEIA 2014) and wind energy is expanding worldwide. Given this expected expansion, we argue that the current small estimates of mortality do not necessarily obviate the need for continued research, management, and policy related to wind energy. In many regions (including most of the United States), wind energy companies are not required to conduct postconstruction monitoring for mortality or to release mortality data to the public. Increased monitoring of proposed and existing facilities and increased public access to unpublished industry reports will facilitate future efforts to identify successful mortality reduction approaches as the wind industry expands.

Collisions with Vehicles

Among the numerous ecological impacts of roads (Forman & Alexander 1998), bird collision with vehicles is one of the most significant (Kociolek et al. 2011). Recent quantitative reviews have generated estimates of between 80 and 340 million birds killed annually by vehicle collisions in the United States (Loss et al. 2014b) and of roughly 13.8 million birds killed each breeding season in Canada (Bishop & Brogan 2013). Both of these studies highlight the need for increased research into surveyor detection and scavenger removal rates to increase the precision of future mortality assessments. The studies also concluded that little information is available to quantify spatiotemporal and taxonomic variation in collision rates. Meta-analyses of the indirect effects of roads have shown clear declines in local bird abundance near roads (Fahrig & Rytwinski 2009, Benitez-Lopez et al. 2010), but these responses may be at least partially driven by other road-related stressors, such as habitat loss and noise. Barn Owls (*Tyto alba*) are vulnerable to vehicle collisions, and this species is likely experiencing collision-related population declines in some regions (Boves & Belthoff 2012, Borda-de-Agua et al. 2014). Strategies to reduce bird-vehicle collision rates are largely untested. Currently recommended measures to reduce mortality are based on documented correlates of collision rates (Bishop & Brogan 2013) and include erecting fences or other flight diverters, reducing speed limits in problem areas, and removing bird habitats near roadsides.

Collisions and Electrocutions at Power Lines

Bird mortality occurs at power lines as a result of collisions with wires and electrocution at both wires and poles. A recent systematic review estimated that between 8 and 57 million birds are killed annually by colliding with US power lines and that between 0.9 and 11.6 million birds are killed by electrocution (Loss et al. 2014c). This study concluded that not enough rigorous studies have been conducted to quantify spatiotemporal and taxonomic variation in mortality or to infer population-level impacts (see also Bevanger 1994, Lehman et al. 2007). Existing estimates of mortality at power lines may be low, because collision studies typically focus only on transmission lines (large, high-voltage lines) and electrocution studies focus only on distribution lines (small, low-voltage lines). Both types of mortality occur at both line types, however (APLIC 2006, Dwyer et al. 2014). For large-bodied species that fly weakly or are unable to rapidly maneuver in flight, power line collisions can represent a major mortality source with potential population-level impacts. A study in Norway estimated annual national mortality for three grouse species—the Capercaillie (*Tetrao urogallus*), Black Grouse (*Tetrao tetrix*), and Willow Ptarmigan (*Lagopus lagopus*)—at 20,000, 26,000, and 50,000, respectively (Bevanger 1995). These figures represent roughly 90%, 47%, and 9%, respectively, of the annual hunting harvest for the three species. A mark-recapture study in Switzerland estimated that one in four juvenile and one in seventeen adult White Storks (*Ciconia ciconia*) die each year from power line collisions (Schaub & Pradel 2004).

An extensive list of best practices has been developed for reducing mortality at new and existing power lines (APLIC 2006, 2012). Examples of electrocution reduction approaches include: (*a*) using low-conductivity (i.e., nonmetal) materials whenever possible, (*b*) capping energized parts, and (*c*) ensuring that distances between adjacent wires, between wires and other energized components, and between energized components and grounded hardware exceed the wrist-to-wrist and head-to-foot distance of at-risk bird species (APLIC 2006). A meta-analysis of 21 studies illustrated that marking wires with flight diverters can reduce collision mortality by as much as 78% (Barrientos et al. 2011). Additional collision reduction approaches that have been suggested but remain largely untested include: managing surrounding land to reduce the number of birds near power lines, using narrower line corridors, and assessing bird habitat use and migratory patterns before constructing power lines (APLIC 2006). For both collisions and electrocutions, retrofitting existing lines to meet suggested practices can reduce bird mortality (Janss & Ferrer 1999, Harness & Wilson 2001, Dwyer et al. 2014). However, the length of installed power lines that must be retrofitted to significantly reduce total mortality is uncertain and likely to be substantial.

Poisoning from Pesticides

Pesticides, including herbicides, insecticides, fungicides, and rodenticides, can directly cause bird mortality as a result of birds coming into contact with sprayed chemicals or consuming contaminated food material. Pesticides broadcast in high volumes and across large areas of agricultural land pose the greatest risk to bird populations. At least 113 pesticides directly cause bird mortality, and the use of pesticides correlates with declining bird populations in the Canadian prairies (Mineau 2005b) and US agricultural lands (Mineau & Whiteside 2013). The high-concentration use of neonicotinoids—the fastest-growing class of insecticides used globally—has also recently been associated with population declines in insectivorous bird species in the Netherlands (Hallmann et al. 2014).

The difficulty of linking rates and locations of chemical applications with the presence and amount of bird poisoning mortality has largely prevented estimation of national bird mortality from this source. An exception is a quantitative review that estimated that between 1 and 4.4 million birds are killed annually by pesticides in Canada (Calvert et al. 2013). This estimate was based on a combination of pesticide toxicity data, the estimated proportion of cropland at risk of experiencing a poisoning event, and the number of birds estimated to be killed in a poisoning event. The study showed that exposure risk can be modeled precisely if pesticide use data are available. However, in most cases, little field-collected information exists to predict bird mortality following exposure.

The large amount of mortality estimated for Canada suggests that poisoning from agricultural chemicals is likely a top mortality source in countries with extensive cropland. One analysis suggested that between 17 and 91 million birds were killed by a single chemical—carbofuran, one of the most toxic chemicals to birds—during its peak period of use in the Midwestern US Corn Belt (Mineau 2005a). The use of this chemical has been banned in Canada and Europe, and nearly all uses have been banned in the United States. However, given the large number of pesticides that cause bird mortality, continued reduction and elimination of highly toxic chemicals (e.g., chlorpyrifos and neonicotinoids; Mineau & Whiteside 2006, Hallmann et al. 2014) and of the amount of cropland receiving broadcast pesticide applications are likely necessary to substantially reduce avian mortality from pesticide poisoning.

Other Sources of Direct Anthropogenic Mortality

Several other sources of direct anthropogenic bird mortality have not been studied sufficiently for systematic analyses to be conducted, including collision and burning at solar power plants (Kagan et al. 2014), burning at natural gas flares (CBC News 2013), entrapment and starvation in open-top PVC and metal pipes used for gates and mine markers (Hathcock & Fair 2014), and entrapment in heater treaters and dehydrators at oil and natural gas well sites (USFWS 2013b). Other mortality sources have comparatively speculative and/or very low estimates of mortality (e.g., drowning mortality at oil mining pits and other examples in **Table 1**). A lack of information about a mortality source or a low overall mortality estimate does not preclude the possibility that a mortality source is biologically significant for some species, locations, and/or time periods. We encourage further study of these mortality sources.

COMPARISONS AMONG MORTALITY SOURCES

The range of estimated bird mortality for different direct anthropogenic sources is enormous; however, overlapping uncertainty ranges among some estimates suggest that rankings should only be approximated to orders of magnitude. Data-driven estimates of annual US mortality vary from billions (cat predation) to hundreds of millions (building and automobile collisions), tens of millions (power line collisions), millions (power line electrocutions, communication tower collisions), and hundreds of thousands (wind turbine collisions) (**Table 1**). Strong agreement between analyses conducted for Canada and the United States exists for the ranking of mortality sources (**Figure 2**). Cat predation is overwhelmingly estimated as the top source of direct anthropogenic mortality in both countries, and the next three mortality sources are also similar (building, automobile, and power line collisions). Estimated mortality related to energy development (e.g., collisions with wind turbines and nest loss, poisoning, and collisions related to oil and gas exploration and development) is relatively low. However, avian mortality from these

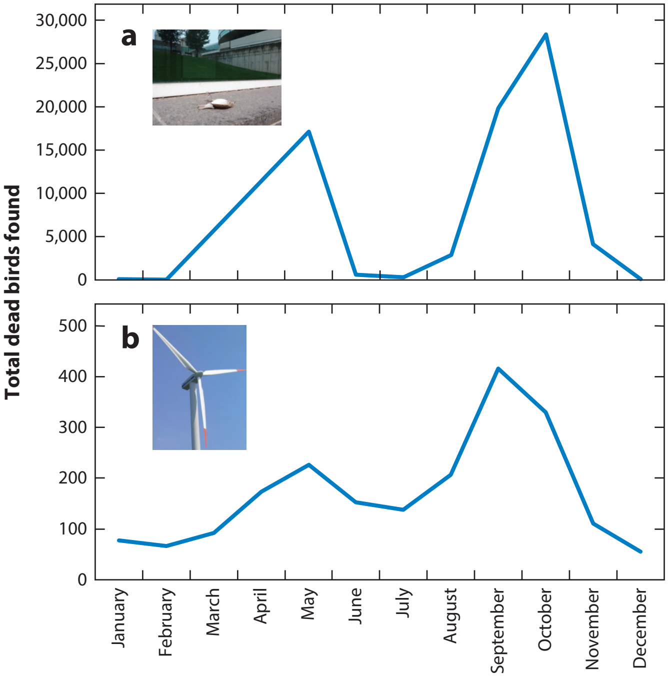

Figure 4

Seasonal mortality patterns for: (*a*) bird-building collisions (summarized across 90,767 records and 26 North American sites in Loss et al. 2014a) and (*b*) bird–wind turbine collisions (summarized across 2,045 records and 73 North American sites in Loss et al. 2013a). Numbers are raw counts that are not corrected for surveyor effort or other methodological differences among studies; nonetheless, seasonal patterns are robust across most study locations. Photo of Swainson's Thrush used with permission from Scott R. Loss; photo of wind turbine used with permission from Wikimedia Commons.

industrial sectors will likely increase with the ongoing development of wind, oil, natural gas, and solar resources (Ellis et al. 2013, Van Wilgenburg et al. 2013, USEIA 2014).

When collectively assessing multiple mortality sources, researchers face the same data limitations as they do for individual source estimates: Information is insufficient to derive a clear picture of spatiotemporal and taxonomic variation in cumulative mortality. The general patterns that emerge from quantitative and qualitative review of the current literature should be viewed as working hypotheses that require additional testing and confirmation. Perhaps the most evident pattern is that spring and fall migration periods are characterized by peak mortality for many migratory passerine species (e.g., thrushes, vireos, warblers, and sparrows) at tall, lighted structures (communication towers, buildings, and turbines at some wind facilities). Of more than 90,000 bird-building collision fatalities analyzed by Loss et al. (2014a), the vast majority occurred during spring and fall migration periods (**Figure 4*a***), a pattern that is robust across most study locations. Patterns of mortality are similar, although less dramatic, for wind turbines (**Figure 4*b***). This dampened seasonal pattern emerges because although some wind facilities have the highest mortality during migratory periods (e.g., for songbirds in eastern US mountains), others have relatively high mortality during breeding or wintering seasons [e.g., for Horned Larks (*Eremophila alpestris*) in summer (Young et al. 2007) and Western Meadowlarks (*Sturnus neglecta*) in winter in the western United States (Kerlinger et al. 2007)]. A relatively large cumulative amount of mortality also occurs in summer, as a result of the increase in breeding season bird activity and abundance creating elevated risk from stressors such as pesticides and cats. Comparatively little mortality appears to occur during winter, with exceptions including the wind turbine examples above, owl-automobile collisions in northern latitudes (Bishop & Brogan 2013), and window collisions of songbirds at residences with bird feeders (Dunn 1993).

Because many sources of direct anthropogenic mortality are related to urban and suburban land development and industrial activities, spatial patterns of cumulative mortality are related to patterns of human activity and population density. A rough spatial extrapolation—based on allocation of mortality to different areas using estimated mortality for each stressor and the proportion of stressor activity occurring in each province—estimated that the vast majority of bird mortality in Canada occurs in urban areas (Calvert et al. 2013). However, when the three largest mortality sources (cats, buildings, and roads) are excluded, mortality was more evenly distributed across the country. These stressor–human population patterns are likely to be generalizable to other countries. Urban and suburban areas—with their large numbers of cats, buildings, and roads—are likely to have the greatest overall mortality. Mortality from wind turbines, communication towers, power lines, and energy extraction activities is likely to be more broadly dispersed across exurban and rural areas.

RESEARCH NEEDS

Several overarching research needs emerge from our previous reviews of direct anthropogenic mortality sources (Loss et al. 2013a,b, 2014a–c). These needs apply to two different categories of research: (*a*) field studies that assess local mortality rates and population impacts and (*b*) large-scale data syntheses that quantify overall mortality, spatiotemporal and taxonomic variation in mortality, and impacts of mortality across bird species' entire geographic ranges.

Research Needs for Local Field Studies

To facilitate minimally biased local estimates of mortality that contribute to large-scale estimates and population impact assessments, local field studies must: (*a*) conduct replicated, controlled, and a priori–designed research in addition to post hoc analysis of opportunistically collected data; (*b*) randomly select sampling sites in addition to sampling at locations already known to experience high rates of mortality; (*c*) search for, record, and present data for all bird species in addition to investigating focal species and species groups; (*d*) sample throughout the calendar year—in addition to focusing on periods thought to have the highest mortality rates—to provide season-specific data that can better inform full life-cycle population models; and (*e*) follow study design and data collection protocols that are standardized to other studies of the same mortality source and, when appropriate, other mortality sources. Relatively few existing local field studies meet all of these criteria, and standardized protocols for study design and data entry, management, and analysis do not exist for most mortality sources. These limitations significantly hamper efforts to quantify local mortality and its correlates, to identify effective approaches for mitigating mortality, and to synthesize data from local field studies into large-scale analyses.

Research Needs for Large-Scale Data Syntheses

Loss et al. (2012) discussed research needs that apply to large-scale data syntheses, but subsequent quantitative reviews have provided additional insights. To elucidate large-scale spatial variation in mortality rates and species vulnerability—and therefore to inform inferences about population

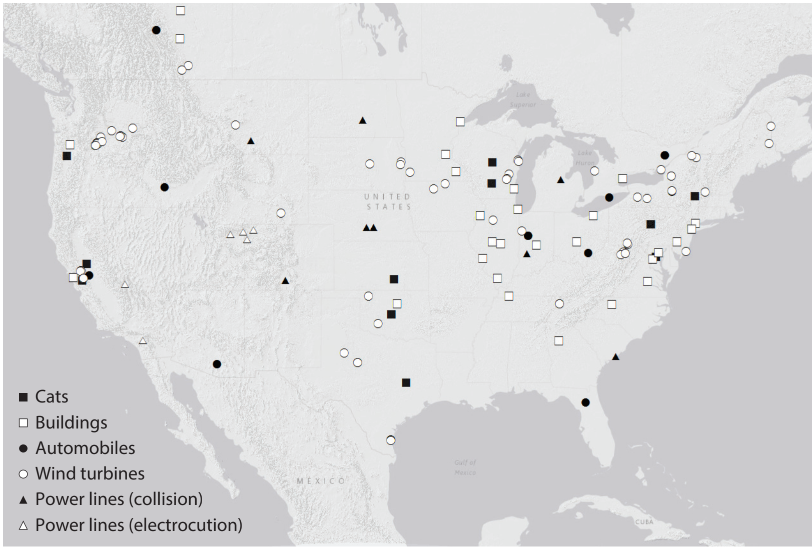

Figure 5

Locations of North American data sources for US estimates of direct anthropogenic bird mortality. All studies met inclusion criteria for a national mortality estimate, a summary of species killed, or both. Some studies met inclusion criteria but were eventually removed for being statistical outliers. For studies that covered large areas (e.g., states or provinces), points are placed in the center of the study area.

impacts across species' annual cycles—the collective body of mortality research must provide improved geographical and seasonal coverage. Globally, data on direct anthropogenic mortality are lacking from most regions outside of North America and Europe. Given rapidly increasing human populations in many understudied regions, direct anthropogenic bird mortality is likely to increase substantially. Even within North America, where the greatest amount of research has been conducted, most studies have occurred in the eastern third of the continent, and vast interior and western areas are virtually unstudied for many mortality sources (**Figure 5**). Additional research on mortality rate correlates (e.g., structural design features of buildings, road characteristics, behaviors of cat owners) is also needed to predict spatiotemporal variation in mortality and identify mortality reduction approaches.

Of central importance to both basic ecology and applied conservation is an improved understanding of how direct mortality sources impact population abundance. Studies addressing population responses to anthropogenic mortality have led to crucial theoretical developments and management applications, but most studies focus on a single mortality source—the purposeful harvest of animals for recreation and/or population management (Burnham & Anderson 1984, Pöysä 2004). Rigorous empirical methods have only begun to be developed for assessing effects for more than one stressor and for mortality sources other than harvest. As mentioned above, PBR models (Wade 1998) and IPMs (Hoyle & Maunder 2004) hold particular promise for assessing population abundance responses of multiple species experiencing mortality from multiple sources (Milner-Gulland & Akcakaya 2001, Weinbaum et al. 2013). The relative clarity of cause-and-effect relationships characteristic of direct anthropogenic mortality sources provides a fruitful arena for further developing modeling approaches that clarify links between mortality sources and population responses. Such models can also be used to assess the degree to which populations compensate for mortality. Rather than testing only for complete additivity versus complete compensation—a common false dichotomy in the population ecology literature and policy and management discourse—analyses should consider the entire continuum of possible responses, including partial compensation, overcompensation, and superadditivity (Sinclair & Pech 1996, Abrams 2009, Peron 2013).

MANAGEMENT RECOMMENDATIONS

Several broad management recommendations apply across all mortality sources. First, we recommend that data-driven scientific evidence form the basis for decisions regarding the distribution of funding, direction of management attention, and development of specific mitigation guidelines. Ideally, this evidence should be weighed using a structured decision-making approach that allows adaptive management (Nichols & Williams 2006, Williams & Brown 2012), transparent identification of desired levels of precaution (Gregory & Long 2009), and evaluation of the potential success of management actions. Examples of criteria by which to judge the potential success of alternative actions include the expected magnitude of mortality reduction, feasibility, regulatory constraints, societal resistance, scale of the action, and estimated cost.

Second, we recommend further research into the magnitude, nature, and impacts of direct human-caused mortality. This research is necessary given the broad uncertainty ranges in national estimates of mortality and the uncertainty about population-level impacts. In particular, we highlight the need for small-scale analyses of population impacts that can inform local management measures. These small-scale studies should be complemented by large-scale studies that examine cumulative effects of multiple mortality sources on species population dynamics across the entire annual cycle (e.g., on breeding grounds and for migratory species during winter and migration).

Third, we recommend adherence to a precautionary approach to management (Foster et al. 2000, Gregory & Long 2009), whereby lack of evidence for a population decline owing to one or more mortality sources does not necessarily preclude implementation of mortality reduction measures. As reviewed by Longcore & Smith (2013), a precautionary approach is desirable because: (*a*) even substantial population declines can be difficult to observe with current monitoring resources and approaches; (*b*) impacts of a single stressor are difficult to identify, except in small areas with intensively monitored populations; and (*c*) direct mortality can also lead to indirect effects on habitats and ecosystem services that affect populations.

Finally, we recommend that ecologists, managers, and policymakers demonstrate leadership in addressing anthropogenic mortality of birds and other wildlife. National-scale estimates and comparisons of different mortality sources can and should provide broad strategic direction on where to invest management, policy, and research effort. Such strategic direction can be paired with focused research that incorporates both social and biological tools to identify and implement viable management solutions for the recovery of declining species.

SUMMARY POINTS

1. Several sources of direct anthropogenic mortality collectively affect a large proportion of Earth's bird species, and many species are affected by multiple direct mortality sources. Currently, large gaps exist in our knowledge about spatiotemporal variation in mortality, ecological and human-related factors driving variation, population-level impacts, and the best management approaches to reduce mortality.

2. The amount of bird mortality is highly variable across direct anthropogenic mortality sources, with annual mortality estimates for different threats ranging from thousands to billions of birds.
3. Much additional information is needed about most direct mortality sources, and a greater proportion of future studies must be randomized, replicated, and transparent to generate local and large-scale insights into the nature, magnitude, and impacts of mortality.
4. The study of direct anthropogenic mortality provides a promising avenue for the development and application of modeling approaches that clarify the individual and cumulative effects of mortality sources on bird populations. Such models will be transferable to other animal taxa and useful for evaluating increasingly important indirect threats, such as habitat loss and global climate change.
5. Given estimate uncertainty and the potential for biologically significant effects on some species at some locations, the information provided by gross mortality estimates alone should not be used to exonerate particular mortality sources from further research and regulation. Likewise, lack of evidence of an impact at the population level should not prevent widely accepted and effective actions to reduce mortality.
6. Decisions about specific mortality reduction measures and broad management directions and regulations should be based on scientifically rigorous data, a precautionary approach, structured and adaptive decision making, and a combination of intensive small-scale studies and broad-scale, data-derived estimates of mortality and population impacts.

DISCLOSURE STATEMENT

The authors are unaware of any affiliations, memberships, funding, or financial holdings that might be perceived as affecting the objectivity of this review. The conclusions and opinions expressed in this review are those of the authors and do not necessarily reflect official positions or policy of the US Fish and Wildlife Service or Smithsonian Conservation Biology Institute.

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Avian mortality at communication towers in the United States and Canada: which species, how many, and where?

Travis Longcore[a,b,*], Catherine Rich[a], Pierre Mineau[c], Beau MacDonald[a], Daniel G. Bert[d], Lauren M. Sullivan[e], Erin Mutrie[c], Sidney A. Gauthreaux Jr.[f], Michael L. Avery[g], Robert L. Crawford[h], Albert M. Manville II[i], Emilie R. Travis[j], David Drake[j]

[a] *The Urban Wildlands Group, P.O. Box 24020, Los Angeles, CA 90024, USA*
[b] *Spatial Sciences Institute, University of Southern California, Los Angeles, CA 90089, USA*
[c] *National Wildlife Research Centre, Science and Technology Branch, Environment Canada, Ottawa, Canada*
[d] *Geomatics and Landscape Ecology Research Laboratory, Carleton University, Ottawa, ON, Canada*
[e] *Department of Geography, University of California, Los Angeles, CA 90024, USA*
[f] *Department of Biological Sciences, Clemson University, Clemson, SC 29634, USA*
[g] *United States Department of Agriculture/Wildlife Services, National Wildlife Research Center, Florida Field Station, 2820 East University Avenue, Gainesville, FL 32641, USA*
[h] *208 Junius Street, Thomasville, GA 31792, USA*
[i] *U.S. Fish and Wildlife Service, Division of Migratory Bird Management, 4401 N. Fairfax Dr. – MBSP-4107, Arlington, VA 22203, USA*
[j] *University of Wisconsin, Department of Forest & Wildlife Ecology, Madison, WI 53706, USA*

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ABSTRACT

Birds migrating to and from breeding grounds in the United States and Canada are killed by the millions in collisions with lighted towers and their guy wires. Avian mortality at towers is highly variable across species, and the importance to each population depends on its size and trajectory. Building on our previous estimate of avian mortality at communication towers, we calculated mortality by species and by regions. To do this, we constructed a database of mortality by species at towers from available records and calculated the mean proportion of each species killed at towers within aggregated Bird Conservation Regions. These proportions were combined with mortality estimates that we previously calculated for those regions. We then compared our estimated bird mortality rates to the estimated populations of these species in the United States and Canada. Neotropical migrants suffer the greatest mortality; 97.4% of birds killed are passerines, mostly warblers (Parulidae, 58.4%), vireos (Vireonidae, 13.4%), thrushes (Turdidae, 7.7%), and sparrows (Emberizidae, 5.8%). Thirteen birds of conservation concern in the United States or Canada suffer annual mortality of 1–9% of their estimated total population. Of these, estimated annual mortality is >2% for Yellow Rail (*Coturnicops noveboracensis*), Swainson's Warbler (*Limnothlypis swainsonii*), Pied-billed Grebe (*Podilymbus podiceps*), Bay-breasted Warbler (*Setophaga castanea*), Golden-winged Warbler (*Vermivora chrysoptera*), Worm-eating Warbler (*Helmitheros vermivorum*), Prairie Warbler (*Setophaga discolor*), and Ovenbird (*Seiurus aurocapilla*). Avian mortality from anthropogenic sources is almost always reported in the aggregate ("number of birds killed"), which cannot detect the species-level effects necessary to make conservation assessments. Our approach to per species estimates could be undertaken for other sources of chronic anthropogenic mortality.

1. Introduction

Avian mortality from collisions with human-made structures is an issue of ongoing conservation concern (Drewitt and Langston, 2008; Longcore et al., 2008, 2012; Manville, 2005, 2009). Mortality at communication towers has generated long-term studies at single sites (e.g., Crawford and Engstrom, 2001; Kemper, 1996), many incidental observations (Avery et al., 1980; Kerlinger, 2000; Trapp, 1998; Weir, 1976), and comparative studies across towers in several regions (Gehring et al., 2009; Johnston and Haines, 1957; Morris et al., 2003; Seets and Bohlen, 1977). The U.S. Fish and

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[*] Corresponding author. Address: The Urban Wildlands Group, P.O. Box 24020, Los Angeles, CA 90024, USA. Tel.: +1 310 247 9719.

E-mail addresses: longcore@urbanwildlands.org (T. Longcore), crich@urbanwildlands.org (C. Rich), Pierre.Mineau@ec.gc.ca (P. Mineau), beaumacdonald@sbcglobal.net (B. MacDonald), dan.bert@glel.carleton.ca (D.G. Bert), laurenmsullivan@gmail.com (L.M. Sullivan), er339081@dal.ca (E. Mutrie), gocajuns@bellsouth.net (S.A. Gauthreaux Jr.), Michael.L.Avery@aphis.usda.gov (M.L. Avery), rlcrawfd@rose.net (R.L. Crawford), Albert_Manville@fws.gov (A.M. Manville II), uvem05@gmail.com (E.R. Travis), ddrake2@wisc.edu (D. Drake).

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Wildlife Service (USFWS) has estimated avian mortality from communication towers at 4–5 million birds per year and released guidelines designed to minimize such mortality (U.S. Fish and Wildlife Service, 2000). We derived an updated estimate of 6.8 million birds per year with a tower height–mortality regression and the characteristics of >70,000 towers demonstrating that mortality increases predictably with tower height (Longcore et al., 2012). The USFWS has made recommendations to the Federal Communications Commission (FCC) on how to further reduce incidental take (Manville, 2007) and Environment Canada is currently assessing incidental mortality of migratory bird species at towers as part of a comprehensive effort to address all sources of incidental mortality.

Avian mortality at communication towers occurs most frequently when nocturnal migrants are attracted to tower lights. Birds that enter the zone of influence of lights then circle the towers and are at risk of death from exhaustion, collision with the tower and its guy wires, and collisions with each other (Gauthreaux and Belser, 2006). This usually occurs in inclement weather when other navigational cues are obscured and around the time of passage of cold fronts that drive birds down to altitudes where they are more likely to encounter towers and their lights (Avery et al., 1976).

Estimates of mortality for individual species are needed to assess biological significance of avian mortality at communication towers (Longcore et al., 2005, 2012). The term *biological significance* is not formally defined in the context of environmental impact assessment, but a logical definition might be that a biologically significant impact would adversely affect a species or its habitat and could be expected to affect the population growth or stability of the species and influence the population's long-term viability. Others have concluded that what constitutes a biologically significant population change is not easy to define (Reed and Blaustein, 1997). It may be important to understand the degree to which population growth is suppressed by a mortality source (Loss et al., 2012). Any change in a population has some biological consequence to other species, and therefore any population decline could be important and determining whether it is "significant" may be arbitrary. Biological significance in this context should not be confused with a statistically significant trend in a biological variable. Although statistical significance may influence the judgment about whether an impact is biologically significant, it is not a prerequisite.

To evaluate the biological significance of mortality, species or populations should be the unit of analysis in most instances. For example, barbed wire fences kill a relatively small proportion of birds compared with such hazards as windows and free-roaming cats, but barbed wire fences are a biologically significant source of mortality for Whooping Cranes (*Grus americana*), an endangered species (Allen and Ramirez, 1990). Higher taxonomic groups, such as families or even guilds that cut across taxonomic groups, may be the appropriate unit of analysis if something is known about the conservation status of the units as a whole. For example, oil pits (pits where oil producers dispose of waste fluids) kill an estimated 500,000–1,000,000 birds per year (Trail, 2006). This raw number can be interpreted with the knowledge that 162 species have been killed in oil pits, of which 63% were ground-feeding birds, including several species of conservation concern (Trail, 2006). Mortality at communication towers, up to this point, has been a conservation issue because the species predominantly killed at towers are Neotropical migratory songbirds, which are of conservation concern as a group. Beyond this general observation, however, only crude estimates have been made of the species composition of the millions of birds killed annually at communication towers (Arnold and Zink, 2011; Shire et al., 2000).

Arnold and Zink (2011) performed an analysis of the proportion of birds killed at towers and regressed the relative risk of collision against 30-year population trends calculated from Breeding Bird Survey data. They concluded from this regression that tower mortality had no discernible effect on population trajectories and claimed that their methods had statistical power to detect as little as a 4.1% contribution to the observed trends. Arnold and Zink (2011) have been criticized for their methods (Schaub et al., 2011) and for the scope of their inferences (Klem et al., 2012), and we have several additional concerns about their analysis. First, they used a flawed secondary data source (Shire et al., 2000) as their raw data for tower mortality. Shire et al. (2000) included a single list of the number of each species killed at towers, which they obtained by summing the results from 47 towers for which they found data. This unpublished report, however, did not exhaustively cover the literature available at the time, contained tabulation errors, and is now dated. It also presents raw sums, which are heavily influenced by the length of the various studies and do not account for regional variation in mortality. Arnold and Zink (2011) identified species that were killed more or less frequently than expected based on population sizes, but because they failed to obtain the primary sources, their mortality proportions contain the errors inherent in the Shire et al. (2000) report and do not account for regional variation or provide a mechanism to combine studies of different lengths in a way that keeps large datasets from overwhelming smaller ones. Failing to account for geographic variability leads to the unrealistic assumption that each tower in North America kills exactly the same proportion of each species of bird. Furthermore, we are unconvinced that impacts of collision mortality would be seen across hundreds of species in the manner assumed by Arnold and Zink (2011). Rather, it is much more likely that tower mortality represents one of an array of stressors affecting the population trajectories of a more limited number of species. In short, we doubt the ability of their method to definitively identify the cumulative impacts of avian mortality at towers and buildings, and make no such sweeping claim for the approach we develop here.

To better understand the effects of avian mortality at communication towers, we combine our previous geographically stratified estimate of total avian mortality at communication towers (Longcore et al., 2012) with estimates of the proportion of each bird species killed within different regions to develop geographically explicit tallies of avian mortality at communication towers by species. We chose geographically specific estimates because avian mortality and tower height vary regionally, and this additional information should be incorporated into any estimates. We then compare these per species mortality estimates with population estimates for these species to gauge the magnitude of this mortality source on a species-by-species basis.

2. Methods

An estimate of the number of each avian species killed at towers annually can be obtained by multiplying an estimate of total avian mortality for a region by the average proportion of each species found in kills at towers in that region. We previously developed an estimate of avian mortality at communication towers in the United States and Canada by Bird Conservation Region (BCR) (Longcore et al., 2012). This estimate was built from a regression relating tower height to annual mortality first developed by Longcore et al. (2005, 2008). The more recent estimate adjusted the raw annual mortality data obtained from existing studies for search efficiency, scavenging, and the sampling scheme (Longcore et al., 2012). The finding of lower avian mortality rates at towers without guy wires and without steady-burning lights (Gehring et al., 2009) was incorporated in these estimates. The corrected relationship between tower height and mortality was then applied to the towers

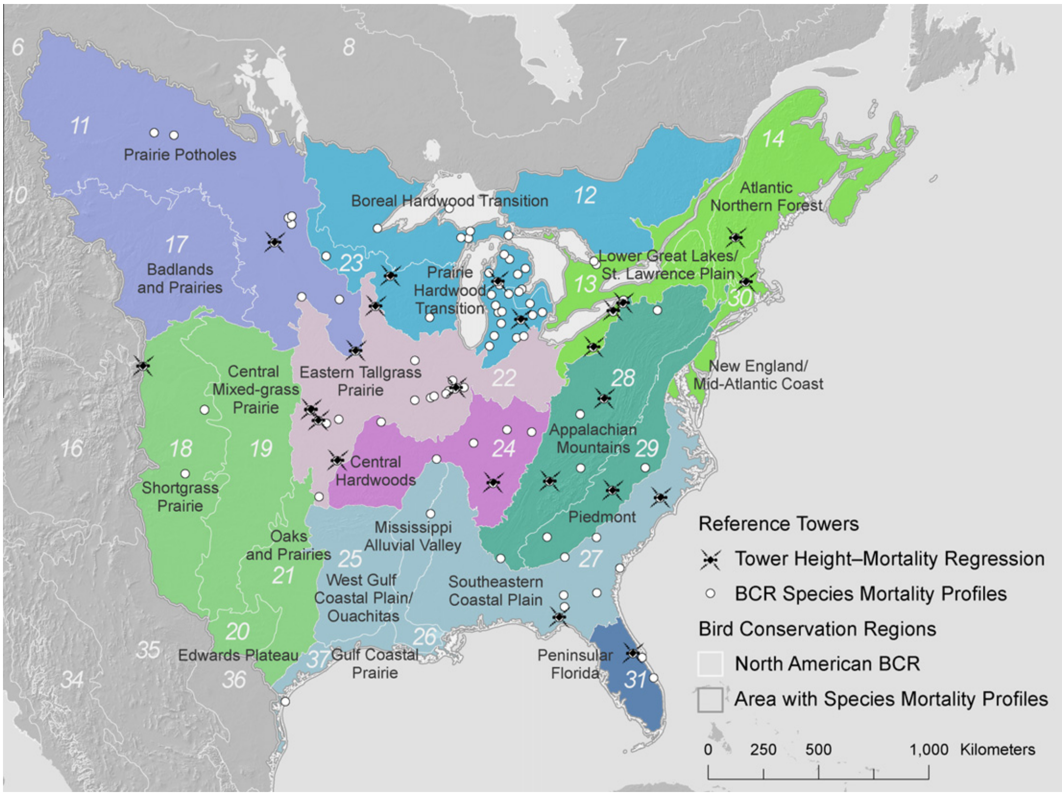

Fig. 1. Bird Conservation Regions in North America with locations of studies used to develop mortality profiles for aggregated regions indicated. Locations of towers used for height–mortality regression are also shown (see Longcore et al., 2012).

Table 1
Bird Conservation Regions and combinations thereof for which per species estimates of mortality were calculated with number of species and specimens in collections used to describe the regional mortality profile.

Bird Conservation Regions (References)	# Species	# Specimens	# Locations	Estimated Mortality[a]
Southeastern Coastal Plain, Mississippi Alluvial Valley, West Gulf Coastal Plain/Ouachitas, Gulf Coastal Prairie	192	64,554	5	1,988,456
Carter and Parnell (1976, 1978), Crawford (1976), Crawford and Engstrom (2001), James (1956), Johnston (1955, 1957), Johnston and Haines (1957), and Teulings (1972)				
Eastern Tallgrass Prairie	132	20,991	21	754,928
Boso (1965), Brewer and Ellis (1958), Cochran and Graber (1958), Gregory (1975), Kleen and Bush (1973), Mosman (1975), Norman (1987), Parmalee and Parmalee (1959), Parmalee and Thompson (1963), Petersen (1959), Robbins et al. (2000), Seets and Bohlen (1977), and Young and Robbins (2001)				
Appalachian Mountains, Piedmont	91	7123	8	711,900
Alsop and Wallace (1969), Bierly (1968, 1969), Ellis (1997), Herndon (1973), Herron (1997) Nicholson (1984), Norwood (1960), Remy (1974, 1975), Rosche (1971), Trott (1957), Turner and Davis (1980), and Welles (1978)				
Shortgrass Prairie, Central Mixed-grass Prairie, Edwards Plateau, Oaks and Prairies	65	611	3	1,128,718
Barkley et al. (1977), Nielsen and Wilson (2006), and Young (1993)				
Prairie Hardwood Transition, Boreal Hardwood Transition	137	128,796	48	452,887
Caldwell and Cuthbert (1963), Caldwell and Wallace (1966), Feehan (1963), Gehring et al. (2009), Green (1963), Kemper (1996), Kemper et al. (1966), Manuwal (1963), Sharp (1971), Strnad (1962, 1975), and Travis (2009)				
Central Hardwoods	113	16,162	7	346,796
Able (1966), Anonymous (1961), Barbour (1961), Bierly (1973), Elder and Hansen (1967), Ganier (1962), George (1963), Goodpasture (1974a,b, 1975, 1976, 1984, 1986, 1987), Laskey (1962, 1963, 1964, 1967, 1968, 1969a,b, 1971), Nehring and Bivens (1999), and Palmer-Ball and Rauth (1990)				
Peninsular Florida	98	15,261	4	341,774
Case et al. (1965), Kale (1971), and Taylor and Anderson (1973, 1974)				
Prairie Potholes, Badlands and Prairies	125	2520	8	382,315
Avery and Clement (1972), Avery et al. (1978), Ball et al. (1995), Houston and Houston (1975), Janssen (1963), Kemper (1964), Lahrman (1959, 1962, 1965), Nero (1961, 1962), Pierce (1969), and Young and Robbins (2001)				
New England/Mid-Atlantic Coast, Atlantic Northern Forest, Lower Great Lakes/St. Lawrence Plain	71	3375	3	285,405
Baird (1970, 1971), Sawyer (1961), and Westman (1967)				

[a] From Longcore et al. (2012).

in each BCR, extracted from digital geographic records for the United States and Canada. The resulting estimate, calculated by BCR, totaled 6.8 million birds per year (Longcore et al., 2012).

2.1. Development of per species mortality estimates

We used the approach described by Longcore et al. (2005) to assign the estimated total mortality to individual species. We conducted an extensive literature search to identify published reports of avian mortality at towers that included complete lists of birds killed. We located these studies from previous reviews (Avery et al., 1980; Kerlinger, 2000; Shire et al., 2000; Trapp, 1998; Weir, 1976) and directly from other researchers. We obtained copies of each report and transferred the number of each species recorded dead at each tower to a spreadsheet. For multiple studies of the same or adjacent towers we summed all observations of each species. We used raw numbers to develop the mortality proportions at each location and did not adjust for scavenging or search efficiency because >97% of the birds were passerines and such differences in detectability and scavenging would be unlikely to have a substantial effect. We also included all species lists without consideration of date of study to avail ourselves of the maximum number of specimens to develop regional profiles.

To develop profiles of birds killed within each BCR we calculated the proportion (P) of each bird species killed at each tower site within the region and took the mean of these proportions weighted by the number of species (S) documented at that location as follows

$$P_{\mathrm{BCR}} = \frac{\sum_{1}^{n} P_i \times S_i}{\sum_{1}^{n} S_i} \tag{1}$$

where n is the number of studies in the BCR. We weighted by species number because species number increases rapidly with study length (measured in number of nights sampled) but quickly reaches an asymptote (unpublished results). By using species number as a weight, we emphasize those studies with greater sampling but do not overemphasize the exceptionally long studies or completely discard short studies that may have recorded a small but diverse sample of birds. Because we only use this weighting within geographic regions, it is not prone to the bias of geographic variations in species richness suggested by Loss et al. (2012).

We multiplied the proportion of each species killed within each BCR for which there were records by the estimated annual mortality derived from the tower data and associated regressions (Longcore et al., 2012) to produce estimates of the numbers of birds killed of each species within those BCRs.

When avian mortality had been recorded at towers in a BCR, but fewer than 3 studies were available to produce a species profile, we combined BCRs for analysis. We also included BCRs where avian mortality at towers had not been recorded but would be expected based on geography (e.g., mortality recorded in adjacent BCRs). Specifically, we combined Prairie Potholes ($n = 8$) and Badlands and Prairies ($n = 0$); Lower Great Lakes/St. Lawrence Plain ($n = 2$), New England/Mid-Atlantic Coast ($n = 2$), and Atlantic Northern Forest ($n = 0$); Southeastern Coastal Plain ($n = 4$), Mississippi Alluvial Valley ($n = 0$), West Gulf Coastal Plain/Ouachitas ($n = 0$), and Gulf Coastal Prairie ($n = 1$); Prairie Hardwood Transition ($n = 12$) and Boreal Hardwood Transition ($n = 1$); Appalachian Mountains ($n = 6$) and Piedmont ($n = 2$); and Shortgrass Prairie ($n = 3$), Central Mixed-grass Prairie ($n = 0$), Edwards Plateau ($n = 0$), and Oaks and Prairies ($n = 0$) (Fig. 1). For Gulf Coastal Prairie we included a record of mortality at streetlights (James, 1956) to develop the species profile because no searches of towers had been reported in the literature from this region. The streetlight kill illustrated the ability of lighted structures to kill migratory birds in this region by attracting and drawing birds down to near ground level. We did not assign the bird mortality to species in BCRs in the western United States and Canada where no studies or only single very short studies were found (Dickerman et al., 1998; Ginter and Desmond, 2004).

Ideally, we would have compared mortality to individual populations of species within BCRs. This is not possible because tower mortality occurs mostly during migration and mortality cannot be connected to local populations. We instead compared per species mortality estimates with estimates of total United States and Canada populations that are available for conservation planning purposes (Brown et al., 2001; Kushlan et al., 2002; North American Waterfowl Management Plan Committee, 2004; Rich et al., 2004). To assess the status of species killed at towers, we cross-referenced them with the most recent list of Birds of Conservation Concern issued by the U.S. Fish and Wildlife Service (2008), the United States and International Union for Conservation of Nature (IUCN) endangered species lists, and the Canadian Species at Risk schedules (http://www.sararegistry.gc.ca/). We regressed $\log_{10}$-transformed total estimated mortality for each species by $\log_{10}$-transformed population size to evaluate whether species are killed in proportion to their population size.

Table 2

Annual avian mortality at communication towers in central and eastern North America by Order, with subtotals by Family in Passeriformes. Only includes BCRs or merged BCRs for which mortality profiles could be developed from more than 1000 specimens.

Order	Number of species	Percent of total mortality (%)	Total mortality estimate
Passeriformes	146	97.35	5,125,205
Parulidae	39	58.42	3,075,659
Vireonidae	8	13.38	704,486
Turdidae	7	7.68	404,203
Emberizidae	24	5.78	304,343
Cardinalidae	9	3.19	167,942
Mimidae	4	2.89	151,898
Regulidae	2	2.03	105,847
Icteridae	10	1.64	86,301
Troglodytidae	6	1.30	68,635
Tyrannidae	9	0.55	29,040
Certhiidae	1	0.13	6586
Calcariidae	5	0.11	5939
Fringillidae	6	0.08	4184
Bombycillidae	1	0.05	2841
Sittidae	2	0.03	1583
Sturnidae	1	0.03	1559
Hirundinidae	6	0.02	1201
Passeridae	1	0.02	958
Corvidae	2	0.01	668
Laniidae	1	0.00	246
Motacillidae	1	0.00	65
Polioptilidae	1	0.00	22
Gruiformes	9	0.97	51,102
Cuculiformes	2	0.49	25,835
Piciformes	7	0.35	18,358
Columbiformes	3	0.32	16,685
Anseriformes	15	0.14	7369
Podicipediformes	4	0.11	6005
Ciconiiformes	14	0.10	5200
Charadriiformes	17	0.07	3623
Apodiformes	1	0.04	2027
Galliformes	5	0.03	1498
Caprimulgiformes	3	0.02	1015
Coraciiformes	1	0.00	226
Falconiformes	2	0.00	146
Strigiformes	2	0.00	65
Pelecaniformes	1	0.00	58
Gaviiformes	1	0.00	22
Procellariiformes	1	0.00	22

3. Results

3.1. Estimates of birds killed by species

We assigned mortality to species for the regions east of the Rocky Mountains with sufficient records to describe mortality profiles (Fig. 1). The studies contributing to these regional profiles documented 259,393 deaths of 239 species at 107 locations. After calculating per species estimates for a combined region of shortgrass prairie BCRs (Shortgrass Prairie, Central Mixed-grass Prairie, Edwards Plateau, Oaks and Prairies), we omitted these results from further reports because of the low number of specimens (611). In our previous analysis (Longcore et al., 2012), the remaining BCRs accounted for 5.26 million annual fatalities, or 77% of all mortality at towers in the United States and Canada. Our regional proportions allowed us to allocate these deaths to species, with 97.4% of estimated mortality consisting of passerines, with the greatest proportion being warblers (Parulidae, 58.4% of all mortality), vireos (Vireonidae, 13.4%), thrushes (Turdidae, 7.7%), and sparrows (Emberizidae, 5.8%) (Table 2). For the regions where we report mortality by species, 234 species were recorded from tower sites. Our database of studies included additional species killed at towers in the shortgrass prairie regions and elsewhere, including Swainson's Hawk (*Buteo swainsoni*) and Hammond's Flycatcher (*Empidonax hammondii*) in New Mexico (Ginter and Desmond, 2004), and Short-tailed Shearwater (*Puffinus tenuirostris*), Fork-tailed Storm-Petrel (*Oceanodroma furcata*), Black-legged Kittiwake (*Rissa tridactyla*), Short-eared Owl (*Asio flammeus*) (Dickerman et al., 1998), Spectacled Eider (*Somateria fischeri*), and Steller's Eider (*Polysticta stelleri*) (E. Lance, U.S. Fish and Wildlife Service, pers. comm.) in Alaska.

3.2. Comparison of per species tower mortality to population size

Avian mortality at towers was estimated to be ⩾1% of total population per year for 29 species (Table 3). Annual mortality was estimated to exceed 0.5% of population size for an additional 15 species. Fifty-four species identified as Birds of Conservation Concern (U.S. Fish and Wildlife Service, 2008), 1 federally endangered species, and 1 IUCN endangered species have been killed at towers (Tables 3 and 4). Thirteen of the 20 bird species killed most frequently by percentage of population are identified as either Birds of Conservation Concern or endangered.

Warblers (Parulidae) are 15 of the 20 species most frequently killed and 12 of the 20 species with highest proportions killed. Some species from other groups show high mortality as a proportion of population size. For example, 9.0% of the population of Yellow Rails and 5.6% of Pied-billed Grebes are estimated to be killed at towers each year.

Regional mortality profiles do show marked differences, which are evident in the ranking of species killed in each region (Table 5). This provides evidence in support of a regional approach to estimate mortality. The correlation between population size and tower mortality is significant but has low explanatory value (regression of $\log_{10}$ transformed variables; coefficient = 0.56, 95% CI = 0.40–0.72; $r^2 = 0.17$; $F_{1,224} = 44.37$, $p < 0.001$).

4. Discussion

Many bird species are killed at towers disproportionate to their abundance. Tower mortality is, therefore, not a random factor affecting all migrating birds. Mayfield (1967) argued that mortality at towers did not affect bird populations in part because birds are

Table 3
Per species avian annual mortality at communication towers in central and eastern North America, for species with >1% annual mortality from communication towers. Older names or lumped species groups are used to accommodate taxonomic changes. Status: BCC Birds of Conservation Concern in United States. SARA1 Endangered under Canada's Species at Risk Act, SARA2 Threatened, and SARA3 Special Concern.

Species	Family	North Am. population estimate	Est. annual mortality	Percent of population (%)	Status
Yellow Rail *Coturnicops noveboracensis*	Rallidae	25,000[b]	2245	9.0	BCC/SARA3
Swainson's Warbler *Limnothlypis swainsonii*	Parulidae	84,000[a]	7473	8.9	BCC
Pied-billed Grebe *Podilymbus podiceps*	Podicipedidae	100,000[b]	5589	5.6	BCC
Bay-breasted Warbler *Setophaga castanea*	Parulidae	3,000,000[a]	165,257	5.5	BCC
Black-throated Blue Warbler *Setophaga caerulescens*	Parulidae	2,000,000[a]	98,578	4.9	
Golden-winged Warbler *Vermivora chrysoptera*	Parulidae	210,000[a]	5276	2.5	BCC/SARA2
Kentucky Warbler *Geothlypis formosa*	Parulidae	1,100,000[a]	27,441	2.5	
Worm-eating Warbler *Helmitheros vermivorum*	Parulidae	700,000[a]	16,153	2.3	BCC
Prairie Warbler *Setophaga discolor*	Parulidae	1,400,000[a]	30,401	2.2	BCC
Ovenbird *Seiurus aurocapilla*	Parulidae	24,000,000[a]	498,714	2.1	
Scarlet Tanager *Piranga olivacea*	Cardinalidae	2,200,000[a]	35,270	1.6	
Henslow's Sparrow *Ammodramus henslowii*	Emberizidae	80,000[a]	1261	1.6	BCC/SARA1
Canada Warbler *Cardellina canadensis*	Parulidae	1,400,000[a]	20,622	1.5	BCC/SARA2
Gray Catbird *Dumetella carolinensis*	Mimidae	10,000,000[a]	139,050	1.4	
Seaside Sparrow *Ammodramus maritimus*	Emberizidae	110,000[a]	1513	1.4	BCC
Louisiana Waterthrush *Parkesia motacilla*	Parulidae	260,000[a]	3572	1.4	BCC/SARA3
Yellow-throated Vireo *Vireo flavifrons*	Vireonidae	1,400,000[a]	17,402	1.2	
Common Yellowthroat *Geothlypis trichas*	Parulidae	32,000,000[a]	386,484	1.2	
Connecticut Warbler *Oporornis agilis*	Parulidae	1,200,000[a]	14,324	1.2	
Trumpeter Swan *Cygnus buccinator*	Anatidae	23,647[c]	280	1.2	
Chestnut-sided Warbler *Setophaga pensylvanica*	Parulidae	9,400,000[a]	108,634	1.2	
Black-and-white Warbler *Mniotilta varia*	Parulidae	14,000,000[a]	149,485	1.1	
Hooded Warbler *Setophaga citrina*	Parulidae	4,000,000[a]	41,551	1.0	
Blackburnian Warbler Setophaga fusca	Parulidae	5,900,000[a]	60,487	1.0	
Blue-winged Warbler *Vermivora cyanoptera*	Parulidae	390,000[a]	3852	1.0	BCC
Prothonotary Warbler *Protonotaria citrea*	Parulidae	1,800,000[a]	17,645	1.0	BCC/SARA1
Philadelphia Vireo *Vireo philadelphicus*	Vireonidae	4,000,000[a]	38,431	1.0	
Cape May Warbler *Setophaga tigrina*	Parulidae	3,000,000[a]	28,731	1.0	

[a] Rich et al. (2004).
[b] Kushlan et al. (2002).
[c] North American Waterfowl Management Plan Committee (2004).

Table 4
Sensitive species killed at communication towers with estimated annual mortality <1% of estimated population size in decreasing order (except King Rail, which has no population estimate). Status: E listed Endangered by United States or International Union for Conservation of Nature, BCC Birds of Conservation Concern in United States. SARA1 Endangered under Canada's Species at Risk Act, SARA2 Threatened, and SARA3 Special Concern.

Blue-winged Warbler *Vermivora cyanoptera*	BCC
Prothonotary Warbler *Protonotaria citrea*	BCC/SARA1
Northern Parula *Setophaga americana*	BCC
Black-capped Petrel *Pterodroma hasitata*	E
Cerulean Warbler *Setophaga cerulea*	BCC/SARA3
Least Bittern *Ixobrychus exilis*	SARA2
Blackpoll Warbler *Setophaga striata*	BCC
Bachman's Sparrow *Peucaea aestivalis*	BCC
Black-throated Green Warbler *Setophaga virens*	BCC
Bobolink *Dolichonyx oryzivorus*	BCC
Black Rail *Laterallus jamaicensis*	BCC
Sharp-tailed Sparrow (Nelson's & Saltmarsh) *Ammodramus nelsoni, Ammodramus caudacutus*	BCC
Yellow-billed Cuckoo *Coccyzus americanus*	BCC
Marsh Wren *Cistothorus palustris*	BCC
Yellow-breasted Chat *Icteria virens*	SARA3
Le Conte's Sparrow *Ammodramus leconteii*	BCC
Sedge Wren *Cistothorus platensis*	BCC
Red-cockaded Woodpecker *Picoides borealis*	E
Black-whiskered Vireo *Vireo altiloquus*	BCC
Grasshopper Sparrow *Ammodramus savannarum*	BCC
Western Grebe *Aechmophorus occidentalis*	BCC
Yellow Warbler *Setophaga petechia*	BCC
Acadian Flycatcher *Empidonax virescens*	BCC/SARA1
Harris's Sparrow *Zonotrichia querula*	BCC
Bell's Vireo *Vireo bellii*	BCC
Savannah Sparrow *Passerculus sandwichensis*	SARA3
Dickcissel *Spiza americana*	BCC
Field Sparrow *Spizella pusilla*	BCC
American Bittern *Botaurus lentiginosus*	BCC
Rusty Blackbird *Euphagus carolinus*	BCC
Song Sparrow *Melospiza melodia*	BCC
Marsh Hawk (Northern Harrier) *Circus cyaneus*	BCC
Painted Bunting *Passerina ciris*	BCC
Red-headed Woodpecker *Melanerpes erythrocephalus*	SARA2
Solitary Sandpiper *Tringa solitaria*	BCC
Little Blue Heron *Egretta caerulea*	BCC
McCown's Longspur *Rhynchophanes mccownii*	BCC/SARA3
Chimney Swift *Chaetura pelagica*	SARA2
White Ibis *Eudocimus albus*	BCC
Upland Sandpiper *Bartramia longicauda*	BCC
Horned Grebe *Podiceps auritus*	BCC
Common Tern *Sterna hirundo*	BCC
Loggerhead Shrike *Lanius ludovicianus*	BCC/SARA1
Common Nighthawk *Chordeiles minor*	SARA2
Chestnut-collared Longspur *Calcarius ornatus*	BCC
Eared Grebe *Podiceps nigricollis*	BCC
Sage Thrasher *Oreoscoptes montanus*	BCC
Black-throated Gray Warbler *Setophaga nigrescens*	BCC
Lark Bunting *Calamospiza melanocorys*	BCC
Northern Bobwhite *Colinus virginianus*	SARA1
Semipalmated Sandpiper *Calidris pusilla*	BCC
American Pipit *Anthus rubescens*	SARA2
Olive-sided Flycatcher *Contopus cooperi*	SARA2
King Rail *Rallus elegans*	SARA1

killed at towers in proportion to their abundance. More recently Arnold and Zink (2011) claimed that population size explained almost 43% of variation in tower collision mortality. Our results show that some species experience mortality far out of proportion with their population size (Fig. 2), as was also shown by Graber (1968), and that population size only explains 18% of variation in tower mortality. Our divergence from Arnold and Zink's (2011) results is most likely attributable to methodological differences in developing species proportions. They did not account for regional variation in mortality or differentially weight the contribution of different tower studies, but rather simply pooled all mortalities at all towers at all locations to develop the proportions of birds killed.

Our estimates indicate that some species of birds experience mortality from towers up to several percent of their total population each year. Neotropical migrants are most affected by collisions with communication towers. For these species, the migratory period has been suspected to be "the critical period contributing to long-term declines in some species" (Hutto, 2000). Sillett and Holmes (2002) presented a long-term study of Black-throated Blue Warbler, one of many species killed at communications towers (our estimate is ~55,000 per year). They found that survival of individuals was high during the summer (0.99 ± 0.01) and winter (0.93 ± 0.05), while survival during both spring and fall migration was only 0.67–0.73. Their study was the first quantification of migration mortality for a Neotropical migrant, and the results reinforced concerns that risks encountered during migration can contribute to species declines. Sillett and Holmes (2002) concluded that both habitat quality before migration as well as conditions during migration, including the number of communication towers encountered along the migratory route, affect mortality.

For short-lived species where a large proportion of individuals may only expect to have a single breeding season, spring mortality is biologically far more important and much less likely to be compensatory. Parulids can have annual mortality of 0.5–0.6 (Sillett and Holmes, 2002) and collectively have the second to shortest maximum lifespan (~6 years maximum) of all passerine families (Wasser and Sherman, 2010). Although tower mortality is typically higher in the fall (both because of the presence of juvenile birds and the higher probability of weather patterns conducive to kills), it is estimated that 25% of mortality still occurs in the spring (Crawford and Engstrom, 2001). Whatever the split between spring and fall, a loss of 1–9% of the total population of a species each year to tower mortality may indeed influence population trajectories, especially for species already in decline (Robbins et al., 1989).

4.1. Uncertainty

Estimates of regional species profiles that were documented as part of long-term records from multiple sites are more reliable than those from shorter records encompassing fewer locations, but it is not possible to provide confidence estimates for our quantification of these estimates. Some regions have not reached asymptotes in species accumulation; the addition of new tower mortality locations and further data would result in spreading the calculated mortality for those regions across more species, potentially changing the apparent effect on those species identified here. It is for this reason that we have not reported the results for the shortgrass prairie regions, which had fewer than 1000 specimens available from towers (Table 1).

The accuracy of the total population estimates also influences the per species assessments. The method of calculating these estimates from breeding bird surveys (Rosenberg and Blancher, 2005) was well received, but has acknowledged limitations (Thogmartin et al., 2006). These population estimates have associated measures of accuracy and precision. For the 20 species ranked as highest annual percent mortality in our analysis, nearly all estimates of accuracy for landbirds are described as either "likely to be well within correct order of magnitude, often within 50% of true number" or "in correct order of magnitude" (Rich et al., 2004). Obviously, higher or lower estimates by an order of magnitude could increase or decrease the estimated population impact dramatically. For example, incorporating a 50% range around the population

Table 5
The ten species of birds killed most at communication towers in each region, as calculated by weighted averages of proportions killed at each location (see 2. Methods).

Overall rank and species	Prairie Potholes, Badlands and Prairies	Southeastern Coastal Plain and others	Central Hardwoods	Eastern Tallgrass Prairie	Prairie Hardwood Transition, Boreal Hardwood Transition	Appalachian Mountains, Piedmont	Peninsular Florida	New England/ Mid-Atlantic Coast and others
1 Red-eyed Vireo	1	1	3	2	3	1		4
2 Ovenbird	2	3	1	1	1	4	2	1
3 Common Yellowthroat	6	2	2	7		6	1	5
4 Tennessee Warbler			4	4	5	5		
5 Swainson's Thrush	7		8	10	2	3		7
6 American Redstart		5			9	10	5	9
7 Magnolia Warbler		6	5	6	7	7		10
8 Bay-breasted Warbler			7	8	8	2		6
9 Black-and-white Warbler		8	10		10		6	
10 Yellow-rumped Warbler		4		5				
11 Gray Catbird	8	9	6	9		9		
12 Blackpoll Warbler					4		4	3
13 Chestnut-sided Warbler		10	9					8
14 Palm Warbler		7					8	
15 Black-throated Blue Warbler							3	
16 Nashville Warbler				3				
17 Ruby-crowned Kinglet								2
18 Northern Waterthrush							10	
20 Northern Parula							7	
21 Gray-cheeked Thrush					6			
25 Wood Thrush						8		
33 Yellow Warbler	3							
39 Dark-eyed Junco	5							
40 Cape May Warbler							9	
42 Sora	10							
44 Lincoln's Sparrow	9							
55 American Tree Sparrow	4							

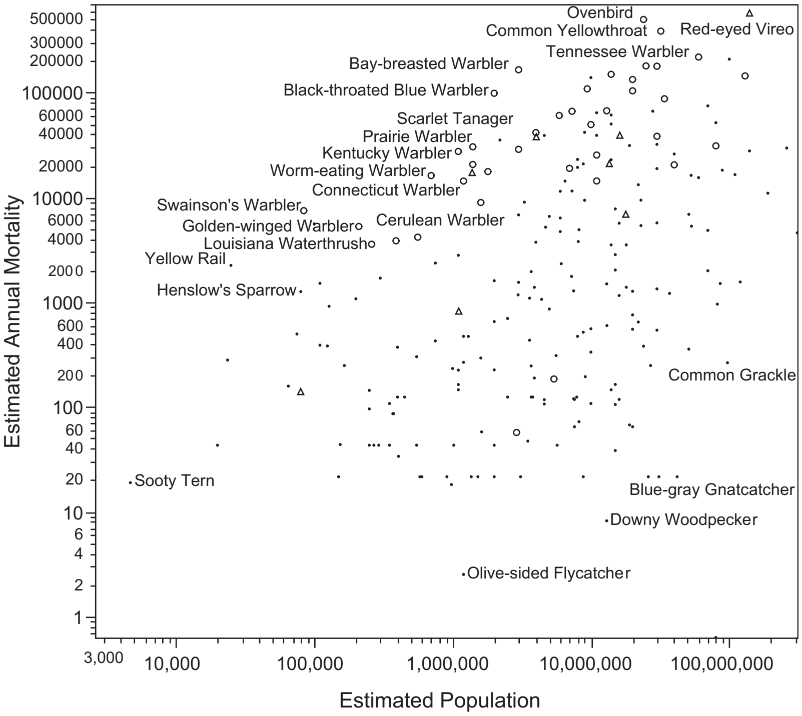

Fig. 2. Relationship of estimated population size of bird species killed at communication towers to estimated annual mortality at communication towers. The species killed at highest and lowest proportions of population size are labeled with standard abbreviations. All warbler species (Parulidae) are marked with circles, and all vireos (Vireonidae) are marked with triangles.

estimate for Golden-winged Warbler (*Vermivora chrysoptera*) gives a range of annual mortality from 1.2% to 5.0% for our annual estimated mortality of ~5300 birds. Furthermore, the uncertainty of population estimates for species that are secretive, or whose ranges or habitats are not covered well by the Breeding Bird Survey, would likely be high.

The results of the mortality assessment illustrate the potential complications of extrapolated species mortality from historical records. Yellow Rails (*Coturnicops noveboracensis*) winter along the Gulf Coast and breed in Canada (Bookhout, 1995). They have been recorded dead at towers across a large range and consequently are estimated to experience losses of ~2200 individuals per year. Towers almost certainly no longer kill as many Yellow Rails as they once did because of the dramatic decline of this species (Bookhout, 1995), although more recent mortality events do include 34 recorded in October 1986 (Ball et al., 1995) and 1 in Fall 2000 (Young and Robbins, 2001), both near Topeka, Kansas. We have assumed that the proportion of each species of bird killed has not changed, so estimates of mortality for some species that have declined dramatically may reflect historical rather than current patterns.

Additional uncertainty could arise from differential detectability of carcasses among species of different sizes (Smallwood, 2007). The effect of carcass size on overall mortality estimates is not likely to be substantial, however, because 97% of birds recovered at towers are small passerines (Table 2). We have not provided statistical estimates of uncertainty, but rather present the best possible estimates from the data currently available, with an explicit and transparent methodology that will allow improvement in these estimates as additional data are collected. It is, however, necessary to make such estimates because policies are currently being formulated to address incidental take from towers that could be informed by these efforts.

4.2. Biological significance

Advocates for the tower industry frequently compare avian mortality at towers to other sources of avian mortality and argue, implicitly or explicitly, that those sources that kill more total birds are more important by virtue of sheer numbers alone (e.g., Woodlot Alternatives, 2005). This approach is flawed for conservation assessments because it lumps all birds together without regard for their status as rare or common. Species are affected differentially and although total tower-related mortality is lower than some other sources of human-caused avian mortality, it can still be significant for individual species. This also applies to other sources of direct avian mortality, such as industrial-scale wind farms, where aggregate mortality numbers can appear to be low compared with other sources, but analysis for individual species can indicate significant impacts (Carrete et al., 2009).

An analysis of the biological significance of avian mortality at towers should consider other sources of human-caused mortality when those other sources are additive and can contribute to an assessment of cumulative impacts. For example, Klem (1990) estimated that glass windows kill on the order of 97.6 million to 976 million birds per year. Although no synthetic analyses of window collision mortality similar to this effort have been undertaken, Klem (1989) identified 20 avian species killed most frequently by windows from inquiries to 125 museum curators for information from their collections. Some of these species, such as Ovenbird (*Seiurus aurocapilla*), Swainson's Thrush (*Catharus ustulatus*), Common Yellowthroat (*Geothlypis trichas*), and Tennessee Warbler (*Oreothlypis peregrina*), are also killed in great numbers at towers. Although not comparable to our analysis, this approach helps to identify species for which cumulative impacts are likely to occur. For species at risk in such situations, addressing both tower and window mortality would be advisable and indeed the species killed in window strikes at tall buildings will be similar to those killed at communication towers. Although the 20 avian species killed most frequently at all windows reported by Klem (1989) do not contain any Birds of Conservation Concern, the 20 avian species killed most frequently at towers contain two such species (Bay-breasted Warbler [*Setophaga castanea*], and Blackpoll Warbler [*Setophaga striata*]) and 11 of 20 species killed in greatest proportion to their populations at towers have special conservation status.

The example of mortality at windows illustrates how mortality estimates from several human-caused sources can be used to weigh alternative policy options to protect migratory birds. First, per species estimates (or at least ranks) are needed. Then, for any particular species of concern, conservation action can be focused on a single source of mortality or address the cumulative effects of multiple sources. This decision cannot be made without some quantification of which bird species are killed by which causes or by integrating multiple sources of mortality into lifecycle models for individual species (Loss et al., 2012). For example, Gray Catbirds (*Dumetella carolinensis*) are among the birds killed most frequently at towers (Table 1) and are killed frequently by free-roaming cats (Balogh et al., 2011) and windows (Klem, 1989). Indeed, mortality from domestic cats alone is capable of reducing local catbird populations (Balogh et al., 2011). Cumulatively, these mortality sources may affect local and regional distribution and abundances even if no rangewide population-level effect is detected from any one source.

Finally, we have illustrated that it is feasible to develop per species estimates of avian mortality, even if the data are imperfect and assumptions are many. Notwithstanding these limitations, our method improves on current approaches to describing lethal effects of human activities on birds, where comparisons are made routinely of the number of "birds" killed with little consideration of which species are affected (e.g., Erickson et al., 2005; Gore, 2009). Such comparisons of undifferentiated totals of birds killed are insufficient to assess the biological significance of different mortality sources. We therefore encourage increased consideration and description of the species composition of avian casualties resulting from human actions and policies.

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EXHIBIT D

Centennial Watershed State Forest Adjacent to Laurel Reservoir

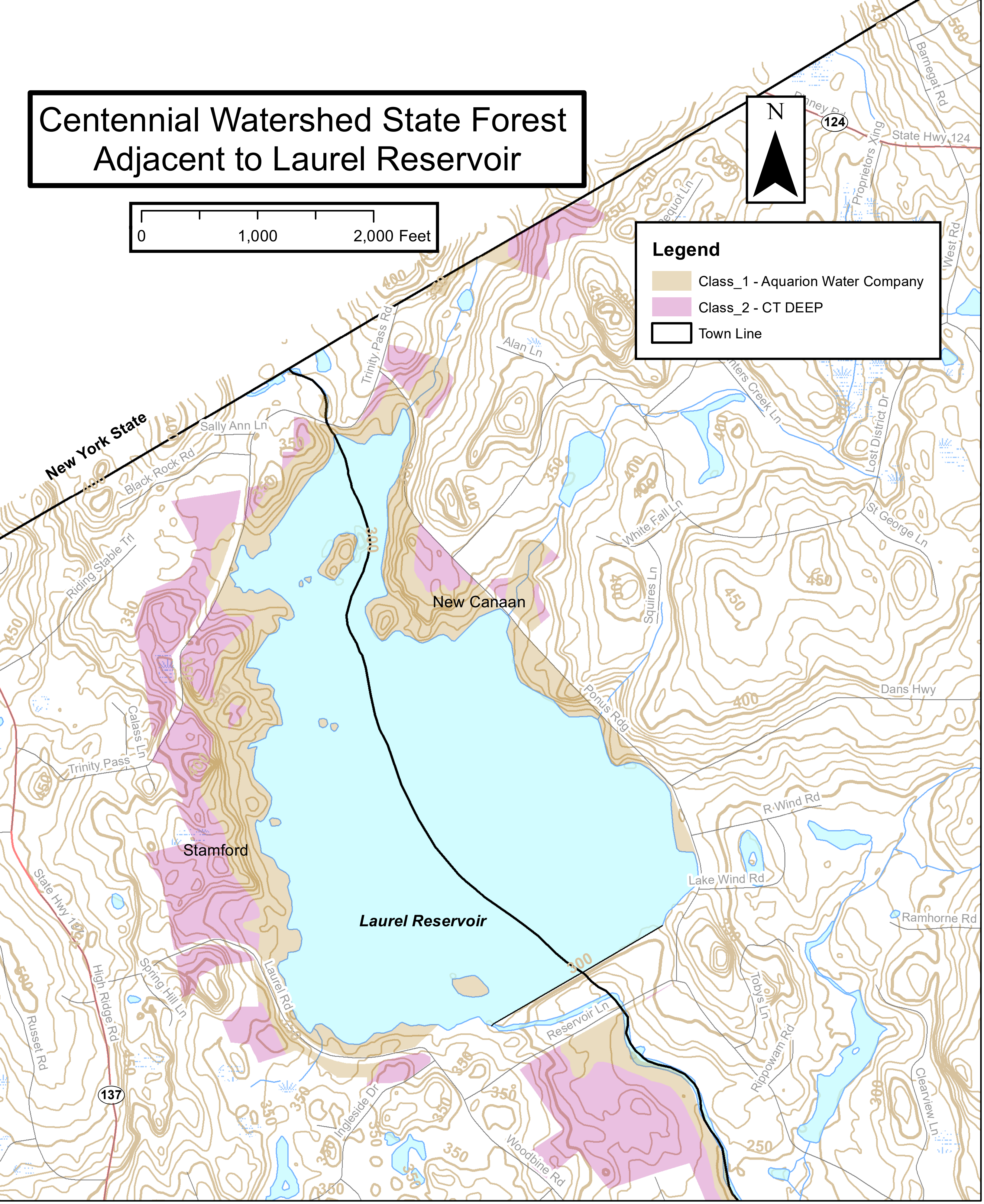

EXHIBIT E

PHOTO NO. 1 – LOOKING NORTHWEST FROM REAR OF GARAGE

PHOTO NO. 2 – LOOKING NORTH FROM DRIVEWAY BEHIND GARAGE

PHOTO NO. 3 – LOOKING NORTH FROM BACKYARD

PHOTO NO. 4 – LOOKING NORTH FROM FENCE LINE

PHOTO NO. 5 – LOOKING NORTH FROM FENCE LINE

PHOTO NO. 6 – LOOKING NORTH FROM FENCE LINE

PHOTO NO. 7 – LOOKING NORTH FROM FENCE LINE

PHOTO NO. 8 – LOOKING NORTH FROM FENCE LINE

PHOTO NO. 9 – LOOKING NORTH FROM REAR OF HOUSE