The role of the North American Breeding Bird Survey in conservation

Authors: Hudson, Marie-Anne R., Francis, Charles M., Campbell, Kate J., Downes, Constance M., Smith, Adam C., et al.

Source: The Condor, 119(3) : 526-545

Published By: American Ornithological Society

URL: https://doi.org/10.1650/CONDOR-17-62.1

THE CONDOR
Ornithological Applications
AmericanOrnithology.org

Volume 119, 2017, pp. 526–545
DOI: 10.1650/CONDOR-17-62.1

REVIEW

The role of the North American Breeding Bird Survey in conservation

Marie-Anne R. Hudson,[1]* Charles M. Francis,[1] Kate J. Campbell,[1] Constance M. Downes,[1] Adam C. Smith,[1] and Keith L. Pardieck[2]

[1] Canadian Wildlife Service, Environment and Climate Change Canada, National Wildlife Research Center, Ottawa, Ontario, Canada
[2] U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, Maryland, USA
* Corresponding author: marie-anne.hudson@canada.ca

Submitted March 24, 2017; Accepted May 10, 2017; Published July 26, 2017

ABSTRACT

The North American Breeding Bird Survey (BBS) was established in 1966 in response to a lack of quantitative data on changes in the populations of many bird species at a continental scale, especially songbirds. The BBS now provides the most reliable regional and continental trends and annual indices of abundance available for >500 bird species. This paper reviews some of the ways in which BBS data have contributed to bird conservation in North America over the past 50 yr, and highlights future program enhancement opportunities. BBS data have contributed to the listing of species under the Canadian Species at Risk Act and, in a few cases, have informed species assessments under the U.S. Endangered Species Act. By raising awareness of population changes, the BBS has helped to motivate bird conservation efforts through the creation of Partners in Flight. BBS data have been used to determine priority species and locations for conservation action at regional and national scales through Bird Conservation Region strategies and Joint Ventures. Data from the BBS have provided the quantitative foundation for North American State of the Birds reports, and have informed the public with regard to environmental health through multiple indicators, such as the Canadian Environmental Sustainability Indicators and the U.S. Environmental Protection Agency's Report on the Environment. BBS data have been analyzed with other data (e.g., environmental, land cover, and demographic) to evaluate potential drivers of population change, which have then informed conservation actions. In a few cases, BBS data have contributed to the evaluation of management actions, including informing the management of Mourning Doves (*Zenaida macroura*), Wood Ducks (*Aix sponsa*), and Golden Eagles (*Aquila chrysaetos*). Improving geographic coverage in northern Canada and in Mexico, improving the analytical approaches required to integrate data from other sources and to address variation in detectability, and completing the database, by adding historical bird data at each point count location and pinpointing the current point count locations would further enhance the survey's value.

Keywords: bird population monitoring, species of conservation concern, breeding bird surveys, conservation planning, bird population trends, bird population status, environmental indicators, citizen science

El papel del Conteo de Aves en Reproducción en la conservación

RESUMEN

El Conteo de Aves en Reproducción (BBS, por sus siglas en inglés) se estableció en 1966 en respuesta a una falta de datos cuantitativos sobre los cambios en las poblaciones de muchas especies de aves en una escala continental, especialmente de aves canoras. El BBS ahora provee las tendencias regionales y continentales más confiables, y los índices de abundancia anual disponibles para más de 500 especies de aves. Este trabajo recopila algunas de las formas en las que los datos del BBS han contribuido a la conservación de las aves en Norteamérica en los últimos 50 años y resalta posibles mejoras futuras al programa. Los datos de BBS han contribuido al listado de especies bajo la Ley de Especies Canadienses en Riesgo, y en algunos casos, ha informado la evaluación de especies bajo la Ley de Especies Amenazadas de EEUU. Al concientizar sobre los cambios en las poblaciones, el BBS ha ayudado a impulsar esfuerzos de conservación de aves a través de la creación de Partners in Flight. Los datos de BBS han sido usados para determinar las especies prioritarias y las localidades para ejecutar acciones de conservación a escalas nacional y regional a través de las Estrategias de Conservación Regional del aves y de Joint Ventures. Los datos del BBS brindaron los datos cuantitativos necesarios para el establecimiento de los reportes del Estado de las Andes Norteamericanas y han informado al público con respecto a la salud del medio ambiente a través de múltiples indicadores, como los Indicadores Canadienses de Idoneidad Ambiental y el Reporte del Ambiente de la Agencia de Protección Ambiental de EEUU. Los datos de BBS han sido analizados con otros datos (e.g. datos ambientales, de cobertura de la tierra, y demográficos) para evaluar los factores potenciales que producen cambios en las poblaciones, que a su vez informan acciones de conservación. En algunos casa, los datos de BBS han contribuido a la evaluación de acciones de manejo de especies como el de *Zenaida macroura, Aix sponsa* y *Aquila chrysaetos*. Es necesario mejorar la cobertura geográfica en el norte de Canadá y en México, mejorar los métodos analíticos que se requieren para integrar datos de otras fuentes y para tratar la variación en detectabilidad, y completar la base de datos histórica de paradas en los censos para incrementar aún más el valor de los conteos.

Palabras clave: ciencia ciudadana, conteos de aves en reproducción, especies de interés para la conservación, estado de las poblaciones de aves, indicadores ambientales, monitoreo de poblaciones de aves, planeación en conservación, tendencias de las poblaciones de aves

Effective conservation and management of wildlife populations requires reliable information about their status, how their status is changing over time, and the factors driving those changes (Baillie 1990). Such information is necessary to understand which species are in need of conservation or management action, what actions might be effectively undertaken to achieve conservation, and, if actions are undertaken, whether these actions are effective (Figure 1). This is particularly important in an adaptive management framework, where information on population change contributes iteratively to planning in an effort to reduce uncertainty (Williams 2011). This approach allows practitioners to learn about the system as they manage it and to adjust their management actions or policies as required (Williams 2011).

Well-designed, large-scale monitoring programs are generally the most effective way to assess and detect changes in the status of populations (Stem et al. 2005). Even without a proper statistical design, large changes in populations, such as the rapid disappearance of Brown Pelicans (*Pelecanus occidentalis*) and Peregrine Falcons (*Falco peregrinus*) due to DDT (Cade et al. 1971, Blus 1982), or the loss of billions of Passenger Pigeons (*Ectopistes migratorius*; Blockstein 2002), can be detected by general observation. However, by the time such large changes have occurred, conservation intervention becomes expensive and difficult, and may even be too late, as in the case of the Passenger Pigeon (Blockstein 2002). Quantitative, precise information on population change derived from standardized monitoring allows for more proactive, informed, and defensible conservation measures (Stem et al. 2005). Quantitative data can also be used to evaluate potential drivers of population change, which, in turn, can help to guide conservation actions (e.g., Butler et al. 2007, Conroy et al. 2011; Figure 1).

The North American Breeding Bird Survey (BBS) was established in 1966 by Chandler S. Robbins in the wake of Rachel Carson's book *Silent Spring* (Carson 1962; see Sauer et al. 2013, 2017a for more information). The creation of the BBS was in response to a lack of reliable large-scale data on changes in the populations of many bird species, especially songbirds (Robbins and Van Velzen 1967). The BBS was one of the first "citizen science" programs; it relies on thousands of highly skilled birders, most of whom are volunteers, to undertake roadside surveys across the North American continent during the peak breeding season (between May and early July, depending on latitude). Each route comprises 50 3-min point count stations (i.e. BBS "stops") spaced roughly 0.8 km apart, as safety conditions allow, along secondary roads. A single observer identifies and counts all birds seen within 400 m of their stop, or heard at any distance (Robbins et al. 1986). The survey is coordinated at the national level by staff at the U.S. Geological Survey (USGS) Patuxent Wildlife Research Center (Laurel, Maryland, USA) and the Canadian Wildlife Service (CWS) of Environment and Climate Change Canada (Ottawa, Ontario, Canada), and, since 2008, the Mexican National Commission for the Knowledge and Use of Biodiversity (CONABIO; Mexico City, Mexico), with the assistance of provincial, territorial, and state coordinators. In the 50 yr since its inception, the survey has expanded to include information from >5,400 BBS routes covering much of the U.S. and Canada, and portions of northern Mexico (Pardieck et al. 2016), and now provides regional and continental trends and annual indices of abundance for >500 species (Sauer et al. 2017a).

Data from the BBS have been analyzed regularly by CWS and USGS staff to estimate how populations have been changing over time (e.g., Erskine 1978, Robbins et al. 1986, Dunn et al. 2000, Downes and Collins 2003, Pardieck and Sauer 2007, Ziolkowski et al. 2010, Sauer et al. 2014, Environment and Climate Change Canada 2017a). Analytical methods have evolved considerably as new statistical approaches have been developed; BBS analyses have moved from graphed indices of the ratios of area-weighted average counts (Erskine 1978) through route regressions (Link and Sauer 1998) and estimating equations (Link and Sauer 1994) to, most recently, hierarchical Bayesian models (e.g., Link and Sauer 2002, 2016, Sauer and Link 2011, Smith et al. 2014). Published estimates of trends and annual indices of abundance have become the quantitative foundation for landbird conservation in North America (NABCI 2016, Rosenberg et al. 2016, 2017), contributing information to many of the steps required for species conservation (Figure 1). In addition to the status and trend estimates (along with their associated reliability [Environment and Climate Change Canada 2017a] and regional credibility [Sauer et al. 2017b] measures) published by the 2 federal agencies, raw BBS data have been analyzed by researchers who have incorporated these results into hundreds of scientific publications. The topics covered include, but are not limited to, range shifts, responses to climate change, population turnover, ecosystem services, migratory connectivity, habitat and land cover associa-

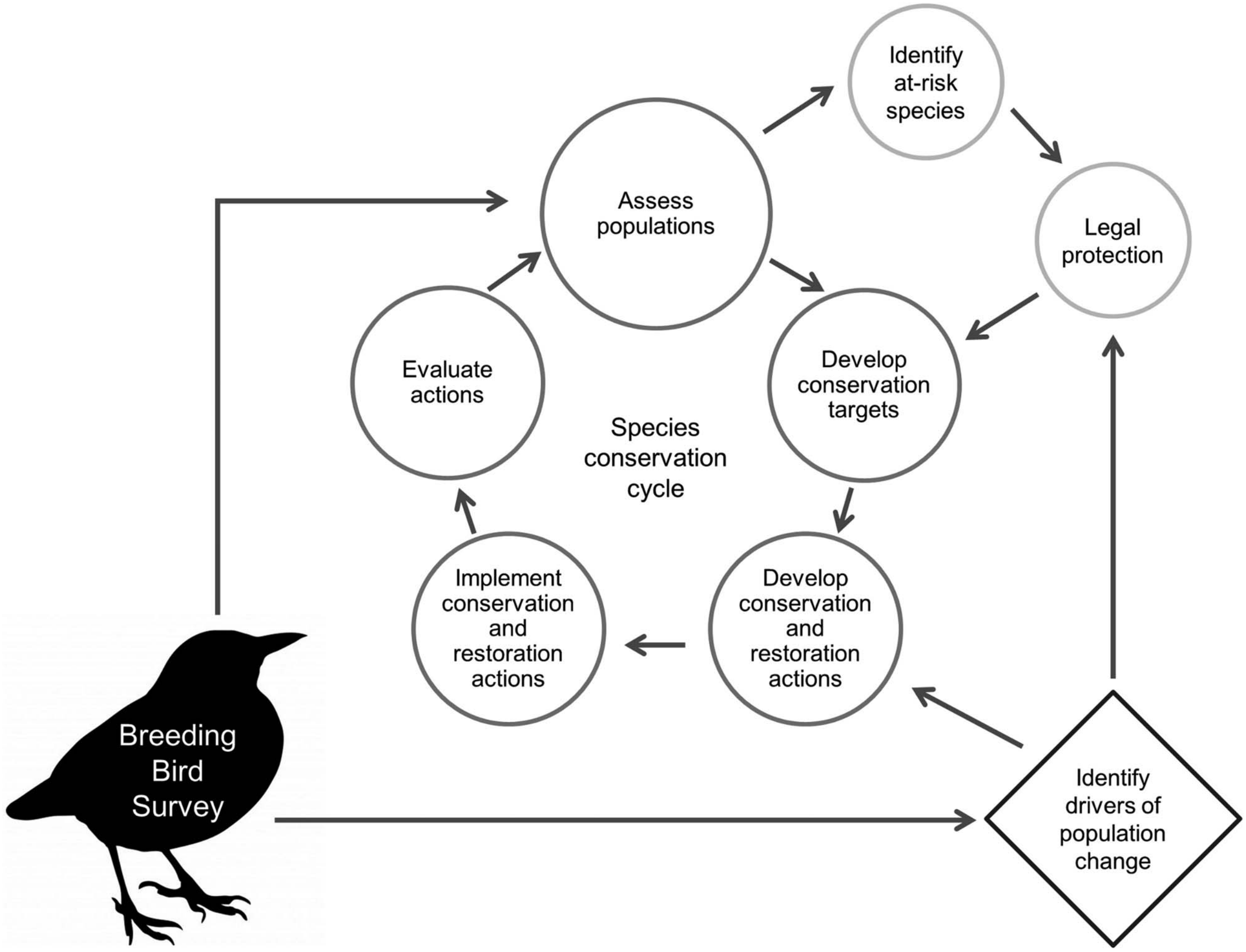

FIGURE 1. An illustration of the flow of information and steps required for the species conservation cycle. The North American Breeding Bird Survey (BBS) contributes information to the assessment of species status, the identification of species at risk, the development of conservation targets and plans, and the evaluation of conservation actions. The identification, assessment, and protection of species at risk flow from the main species conservation cycle, and feed back into it. Data from the BBS also help to identify drivers of population change, which can then inform conservation actions and legal listing processes.

tions, effects of diseases and pesticides, invasive competitors, and impacts of land use change (see the USGS's BBS bibliography for a partial list: https://www.pwrc.usgs.gov/bbs/about/bbsbib.pdf).

In this paper, we review some of the ways in which data from the BBS have contributed to conservation of birds in North America. Specifically, we examine the extent to which the BBS has been used to: (1) identify conservation priorities, including assessing the status of individual species at national and regional levels, identifying species that may be at risk, and identifying priority locations and/or habitats for conservation; (2) inform conservation actions by identifying potential drivers of population change; (3) motivate conservation actions by reporting on ecosystem health through environmental indicators; and (4) evaluate the effectiveness of conservation management actions, including informing harvest management. We also consider some of the factors that have limited the application of the BBS to conservation and how these may be addressed in the future.

Identifying Conservation Priorities

Assessing species population status and conservation priorities. The BBS's rigorous survey design, consistent field methods, volunteer commitment, and continental coverage have made it the most valuable source of status information available for many species. Data from the BBS have been, and continue to be, used in a wide variety of conservation assessment databases at regional to continental scales. Here, we highlight 5 examples of broad-scale assessments, each developed for different purposes, all of which rely to a large degree on BBS data.

Avian Conservation Assessment Database. Formerly known as the Partners in Flight (PIF) Species Assessment Database, the Avian Conservation Assessment Database (ACAD) relies heavily on the BBS. Originally developed by PIF just for landbirds in the U.S. and Canada, the database has been expanded to include all other bird groups (waterfowl, seabirds, shorebirds, and other waterbirds), as well as Mexico and Central America (Rosenberg et al. 2017). The ACAD provides an assessment of the population status for all North American, Mexican, and Central American bird species based on several criteria including distribution, population size, population trend, and threats (Carter et al. 2000, Rosenberg et al. 2017). The BBS has been used to generate continental population trends for 62% (287 of 460) of the landbirds in the database. BBS data have also been used to generate population size scores for 89% (274 of 308) of the landbirds that have the majority of their breeding range within the U.S. and Canada (Rosenberg et al. 2017). The database now provides the quantitative basis for several national conservation plans (e.g., the PIF Landbird Conservation Plan), which contain lists such as the "Common Birds in Steep Decline List" and "PIF Watch List," as well as various metrics such as an extinction half-life, and PIF's population objectives (Rosenberg et al. 2016, 2017).

NatureServe Network. The NatureServe Network (www.natureserve.org) collects, compiles, analyzes, and disseminates species and ecosystem status assessments for the Western Hemisphere, with the aim of providing a basis for sound and effective conservation action. NatureServe is a nonprofit organization that coordinates a public–private–academic network of programs operating in the U.S., Canada, and Latin America. One of the network's many products is conservation status assessments, which estimate the risk of extinction and extirpation of species and ecosystems, respectively, at global, national, and subnational levels. While the ACAD approach was developed specifically for birds, the NatureServe criteria are designed to work for all taxa, including fungi, plants, and animals. The "conservation status ranks" are calculated based on 10 ranking factors, which are grouped into the following 3 categories: rarity, threats, and trends (Faber-Langendoen et al. 2012). The first 2 factors are scaled and weighted relative to their effect on the risk of extinction, and an initial score is created. That score is then modified by adding or subtracting the trends factor, which results in a final rank on a 1–5 scale. These rankings are then translated into status descriptions ranging from "secure" to "critically imperiled" (Faber-Langendoen et al. 2012). As of 2017, BBS trends had been considered in the most recent review of the conservation status rank of ~600 avian species or subspecies that occur in North America (B. Young, Director of Species Science, personal communication).

General Status of Species in Canada report. Canada's Species at Risk Act requires the preparation of a "general report on the status of wildlife species" (Minister of Justice 2015: section 128) every 5 yr. All governments in Canada made a commitment to prepare such a report under the 1996 Accord for the Protection of Species at Risk. For the Wild Species 2015 report (CESCC 2016), provincial, territorial, and federal governments adopted the NatureServe protocol for their assessments of plant and animal species at national and subnational levels in Canada. These ranks were then integrated into the NatureServe Network. Species assessments were based on range, abundance (i.e. rarity), environmental specificity, threats, and short- and long-term population trends. Nonmigratory species were assigned only one rank, whereas migratory species received separate ranks for breeding, nonbreeding, and migration periods. The use of BBS trends varied among regions, but contributed information to more than half of all breeding bird species assessments in the regions for which we were able to obtain information. For example, in the Canadian prairies, BBS trends informed the short-term trend metric for 66% (174 of 264) of species breeding in Alberta, 60% (150 of 252 species) in Saskatchewan, and 60% (159 of 267 species) in Manitoba (E. Beck, CWS Biologist, personal communication). In British Columbia, BBS trends were used for 61% of species (180 of 295 breeding bird species; A. Norris, CWS Biologist, personal communication), while in Quebec, they informed 50% (140 of 278 breeding bird species; S. Légaré, CWS Biologist, personal communication).

Status of birds in the United States. Under the Fish and Wildlife Conservation Act (Public Law 100-653, 102 Stat. 3825), the U.S. Fish and Wildlife Service (USFWS) is required to "identify species, subspecies, and populations of all migratory nongame birds that, without additional conservation actions, are likely to become candidates for listing under the Endangered Species Act" (16 USC 2912, Sec. 13 [a][3]). This "Birds of Conservation Concern" list (USFWS 2008) provides the primary motivation for conducting species assessments in the U.S. The USFWS uses a tapestry of partnerships and programs formed around 4 major bird groups (landbirds, shorebirds, waterbirds, and waterfowl; USFWS 2004) to assess avian populations at the national level. These partnerships, programs, and initiatives (e.g., PIF, U.S. Shorebird Conservation Partnership, Waterbird Conservation for the Americas, and North American Waterfowl Management Plan) provide population information for focal species at varying intervals and scales that then feed into national species assessments (e.g., the Birds of Conservation Concern list). Work is underway to develop a unified national assessment process based on a single standardized database that would follow the ACAD model (Rosenberg et al. 2017, R. Dettmers, USFWS Biologist, personal communication).

Currently, reports for the 4 bird groups are created separately, and all have made use of the BBS to varying degrees. For example, the primary data source for landbird assessments is the ACAD, which relies heavily on the BBS (PIFSC 2012). The most recent shorebird assessment (USSCPP 2016) relied on BBS data and trends for 14 of the 52 (27%) shorebird species that were evaluated. The most recent evaluation of waterbird populations for the USFWS Birds of Conservation Concern report (currently in review) used BBS data for 7 of the 106 (7%) waterbird species evaluated (B. Andres, USFWS Biologist, personal communication). However, with one exception (Wood Duck [*Aix sponsa*]; USFWS 2016a), waterfowl population assessments have not used BBS data, relying instead on data derived from aerial surveys, banding, and harvest surveys conducted by the USFWS and North American Waterfowl Management Plan partners.

Status of birds in Canada. The "Status of Birds in Canada" website (http://ec.gc.ca/soc-sbc/) was developed by Environment and Climate Change Canada to guide Canadian conservation planning. This web-based database informs management agencies by identifying and tracking changes in the national status of 452 bird species that regularly breed or occur in Canada and by providing assessments and detailed trend information that may be used to flag candidate species for listing (Environment Canada 2014). The website presents summary information on the status of each species, including an evaluation of the reliability of each assessment, along with the underlying data. For 217 species (48%), including 17 waterbirds and shorebirds, trends and annual indices from the BBS in Canada were the primary or sole sources of information used to determine population status. For another 24 species (6%), BBS results were used to supplement other sources of information, such as the Christmas Bird Count, Breeding Bird Atlases, or species-specific surveys. All told, the BBS was used to inform the population status assessment of more than half (53%) of all bird species in Canada, and 88% of all landbirds. In the assessment of the reliability of each species' population status (ranked as high, medium, or low reliability, or as data deficient), 66% of the 149 species with highly reliable status assessments were landbirds whose assessments relied on the BBS.

Informing legal protection for species at risk. In addition to species status assessments, BBS data have also informed the listing process for individual species under both the U.S. Endangered Species Act (ESA) and Canada's Species at Risk Act (SARA). In Canada, the listing process includes criteria specific to the magnitude of population change, and so some species have been listed as a direct result of their BBS trend estimates. As noted above, trend estimates derived from the BBS have also contributed to the listing process indirectly by highlighting species in decline that may be candidates for future assessment under the ESA and/or SARA.

The U.S. Endangered Species Act. The ESA was the first piece of legislation to identify, protect, and recover imperiled species from extinction (Waples et al. 2013). The listing of terrestrial and freshwater species is determined by USFWS managers, and is based solely on the best available scientific information (i.e. economic and social factors are not taken into consideration). A species may be listed as either "endangered" or "threatened" if the species is at risk due to one of the following 5 categories of issue: habitat destruction or damage, overuse, disease or predation, inadequate protection from existing regulatory mechanisms, or other natural or manmade factors that endanger the species' existence (Waples et al. 2013). We reviewed the bird species listed under the ESA and searched for documents containing the words "Breeding Bird Survey" in the U.S. Federal Register under 50 CFR Part 17 – Endangered and Threatened Wildlife and Plants. We also queried the listed bird species on the USFWS website (https://www.fws.gov).

Of the 16 species and 24 subspecies of bird listed as "endangered" or "threatened" (as of November 2016) that breed in the continental U.S. (USFWS's Environmental Conservation Online System, https://ecos.fws.gov/ecp/), we found that BBS trends informed the assessments of 5 species or subspecies. Most listed species were extremely rare, with small populations or small breeding ranges that were not adequately detected by the BBS. Thus, it is hardly surprising that we were unable to find a single assessment that indicated that data from the BBS were pivotal in the decision to list the species. However, we found that trend information at the species level was used to inform 2 species assessments, although neither species was found to meet the criteria for listing (Cerulean Warbler [*Setophaga cerulea*]: USFWS 2006, and Mountain Plover [*Charadrius montanus*]: USFWS 2011). BBS trend information at a species, guild, and/or national level was also used to inform evaluations when insufficient evidence was available for assessment at the subspecies or regional level (e.g., Streaked Horned Lark [*Eremophila alpestris strigata*]: USFWS 2013, and western population of the Yellow-billed Cuckoo [*Coccyzus americanus*]: USFWS 2014). Finally, "declining detections" of parasitic Brown-headed Cowbirds (*Molothrus ater*) on BBS routes in areas of overlap with their at-risk host, the Black-capped Vireo (*Vireo atricapilla*), was cited as one of several reasons behind a delisting proposal for the vireo (USFWS 2016b). Although our search was restricted to the Federal Register, and thus dependent on cited references in these published entries, data from the BBS may play a more important role than our results imply. USFWS biologists evaluate more data than are cited in the 12-month petition findings for "not warranted" species or in the proposed and final rules for listed species. These sources, which include the BBS, are still informative in the overall assessment process, depending on the species (K. Gifford, ESA Listing Coordinator, personal communication).

The Canadian Species at Risk Act. In Canada, candidate species at risk are assessed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), an independent scientific advisory body. COSEWIC reviews status reports for candidate species and determines whether species meet the criteria for listing as "endangered," "threatened," "special concern," or "not at risk" under the SARA. COSEWIC's designation is then submitted to the Minister of the Environment, who considers the scientific assessment in conjunction with any political, social, or economic factors. We reviewed all COSEWIC status reports for birds (including those for species or populations assessed as "not at risk") and identified those that used BBS data as a primary or supplementary source of information.

We found that data from the BBS were considered in 57% (65 reports) of the 114 status reports available from 1978 to April 2016 for birds. Of these, 40% (26 reports) used BBS trends or indices as the basis for the designation, including reports for 18 species or subspecies that were assessed as either "endangered" or "threatened," 4 that were assessed as "special concern," and 4 as "not at risk." Of these 26 reports, all but 1 (Black Tern [*Chlidonias niger*]) are for landbirds. The remaining 39 reports used BBS trend information in some capacity, often supplementing BBS trends with other sources of information (e.g., Christmas Bird Count, species-specific surveys, Breeding Bird Atlases), or using BBS trends to assess the likelihood of a rescue effect from the United States (based in part on trends from throughout North America). The BBS was not used for 43% of reports; these included reports for waterbirds and raptors that are not well monitored by the BBS, as well as reports for a few passerines that are extremely rare in Canada and therefore not detected often enough by the BBS to estimate trends.

Informing regional conservation and land use planning. BBS data have often been used to develop species distribution models, which can inform conservation actions by identifying important habitats and areas for conservation (e.g., Lipsey et al. 2015), to calculate regional stewardship metrics (e.g., Carter et al. 2000), and to inform environmental assessments and land use planning, which most often occur at regional or local levels. Here, we highlight some examples of the ways in which such BBS products have been used at the biome scale (e.g., Bird Conservation Regions [BCRs], Migratory Bird Joint Ventures [MBJVs], and the Boreal Avian Modelling [BAM] project), as well as at the state and provincial or territorial scale (e.g., State Wildlife Action Plans [SWAPs], and Breeding Bird Atlases).

Bird Conservation Region strategies. BBS trend estimates have contributed to Bird Conservation Region (BCR) planning and conservation strategies. As part of the North American Bird Conservation Initiative (NABCI), Canada, the U.S., and Mexico have committed to developing conservation plans for all birds at the scale of BCRs (Schmidt et al. 1998). In Canada, conservation strategies have identified priority species within BCRs to focus management attention and resources where they are most needed, to determine conservation needs and establish measurable objectives, and to make recommendations for conservation actions to reach these objectives. Priority species have been identified based on their vulnerability and population status using a quantitative assessment of population size, distribution, trend, threats, and regional abundance (Kennedy et al. 2012). In these assessments, the population trends for 393 of 544 species (234 landbirds, 76 waterbirds, 44 waterfowl, and 39 shorebird species) were based on the BBS for at least 1 subregion (intersection of BCRs and provinces or territories; 32 in total; CWS 2014. In total, for all species and subregions that indicated a data source, 28% (1,138 of 4,133) used BBS data, and another 19% (805 of 4,133) listed the PIF Species Assessment Database (2005 data version) as the main data source (CWS 2014). Also, the late 1960s was chosen as the baseline (target) population level for landbirds, in part because this time period coincides with the start of the BBS and thus provides a means to track progress and evaluate the effectiveness of conservation actions implemented under the Canadian BCR strategies (Kennedy et al. 2012).

Migratory Bird Joint Ventures. In the U.S., conservation implementation and planning are done through Migratory Bird Joint Ventures (MBJVs). MBJVs are large-scale, regional partnerships that focus on habitat conservation for all bird species across North America. These programs have incorporated the few U.S.-based BCR strategies that were developed (these strategies used BBS trends within a PIF-style assessment framework to determine regional conservation priorities specific to each BCR; R. Dettmers, USFWS Biologist, personal communication). The idea behind MBJVs was first outlined in the North American Waterfowl Management Plan in 1986 (USFWS and Environment Canada 1986). There are now 22 habitat-based and 3 species-based MBJVs (see http://mbjv.org for more information). The extent to which BBS data have been used or incorporated into the various MBJVs has varied, but, generally, BBS trends have been used to identify priority species and develop conservation plans for a given joint venture, while BBS abundance indices have been used to inform relative abundance and distribution maps (e.g., Upper Mississippi River and Great Lakes

Region Joint Venture; Potter et al. 2007). For example, by integrating BBS data and land cover characteristics, Lipsey et al. (2015) created species distribution models for the Sprague's Pipit (*Anthus spragueii*). The resulting maps, and others (e.g., Niemuth et al. 2005, 2007), have been used to inform and direct wetland and grassland acquisition within the Prairie Pothole Joint Venture (e.g., http://ppjv.org/science/spatial-planning-tools, http://ppjv.org/science/projects/breeding-bird-survey-data-to-develop-species-distribution-models).

Boreal Avian Modelling project. The Boreal Avian Modelling project (BAM; Cumming et al. 2010) has also made use of data at the level of individual BBS point count stations (BBS "stops") to model the distribution and relative abundance of birds throughout the boreal forests of North America. BAM was established to bring together point count survey data from a wide range of sources to inform the management and conservation of boreal birds, as well as to forecast impacts of human land uses (Cumming et al. 2010, Barker et al. 2015, 2016). As of March 2016, BAM's BBS dataset included data from >65,000 locations, which, over time, represent >600,000 BBS point counts (including all Canadian and Alaskan BBS routes, as well as some routes from the contiguous U.S.; Barker et al. 2016). The database also contains information from >250,000 other point counts, spanning 135 different projects (Barker et al. 2016). Considerable effort has been undertaken to develop statistical models to integrate point count data collected using diverse protocols, including listening times ranging from 3 to 20 min, observations with or without distance information, and a mixture of roadside and off-road counts (Matsuoka et al. 2012, Sólymos et al. 2013, Barker et al. 2015). These models have been used to estimate the distribution and abundance of 98 landbird species in relation to current habitat and climatic variables (Cumming et al. 2014), as well as to simulate the responses of 80 species to potential changes in climate across North America (Stralberg et al. 2015, 2016). Mahon et al. (2014) also simulated cumulative effects of climate and land use changes on songbirds in boreal Alberta, Canada. Map outputs from these models are available on BAM's website (http://www.borealbirds.ca/). Additional applications of the data include ongoing work to identify priority areas for conservation of select landbirds in Canada's boreal forest (A. Camfield, CWS Biologist, personal communication).

State Wildlife Action Plans. Beginning in 2005, all U.S. states were required by congressional mandate to develop a State Wildlife Action Plan (SWAP) to be eligible for a portion of the US$50 million of federal funding available through the State and Tribal Wildlife Grants Program (AFWA 2012, Public Law 106-291: www.gpo.gov/fdsys/pkg/PLAW-106publ291). SWAPs identify the species and habitats in greatest conservation need. Many of these SWAPs cite survey-wide and state-wide BBS trends in their species assessments, and/or incorporate BBS data through a PIF assessment framework to evaluate and prioritize landbird conservation actions (e.g., SCDNR 2005, NMDGF 2006, KDFWR 2013).

Breeding Bird Atlases. Breeding Bird Atlases, which have been undertaken in many provinces and states in North America, are specifically designed to provide information on the distribution and relative abundance of bird species at a moderate spatial scale (typically 5 × 5 km or 10 × 10 km square grids; Beck et al. 2017). This information is used in a multitude of ways (reviewed by Gibbons et al. 2007), but, in terms of environmental assessment, atlas data are mostly used to determine species presence and to provide a regional context against which site-level data can be compared (Beck et al. 2017). Maps from some of the more recent atlases have helped to identify species-rich areas that have then been flagged as priorities for acquisition and restoration or enhancement by the Pacific Birds Habitat Joint Venture and the National Wetland Conservation Fund (K. Moore, CWS Conservation Planner, personal communication).

While breeding bird atlases primarily focus on collection of new data during the atlas period, numerous state and provincial atlases have incorporated data from the BBS. We scanned the methods summaries from a selection of published atlases, and asked subscribers to the North American Ornithological Atlas Committee list-serve (http://www.bsc-eoc.org/norac/index.jsp?targetpg=listserv&lang=EN) to provide examples of how their atlases used BBS data. Many atlases have included state-wide and/or survey-wide BBS trend information in the species accounts, especially to provide context for changes in distributions between atlases (e.g., Kleen et al. 2004, Ellison 2010, Davidson et al. 2015). BBS data have commonly contributed to the creation of distribution maps; species observed on BBS routes are assigned a breeding evidence code (usually "possible") within the atlas grid squares where they were detected (e.g., Cadman et al. 2007, Schneider et al. 2010, Rodewald et al. 2016). Presence data have also contributed to "probability of observation" maps, which provide an index of abundance with which comparisons between atlases can be made (e.g., Davidson et al. 2015, Stewart et al. 2015). Finally, some atlases have used BBS data to map relative abundance at the stratum level within the state (e.g., Busby and Zimmerman 2001), and at the grid square level by combining BBS data with miniroutes that followed BBS protocols but were shorter so as to remain within an atlas grid cell (e.g., Jacobs and Wilson 1997). To date, BBS point count data have not been integrated with atlas-specific point counts to estimate the relative abundance of species among grid cells, largely because BBS point counts are 3 min long and atlas point counts are 5 min long. However, plans for the upcoming atlas in Saskatchewan, Canada, include dividing atlas point counts into 3- and 2-min intervals to allow for the possibility of incorporating BBS data into relative abundance maps (K. Drake, Saskatchewan Atlas Coordinator, personal communication). Some atlases are also asking their observers to capture GPS coordinates for each of their BBS stops so that their checklists can be tied to specific locations on the landscape (A. Peele, Virginia Atlas Coordinator, and N. Anich, Wisconsin Atlas Coordinator, personal communications).

Evaluating Causes of Population Change

The factors that drive population change must be understood if conservation and management actions are to be effective, particularly when these factors are driving population declines. Population trends, such as those derived from the BBS, do not, by themselves, indicate why populations are changing. However, trends can be used to evaluate potential drivers of population change if combined with covariates or if incorporated into adaptive management models (Sauer et al. 2013) or integrated population models (Schaub and Abadi 2011).

Even for a topic as focused as applied avian conservation, an exhaustive review of the uses of BBS data is beyond the scope of this paper. The USGS's BBS bibliography database (http://www.pwrc.usgs.gov/rwp/database_descriptions.htm#Breeding%20Bird%20Survey) includes 578 entries from 1965 to 2014. A Google Scholar search on July 20, 2016, for peer-reviewed papers with the wording "North American Breeding Bird Survey" between 2014 and 2016 provided 96 additional papers. We selected examples of different approaches from this extensive literature.

Some early analyses laid the groundwork by inferring causes of change based on differences in trends among geographic regions or habitats (e.g., Robbins et al. 1989, Flather and Sauer 1996) or between groups of species (e.g., Sauer and Droege 1992). More recently, analyses have generally used 1 of 3 approaches to combine BBS data with other data sources to evaluate drivers of population change at different scales: integration with demographic data, integration with environmental data on the breeding grounds, or integration with data throughout the annual life cycle.

Integration with demographic data. BBS data have been linked with demographic data from the Monitoring Avian Productivity and Survivorship (MAPS) program to evaluate which demographic rates influence population change on the breeding grounds. For example, DeSante et al. (2005) modeled spatial variation in MAPS data as a function of spatial variation in BBS trends to investigate the relative influence of productivity and survival rates on population change. They concluded that low adult survival was the proximate cause of decline at both continental and regional scales for the Gray Catbird (*Dumetella carolinensis*). Saracco et al. (2008) used MAPS data and reverse-time capture–recapture models to evaluate the effects of recruitment and adult immigration on adult survival of Yellow Warblers (*Setophaga petechia*). They found that apparent adult survival, not productivity, likely drove variation in the species' BBS population trends. More recently, Ahrestani et al. (2017) formalized this union of data by creating and testing an integrated population model that combined BBS and MAPS data for the Gray Catbird and Wood Thrush (*Hylocichla mustelina*). These analyses have not only provided insights into the demographic processes driving observed changes in abundance in different strata, which have helped to focus local conservation measures on the most appropriate period of the life cycle; they have also potentially improved the robustness of parameter estimation and provided the ability to estimate latent parameters that are not measured by either survey (e.g., recruitment; Ahrestani et al. 2017).

Integration with environmental data on the breeding grounds. BBS data have been integrated into analyses evaluating how various environmental factors might influence survival and productivity on the breeding grounds. Recent studies on grassland bird species, a group which has undergone significant declines first highlighted by the BBS (Houston and Schmutz 1999, Peterjohn and Sauer 1999), provide examples of ways in which BBS data have been used to evaluate several factors. Mineau and Whiteside (2013) created an index of grassland bird health in the contiguous U.S. (i.e. the numbers of species showing positive or negative trends in each state) from state-wide and national BBS trends, and examined the effects of agricultural intensity, insecticide use, lethal pesticide risk, herbicide use, and changes in permanent and cropped pasture on this index. Hill et al. (2014) based their analyses on those of Mineau and Whiteside (2013), but added 3 additional covariates in an information-theoretic framework: statewide grassland coverage, Conservation Reserve Program area, and change in rangeland area during the study period. Despite the fact that Hill et al. (2014) and Mineau and Whiteside (2013) came to different conclusions, possibly because the latter were missing the additional covariates incorporated by Hill et al. (2014), both studies found that insecticide use and habitat availability on the breeding grounds were correlated with BBS trends of grassland birds. Evans and Potts (2015) calculated yearly land cover uses and conversion in a 400 m buffer surrounding BBS routes across 11 Midwestern states, and estimated grassland bird abundance using BBS data. Using a generalized linear model, they found that commodity prices affected farmers' land use decisions (i.e. cropland area), which were then correlated with grassland bird relative abundance. Gorzo et al. (2016) used BBS abundance data and weather variables (e.g., precipitation and temperature indices) in a Bayesian hierarchical framework to model 14 grassland bird species' responses to broad-scale weather effects. In doing so, they identified Baird's Sparrow (*Ammodramus bairdii*) as a species vulnerable to drier and hotter conditions, and thus more susceptible to climate change. Collectively, these studies suggest that multiple factors are relevant to grassland bird declines, and indicate the need for multipronged conservation approaches.

Integration with data throughout the annual life cycle. Research has recently expanded to include covariates or trend information from the nonbreeding season to provide a more complete understanding of population changes in North American birds. For example, by jointly analyzing BBS and Christmas Bird Count data, Link et al. (2008) determined that Northern Bobwhite (*Colinus virginianus*) populations were changing more over the winter and spring than during the summer and fall. Pinpointing the times when populations are changing the most can help to focus conservation efforts on these potentially sensitive periods.

BBS data have also been used in conjunction with climatic and other environmental data in an annual life cycle framework to evaluate drivers of Neotropical migrant population change on the breeding and wintering grounds (e.g., Wilson et al. 2011, Rushing et al. 2016, Taylor and Stutchbury 2016). Wilson et al. (2011) examined how nonbreeding ground climatic conditions might affect bird abundance in the following breeding season. In a hierarchical Bayesian framework, they analyzed American Redstart (*Setophaga ruticilla*) annual abundance, as measured by the BBS, for 15 different populations covering the species' range (Wilson et al. 2011). They found that higher plant productivity and wetter conditions in the Caribbean (nonbreeding grounds) were positively correlated with changes in abundance in the eastern populations of the American Redstart. Taylor and Stutchbury (2016) used a network population model to examine migratory connectivity in Wood Thrush (*Hylocichla mustelina*) populations across the annual cycle to explain the steep decline in this species. Network models capture the relationships between objects of interest (nodes) using connectivity (links). Taylor and Stutchbury (2016) partitioned Wood Thrush breeding and overwintering ranges into several nodes based on geolocator tracking data. They incorporated BBS-derived node-specific relative abundances and trends for the Wood Thrush into their models with breeding, migrating, and overwintering survival rates, reproductive success rates, and total forest and core area estimates to build and validate a migratory network population model for the Wood Thrush, and then ran various scenarios to predict population declines over time. Rushing et al. (2016) also examined annual BBS abundance for many Wood Thrush populations in a hierarchical Bayesian framework, modeling annual population abundance as a function of forest loss and primary productivity and complexity on both the breeding and nonbreeding grounds. Although the authors of these 2 Wood Thrush studies disagreed on the relative importance of habitat loss and climate, possibly due to differences in analytical approaches (Rushing et al. 2016), Taylor and Stutchbury (2016) and Rushing et al. (2016) both recommended a "targeted" or "strategic" approach, including conservation efforts on both the breeding and nonbreeding grounds.

Motivating Conservation Action by Reporting on the Environment

In general, an environmental indicator summarizes complex information into a succinct, easily understood format, which allows the evaluation of progress toward conservation goals or environmental sustainability, and can serve as an early warning system (Heink and Kowarik 2010 and references therein). BBS data have been incorporated into multispecies indicators at various geographic scales, from subcontinental (e.g., Stephens et al. 2016) to regional (e.g., O'Connell et al. 2007). Conservation and federal agencies have also begun producing regular analyses based on BBS data for such indicators as "State of the Birds" reports, the Canadian Environmental Sustainability Indicators, and the U.S. Environmental Protection Agency's Report on the Environment.

State of the Birds reports. Over the past 2 decades, State of the Birds reports have presented comprehensive analyses of bird populations for the world (BirdLife International 2004a), Europe (e.g., Tucker et al. 1994, BirdLife International 2004b), North America (NABCI 2016), and many individual countries, including the U.S. (NABCI-US 2009, 2014) and Canada (NABCI-C 2012). These State of the Birds reports assess the conservation status of groups of bird species to provide a measure of the success of conservation actions, and a signal of ecosystem health. Perhaps most importantly, these reports serve as a call to action to bring about the social, economic, and political changes needed to preserve habitats and address global threats. Here, we focus on the contributions that the BBS has made to the reports for North America.

Before most national State of the Birds reports were initiated, a 1989 analysis of BBS data reported widespread declines in many long-distance Nearctic–Neotropical migrants (Robbins et al. 1989). This watershed report served as a catalyst for several conservation actions, despite some debate over the results (Sauer et al. 2013), and led to greatly increased recognition of the need for internationally integrated work to protect bird species. It triggered the formation of Partners in Flight (Carter et al. 2000), and sparked a synthesis of the state of research at the time (e.g., Finch and Stangel 1993, Martin and Finch 1995), which helped to launch the full life cycle and continental approach to conservation (Faaborg et al. 2010). Neotropical migrant declines in the U.S. were highlighted as the motivation behind the 2000 Neotropical Migratory Bird Conservation Act (Public Law 106-247, Section 2[3][A]; U.S. Congress 1998). Although the source was not explicitly stated, the data ("approximately 210 species of migratory birds in the United States are in serious decline"; U.S. Congress 1998:2) cited in the documentation preceding the Act were presumably based on BBS trends calculated by the USGS. Since 2002, this Act has provided >US$58 million to 510 projects in 36 countries, and has enabled 3:1 matching of funds in excess of US$221 million (USFWS 2016c).

The first comprehensive national report on the state of bird populations in North America was the State of the Birds United States of America 2009 report (NABCI-US 2009), which was followed by an updated analysis in 2014 (NABCI-US 2014). The State of Canada's Birds (NABCI-C 2012) was the first national assessment for Canada. In 2016, Canada, the U.S., and Mexico worked together to prepare an integrated report on the State of North America's Birds (NABCI 2016). The BBS was by far the most widely used data source in developing these national reports. The 2009 and 2014 U.S. reports calculated composite population trend data for all species with adequate data, separated into major habitat groups (NABCI-US 2009). BBS annual indices of abundance provided population status estimates for 368 (73%) of the species included in the indices for the 2009 report. Other sources of data included the Christmas Bird Count and the Waterfowl Breeding Population and Habitat Surveys. For the 2014 report, BBS data were used to a similar extent, though the percentage of the total number of species relying on BBS data was slightly lower because of the incorporation of shorebird migration surveys, which increased the total number of species covered (NABCI-US 2014). The State of Canada's Birds 2012 report used similar methods to calculate an "all birds" indicator that included 317 of the 451 native species that regularly occur in Canada for which suitable data were available (NABCI-C 2012). The BBS annual indices of abundance were used for 227 of the 317 (72%) species with adequate data for analysis.

The State of North America's Birds 2016 report used a different approach from these earlier national reports. It used the Avian Conservation Assessment Database to summarize the conservation vulnerability of 1,154 native bird species based on population trends, population sizes, range extents, and threats (NABCI 2016). The BBS contributed in several ways to the assessment of species occurring primarily in Canada and the U.S. (see Rosenberg et al. 2017 for a review of this process), including being the primary data source for the population trend and population size estimates for the majority of landbird species. These national and continental State of the Birds reports highlighted some guilds that were of particularly high conservation concern, such as aerial insectivores (NABCI-C 2012) and grassland birds (highlighted in all 4 reports); nearly all of the data for these guilds were derived from the BBS.

Canadian Environmental Sustainability Indicators. The Canadian Environmental Sustainability Indicators (CESI) program tracks and reports on Canada's performance in environmental sustainability (Environment and Climate Change Canada 2017b). These indicators are intended not just to reflect the status of a particular taxonomic group, but to represent the overall quality of the environment. Two different CESI indicators have been produced for migratory birds in Canada. The "Trends in Canada's Migratory Bird Population" indicator was derived from the State of Canada's Birds report (NABCI-C 2012). It represents the overall average population status for all bird species with adequate data, as well as a breakdown based on wintering location and migratory behavior (e.g., Canada, U.S., and Central and South America, which represent residents, short-distance migrants, and long-distance migrants, respectively.). As noted above, BBS data were used for 72% of the species with sufficient data. The second indicator, the "Population Status of Canada's Migratory Birds," presents the proportion of migratory bird species that are within acceptable bounds of established long-term population targets. These targets serve as guidelines for defining conservation priorities (i.e. species that are below acceptable bounds may merit conservation action) and to inform conservation planning in Canada. A range of data sources were used for this indicator, of which the BBS was the largest contributor. Annual indices of abundance from the BBS were used to set the population targets and evaluate the status for 191 of the 368 (52%) migratory bird species or populations that had sufficient data to be included in the CESI indicator. The remaining species were assessed based on several different surveys, including waterfowl and seabird surveys, shorebird migration counts, and the Christmas Bird Count.

U.S. Environmental Protection Agency's Report on the Environment. The U.S. Environmental Protection Agency's Report on the Environment (2008, and its most recent online version: https://cfpub.epa.gov/roe/index.cfm) describes the condition of the U.S. environment and human health, and how it is changing over time. Eighty-five indicators in 5 theme areas (Air, Water, Land, Human Exposure and Health, and Ecological Condition) provide the information needed to determine whether the EPA's mission of protecting human health and the environment is being met. Within the Ecological Condition subcategory of Diversity and Biological Balance, the EPA presents 2 indicators that rely entirely on BBS trend data (Sauer et al. 2012). The first summarizes BBS population trends in the U.S. for 347 bird species grouped by 5 breeding habitat types (e.g., wetland, grassland, urban; https://cfpub.epa.gov/roe/indicator.cfm?i=83#1), while the second shows the cumulative percentage change in bird populations in the U.S. and southern Canada by 7 different breeding habitats (https://cfpub.epa.gov/roe/indicator.cfm?i=83#2).

Evaluating the Effectiveness of Conservation Management Actions

Although there have been relatively few large-scale management actions undertaken for most landbirds, the group of species best monitored by the BBS, we found several cases in which data from the BBS were used to evaluate the effectiveness of management actions. Here, we highlight cases in which BBS data informed the management of harvested game species, the issuance of incidental take permits, the evaluation of habitat conservation actions, and the establishment of recovery actions for species at risk.

BBS data have been used to a limited extent to inform the management of migratory game bird hunting. Recreational hunting of migratory game birds is regulated by the U.S. Fish and Wildlife Service and by Environment and Climate Change Canada. Both population monitoring data and bird-banding data support the regulation-setting processes. In Canada, the most recent report in the Population Status of Migratory Game Birds in Canada series (Canadian Wildlife Service Waterfowl Committee 2015) mentioned the BBS in assessments of 10 of 46 game bird species. Of those 10, the BBS was the sole source of monitoring data for the Mourning Dove (*Zenaida macroura*), and one of the main data sources for the Band-tailed Pigeon (*Patagioenas fasciata*), Wilson's Snipe (*Gallinago delicata*), Virginia Rail (*Rallus limicola*), and Sora (*Porzana carolina*). In the U.S., population trends for the most heavily harvested game bird in this country, the Mourning Dove (Raftovich et al. 2016), were monitored for many years using a dedicated call-count survey (CCS). However, Sauer et al. (1994a, 2010) found that the BBS provided greater coverage (i.e. more routes per state and more strata with estimates per state), larger sample sizes, smaller variance estimates, and more consistent trend information than the CCS. The BBS is currently the primary survey for monitoring this species, although other data sources are used to set hunting regulations (Seamans 2016a). Similarly, the BBS is the main survey used to monitor Band-tailed Pigeon populations, although sample sizes are smaller and variances are higher than for Mourning Doves (Seamans 2016b). The BBS also provides the only source of regional, long-term estimates of annual abundance for the Wood Duck (Wilkins and Cooch 1999, USFWS 2016a), providing a measure of how hunting harvest may be affecting the species. Recently, by integrating Atlantic Flyway Breeding Waterfowl Survey ground-plot information with BBS data, Zimmerman et al. (2015) used BBS indices to estimate current and historical Wood Duck population sizes for all Bird Conservation Regions within the Atlantic Flyway.

In the U.S., data from the BBS have also been used to inform the management of incidental take permits for eagles. Eagles are subject to permitting activities such as unintentional lethal take and disturbance (see the Bald and Golden Eagle Protection Act [16 U.S.C. 668–668d] and 2016 update; USFWS 2009 and USFWS 2016d, respectively). Millsap et al. (2009) used scaled BBS indices in combination with data from the aerial Western United States Summer Golden Eagle Survey to create density estimates for Golden Eagles (*Aquila chrysaetos*). These density estimates have been used to ensure that permitted activities do not unduly affect the number of breeding pairs (Millsap et al. 2009).

Evaluations of management programs such as the Conservation Reserve Program (CRP) have benefited from the use of BBS data. Niemuth et al. (2007) calculated regional population estimates for several grassland bird species by creating spatial models that linked the birds detected at BBS stops with the habitat characteristics on the landscape. They used these estimates to evaluate whether changes in the amount of land being managed for conservation through the CRP would affect these grassland bird populations. They predicted that their study region, which is at the heart of North America's grassland conservation efforts, would lose >900,000 individuals of the 4 species that they examined if the land currently being managed under the CRP was converted to cropland (Niemuth et al. 2007). They evaluated their use of the BBS by conducting an independent study of ~2,800 point counts, which resulted in density and population size estimates by habitat type that were remarkably consistent with the BBS estimates, despite the different approaches (Niemuth et al. 2007).

To date, in Canada, changes in BBS trend estimates have been used to set population recovery objectives for 3 grassland bird species and 3 aerial insectivores (e.g., statements in SARA Recovery Strategies and/or Management Plans to the effect that the species' BBS trend should be either stable or increasing over the next 15 yr; Environment Canada 2012, 2014, 2015, 2016a, 2016b, Environment and Climate Change Canada 2016a). Maintaining and expanding the number of BBS routes in the Canadian grasslands has also been cited as a high-priority measure to monitor recovery in a multispecies Action Plan that includes Sprague's Pipit and McCown's Longspur (*Rhynchophanes mccownii*; Environment and Climate Change Canada 2016b).

Future Directions

Although the BBS has already become the most important quantitative survey used to support landbird conservation in North America, the survey's impact on conservation could be improved through enhancements in 4 key areas: (1) improving the survey's geographic coverage across the continent and across habitats, (2) enhancing analytical techniques to address sources of bias, (3) filling coverage gaps through quantitative integration of data with other surveys, and (4) completing the dataset, both in terms of adding all historical point count station bird data, and pinpointing the current locations of each BBS route's 50 point count stations (the "stop-level" dataset). The national agencies that coordinate the BBS are making progress on all of these fronts.

Improving geographic coverage. BBS trend estimates for many species would be further enhanced by improved geographic coverage. Uneven geographic coverage may result in biased estimates of trends at regional or national scales if rates of population change vary between the areas covered by the BBS and the rest of the species' range. For example, recent work suggests that trends of species in the southern fringe of the Canadian boreal forest, which is covered by the BBS, differ from trends of the same species in the more northerly portions of the boreal forest where BBS coverage is lacking (Machtans et al. 2014, Van Wilgenburg et al. 2015).

The main approach being used to expand coverage is to add routes, especially in northern Canada and in Mexico. Progress is being made: the number of routes being run each year in Mexico is now 44, up from the original 2 in 2008. New routes have been established and run in high-latitude regions of British Columbia and in remote regions of Quebec, Labrador, and Saskatchewan, Canada, filling important gaps in regional coverage. Routes have also been added recently throughout Montana, Missouri, Arkansas, and Nebraska, USA, to improve route density in those states. Increased coverage can also help to fill gaps in undersampled habitats (e.g., large intact grasslands [Dale et al. 2005] and boreal forest [Van Wilgenburg et al. 2015]). Provided that a road network exists, the main challenge is finding dedicated, experienced volunteers to run routes in difficult-to-access areas. BBS staff and coordinators are experimenting with ways to address gaps in coverage, such as encouraging observers through reimbursement of transportation costs, and using rotating panel designs to select which routes, out of a number of routes across a large area, are run in a given year. New technologies may also provide opportunities for innovative ways to improve coverage beyond traditional BBS routes. Research is currently underway to assess the feasibility of using digital audio recorders to complement field observers, especially in habitats where most species detections are by sound. This could expand the pool of potential volunteers to allow less-skilled birders to collect field data, while experts help with the interpretation of recordings. This may also help to address some concerns about detectability by allowing multiple listeners to review the recordings. Even with innovative approaches, however, coverage will continue to be limited by the distribution of safe roads from which to conduct surveys.

Enhancing analytical techniques to address sources of bias. Enhancements to the statistical models used to estimate population status could further reduce the potential effects of imperfect detections during BBS surveys. The BBS field protocols are designed to limit variations in detectability by minimizing changes in observers on a given route, limiting acceptable weather conditions in which to conduct surveys, and limiting observations to a relatively strict time window within a day and season. Changes to BBS protocols have been proposed that would allow for the direct and separate estimation of abundance and detectability (e.g., Farnsworth et al. 2002, Forcey et al. 2006, Somershoe et al. 2006, Simons et al. 2007, and reviewed by Nichols et al. 2009). However, the potential benefits of any changes must be explicitly evaluated across a large number of species and habitats, and must outweigh their practical limitations (e.g., increased costs and demands on observers). For example, field methods that allow for the application of removal models impose a nontrivial demand on volunteer observers, double-observer approaches effectively double the volunteer effort required to run the survey (and have only improved the accuracy of abundance estimates for certain quiet species; Leston et al. 2015), and distance sampling methods require observers to estimate the distance to auditory cues, which is notoriously inaccurate and could therefore increase error and bias (Alldredge et al. 2008). These proposed changes could result in decreased sample sizes (i.e. reduced coverage through volunteer attrition) or reduced geographic coverage, and could actually lead to estimates that have lower precision and/or increased bias (Johnson 2008). Preliminary results from a study focused on incorporating distance sampling techniques into the BBS protocol resulted in 80% of species with lower counts than when standard BBS methodology was used, which, on average, represented a 10% decline in the overall count (J. Sauer, USGS Research Wildlife Biologist, personal communication). In the end, imperfect detectability does not necessarily confound many uses of BBS data because BBS counts are generally treated as indices of bird populations. Most conservation uses of the BBS require only that the correlation between the counts and the population is relatively consistent. That is, detectability should not be a problem if the variation in detectability is not correlated with the pattern of interest (e.g., detectability is on average constant in time, if the interest is in population trends) and/or the magnitude of the variation in detectability is small relative to the true change in population size (Johnson 2008).

Beyond the existing approaches for reducing variance, analytical approaches are also being developed to address potential bias associated with variation in detectability. For example, current BBS trend models already account for the variability among observers (Sauer et al. 1994b) and start-up effects within observers (Link and Sauer 2002). The PIF population estimates derived from BBS data adjust for variation in detection distances among species estimated from independent data, as well as changes in detectability with the time of day and season (Blancher et al. 2013). Research is underway to develop ways to account for the effects of other covariates of detectability in the trend models, such as phenological shifts, changing noise levels related to traffic (e.g., Griffiths et al. 2010), and age-related hearing loss (e.g., Farmer et al. 2014). The hierarchical Bayesian framework of the current trend models lends itself well to incorporating estimates of detectability covariates derived from independent datasets, which would help to reduce bias associated with any temporal or spatial correlations between detectability and population status.

Filling coverage gaps through quantitative integration of data from multiple surveys. Population trends for many bird species could be improved by integrating BBS data and other breeding season survey data to fill geographic gaps in coverage or to address the unevenness in coverage of certain habitats. For example, BBS data could be combined with data from off-road surveys, which could be key to improving coverage in otherwise inaccessible areas such as the boreal forest (e.g., Sólymos et al. 2013, Handel and Sauer 2017). Research is underway to determine whether Automated Recording Units (ARUs) could also be used to fill geographic gaps in ways that could be integrated into the BBS. For example, units could be preprogrammed to record during the breeding season and positioned along winter roads or other areas that are most readily accessible outside the breeding season (S. Haché, CWS Biologist, personal communication). Preprogrammed ARUs could also record at several times of day, thereby capturing information on crepuscular or nocturnal species, which are generally only detected during the first few stops on a BBS route. Coverage could be further improved through integration of data from targeted, standardized surveys such as the Marsh Monitoring Survey (Meyer et al. 2006). While these surveys have their own limitations and weaknesses, they complement the BBS because they target undersampled habitats. It may also be possible to integrate data from unstandardized surveys, such as eBird, which cover many different times of day and times of year, and have extremely large sample sizes (e.g., Pacifici et al. 2017, Walker and Taylor 2017), although such surveys also have a range of potential biases of their own (e.g., variable sampling effort, observer ability, and species detectability, as well as unrestricted, uneven geographic sampling; Sullivan et al. 2009).

As shown in previous sections, quantitative integration is possible on a species-by-species basis (e.g., Link and Sauer 2007, Link et al. 2008, Millsap et al. 2009, Zimmerman et al. 2015), but a generalized national model across all species has not yet been developed (but see Ahrestani et al. 2017). Setting aside the interesting potential of multi-survey analyses, which require significant thought and statistical finesse, it is important to remember that often the most effective way to assess and detect changes in the status of populations is to rely on a carefully designed, consistent, large-scale monitoring program, such as the BBS.

Completing the stop-level dataset. The completion of the stop-level BBS dataset would greatly enhance our understanding of how population change may be driven by local changes in habitat. With the increasing availability of long-term land cover and land use GIS data layers, information on changes in bird populations at a stop (point count station) level would allow the expansion of analyses, such as those done by Niemuth et al. (2007), to a continental scale. From the BBS's inception through 1996, bird count data from the individual 50 stops on a route were digitized in a summarized (i.e. 10-stop) format due to logistical constraints at the time (i.e. computer memory capacity and cost). Recognizing that the value of the dataset for many types of analyses would be further enhanced if the stop-level bird data were digitized, the national agencies running the BBS began digitizing the data from all 50 individual stops in 1997, and continue this practice today. BBS staff have also been working to digitize, vet, and integrate stop-level bird data collected from 1966 to 1996 so that the entire dataset will be available for use. This project is currently ~80% complete.

Providing accurate stop location data is a natural complement to the 50-stop bird dataset. Without precise geographic information, researchers must estimate the location of each stop along a BBS route. These estimates may be inaccurate for 2 reasons: (1) when a route is first established, the stop locations are not known to the BBS office (unless the observer provides GPS coordinates) and may not strictly follow the 800 m spacing protocol because, for safety reasons, observers are allowed to move their stops by up to 160 m (0.1 mile); and (2) stop locations may change over time (e.g., odometers vary and there is the potential for drift between observers if stop descriptions are unclear or landmarks change). Cumulatively, these factors can result in uncertainty in stop locations by up to a few kilometers by the end of a route. Having the ability to pinpoint stop locations with the accuracy of a GPS unit will increase the reliability of analyses of BBS data in relation to local habitats. While it will never be possible to determine the precise location of all historical stops, it may be possible to estimate a portion of these from old maps on which stops have been indicated by hand. At present, BBS staff are compiling stop-level coordinates and evaluating ways to manage these geospatial data. Additional resources will be needed to develop a system that can accurately track changes in stop locations over time. Once this system is in place, the potential for detailed, accurate stop-level analyses will increase substantially.

Conclusions

The BBS provides the most reliable data currently available on regional and continental population trends for hundreds of species, and is therefore considered invaluable to landbird conservation in North America (Rich et al. 2004, Downes et al. 2016). The free and easy access to the various BBS data products also makes it one of the most productive citizen-science projects for generating scientific outputs (Kullenberg and Kasperowski 2016). BBS data are most often used to assess the population status and drivers of population change of landbirds. It is often assumed that the BBS is not as useful for waterbirds or waterfowl, but, to our knowledge, this has not been rigorously tested (but see Sauer 1999). For example, for widespread wetland species, data from the BBS may prove to be just as accurate as the intensive, expensive regional surveys that focus on wetlands. The conservation value of the BBS will certainly increase if future analyses demonstrate that it can provide reliable population change information for more than just landbirds.

While no survey is perfect, the BBS has proven its worth over its 50-yr history and is well positioned to meet future needs. One of the unsung strengths of the BBS is the openness and responsiveness of the program managers and analysts. This collaborative and pioneering spirit has shown itself many times as the survey has evolved, generally through carefully tested modifications to the analyses and subsequent results (e.g., Kendall et al. 1996, Sauer and Link 2002, Sauer et al. 2003, Smith et al. 2014). For example, BBS trends used to be reported at the physiographic stratum level (e.g., Bystrak 1981, Sauer et al. 2003). This changed when Bird Conservation Regions (BCR) became one of the units of conservation management in North America; analysts tested for adverse effects and, when none were found, changed the way in which they estimated and reported regional trends so that the trends would be most useful to conservation strategies at the BCR level (Sauer et al. 2003). As we move forward and as new technologies arise, we are confident that this cautiously open spirit will serve the program well, welcoming the testing of new approaches for improvement of the BBS. BBS methods, coordination, data storage, and analyses will continue to evolve: increasing spatial coverage, incorporating new technologies, integrating data from other surveys, accounting for variation in detectability, and increasing the availability of stop-level information. With so many species under threat (NABCI 2016), continued monitoring and increased collaboration across regional and national boundaries are essential. Partnerships such as the North American Bird Conservation Initiative (http://www.nabci.net/), Bird Conservation Region strategies, and Migratory Bird Joint Ventures are key to providing a communication link between the BBS and other monitoring programs, and among decision-makers and researchers (Ruth et al. 2003). Thanks to the foresight of Chandler S. Robbins, and all of the participants who have contributed since then, we have a powerful, unparalleled continental monitoring tool to help inform and guide effective avian conservation measures.

ACKNOWLEDGMENTS

We would like to dedicate this manuscript to the memory of Chandler S. Robbins, the father of the North American Breeding Bird Survey, and to thank Anthony Erskine for bringing the survey to Canada. We would also like to thank the thousands of dedicated volunteers who have donated their time and extensive experience to the survey; we could not have celebrated the 50-yr mark without you. Finally, we would like to acknowledge the time and skill donated by the state, provincial, and territorial coordinators, as well as the biologists who took the time to provide information for this paper. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. or Canadian Government.

Author contributions: C.M F. conceived the idea, M.-A.R.H., K.J.C., C.M.D., and K.L.P. conducted the literature review, and M.-A.R.H., K.J.C., C.M.D., A.C.S., C.M.F., and K.L.P. wrote the paper.

Data deposits: Our data is deposited with the North American Breeding Bird Survey Dataset at https://www.pwrc.usgs.gov/bbs/RawData/

LITERATURE CITED

AFWA (Association of Fish and Wildlife Agencies, Teaming With Wildlife Committee, State Wildlife Action Plan [SWAP] Best Practices Working Group) (2012). Best Practices for State Wildlife Action Plans: Voluntary Guidance to States for Revision and Implementation. Association of Fish and Wildlife Agencies, Washington, DC, USA. http://teaming.com/sites/default/files/SWAP%20Best%20Practices%20Report%20Nov%202012.pdf

Ahrestani, F. S., J. F. Saracco, J. R. Sauer, K. L. Pardieck, and J. A. Royle (2017). An integrated population model for bird monitoring in North America. Ecological Applications 27: 916–924.

Alldredge, M. W., K. Pacifici, T. R. Simon, and K. H. Pollock (2008). A novel field evaluation of the effectiveness of distance and independent observer sampling to estimate aural avian detection probabilities. Journal of Applied Ecology 45:1349–1356.

Baillie, S. R. (1990). Integrated population monitoring of breeding birds in Britain and Ireland. Ibis 132:151–166.

Barker, N. K. S., E. M. Bayne, S. G. Cumming, T. Fontaine, S. Haché, L. Leston, C. L. Mahon, S. M. Matsuoka, F. K. A. Schmiegelow, P. Sólymos, S. J. Song, et al. (2016). Annual Report April 2015–March 2016. Boreal Avian Modelling Project, Edmonton, AB, Canada. http://www.borealbirds.ca/files/BAM.AnnualReport.2015_16.Final.pdf

Barker, N. K. S., P. C. Fontaine, S. G. Cumming, D. Stralberg, A. Westwood, E. M. Bayne, P. Sólymos, F. K. A. Schmiegelow, S. J. Song, and D. J. Rugg (2015). Ecological monitoring through harmonizing existing data: Lessons from the Boreal Avian Modelling Project. Wildlife Society Bulletin 39:480–487.

Beck, G. G., A. R. Couturier, C. M. Francis, and S. Leckie (2017). North American Ornithological Atlas Committee Handbook: A Guide for Managers on the Planning and Implementation of a Breeding Bird Atlas Project. Bird Studies Canada, Port Rowan, ON, Canada.

BirdLife International (2004a). State of the World's Birds: Indicators for Our Changing World. BirdLife International, Cambridge, UK.

BirdLife International (2004b). Birds in the European Union: A Status Assessment. BirdLife International, Wageningen, Netherlands. http://centrostudinatura.it/public2/documenti/608-45827.pdf

Blancher, P. J., K. V. Rosenberg, A. O. Panjabi, B. Altman, A. R. Couturier, W. E. Thogmartin, and the Partners in Flight Science Committee (2013). Handbook to the Partners in Flight Population Estimates Database, Version 2.0. PIF Technical Series No. 6. http://rmbo.org/pifpopestimates/downloads/Handbook%20to%20the%20PIF%20Population%20Estimates%20Database%20Version%202.0.pdf

Blockstein, D. E. (2002). Passenger Pigeon (*Ectopistes migratorius*). In The Birds of North America (P. G. Rodewald, Editor). Cornell Lab of Ornithology, Ithaca, NY, USA. https://birdsna.org/Species-Account/bna/species/paspig

Blus, L. J. (1982). Further interpretation of the relation of organochlorine residues in Brown Pelican eggs to reproductive success. Environmental Pollution Series A, Ecological and Biological 28:15–33.

Busby, W. H., and J. L. Zimmerman (2001). Kansas Breeding Bird Atlas. University Press of Kansas, Lawrence, KS, USA.

Butler, S. J., J. A. Vickery, and K. Norris (2007). Farmland biodiversity and the footprint of agriculture. Science 315:381–384.

Bystrak, D. (1981). The North American Breeding Bird Survey. In Estimating Numbers of Terrestrial Birds (C. J. Ralph and J. M. Scott, Editors). Studies in Avian Biology 6:34–41.

Cade, T. J., J. L. Lincer, C. M. White, D. G. Roseneau, and L. G. Swartz (1971). DDE residues and eggshell changes in Alaskan falcons and hawks. Science 172:955–957.

Cadman, M. D., D. A. Sutherland, G. G. Beck, D. Lepage, and A. R. Couturier (Editors) (2007). Atlas of the Breeding Birds of Ontario, 2001–2005. Bird Studies Canada, Environment Canada, Ontario Field Ornithologists, Ontario Ministry of Natural Resources, and Ontario Nature, Toronto, ON, Canada.

CWS (Canadian Wildlife Service) (2014). National Database to Support Bird Conservation Region Planning in Canada. http://open.canada.ca/data/en/dataset/ab5ffc67-64ec-47cc-9748-11af0c8f230e

Canadian Wildlife Service Waterfowl Committee (2015). Population Status of Migratory Game Birds in Canada – November 2015. CWS Migratory Birds Regulatory Report Number 45. https://www.ec.gc.ca/rcom-mbhr/default.asp?lang=En&n=9DB378FC-1

Carson, R. S. (1962). Silent Spring. Houghton Mifflin, Boston, MA, USA.

Carter, M. F., W. C. Hunter, D. N. Pashley, and K. V. Rosenberg (2000). Setting conservation priorities for landbirds in the United States: The Partners in Flight approach. The Auk 117:541–548.

CESCC (Canadian Endangered Species Conservation Council) (2016). Wild Species 2015: The General Status of Species in Canada. National General Status Working Group, Ottawa, ON, Canada.

Conroy, M. J., M. C. Runge, J. D. Nichols, K. W. Stodola, and R. J. Cooper (2011). Conservation in the face of climate change: The roles of alternative models, monitoring, and adaptation in confronting and reducing uncertainty. Biological Conservation 144:1204–1213.

Cumming, S. G., K. L. Lefevre, E. Bayne, T. Fontaine, F. K. A. Schmiegelow, and S. J. Song (2010). Toward conservation of Canada's boreal forest avifauna: Design and application of ecological models at continental extents. Avian Conservation and Ecology 5:art.8.

Cumming, S. G., D. Stralberg, K. Lefevre, P. Sólymos, E. M. Bayne, T. Fontaine, D. Mazerolle, F. K. A. Schmiegelow, and S. J. Song (2014). Climate and vegetation hierarchically structure patterns of songbird distribution in the Canadian boreal region. Ecography 37:137–151.

Dale, B., M. Norton, C. Downes, and B. Collins (2005). Monitoring as a means to focus research and conservation – the Grassland Bird Monitoring example. In Bird Conservation Implementation and Integration in the Americas: Proceedings of the Third International Partners in Flight Conference (C. J. Ralph and T. D. Rich, Editors). USDA Forest Service General Technical Report PSW-GTR-191. pp. 485–495.

Davidson, P. J. A., R. J. Cannings, A. R. Couturier, D. Lepage, and C. M. Di Corrado (Editors) (2015). The Atlas of the Breeding Birds of British Columbia, 2008–2012. Bird Studies Canada, Delta, BC, Canada. http://www.birdatlas.bc.ca

DeSante, D. F., M. P. Nott, and D. R. Kaschube (2005). Monitoring, modeling, and management: Why base avian management on vital rates and how should it be done? In Bird Conservation Implementation and Integration in the Americas: Proceedings of the Third International Partners in Flight Conference (C. J. Ralph and T. D. Rich, Editors). USDA Forest Service General Technical Report PSW-GTR-191. pp. 795–804.

Downes, C. M., and B. T. Collins (2003). The Canadian Breeding Bird Survey, 1967–2000. Canadian Wildlife Service Progress Notes No. 219. Canadian Wildlife Service, Environment Canada, Ottawa, ON, Canada.

Downes, C. M., M.-A. R. Hudson, A. C. Smith, and C. M. Francis (2016). The Breeding Bird Survey at 50: Scientists and birders working together for bird conservation. Avian Conservation and Ecology 11:art.8.

Dunn, E. H., C. M. Downes, and B. T. Collins (2000). The Canadian Breeding Bird Survey, 1967–1998. Canadian Wildlife Service

Progress Notes No. 216. Canadian Wildlife Service, Environment Canada, Ottawa, ON, Canada.
Ellison, W. G. (Editor) (2010). 2nd Atlas of the Breeding Birds of Maryland and the District of Columbia. Johns Hopkins University Press. Baltimore, MD, USA.
Environment and Climate Change Canada (2016a). Recovery Strategy for the Chestnut-collared Longspur (*Calcarius ornatus*) in Canada [Proposed]. Species at Risk Act Recovery Strategy Series, Environment and Climate Change Canada, Ottawa, ON, Canada.
Environment and Climate Change Canada (2016b). Action Plan for Multiple Species at Risk in Southwestern Saskatchewan: South of the Divide [Proposed]. Species at Risk Act Action Plan Series, Environment and Climate Change Canada, Ottawa, ON, Canada.
Environment and Climate Change Canada (2017a). North American Breeding Bird Survey – Canadian trends, data-version 2015. Environment and Climate Change Canada, Gatineau, QC, Canada. http://ec.gc.ca/ron-bbs/P001/A001/?lang=e
Environment and Climate Change Canada (2017b). Environmental indicators: Environmental indicators on air, climate, water, nature, and human influence. Environment and Climate Change Canada, Gatineau, QC, Canada. https://www.ec.gc.ca/indicateurs-indicators/
Environment Canada (2012). Amended Recovery Strategy for the Sprague's Pipit (*Anthus spragueii*) in Canada. Species at Risk Act Recovery Strategy Series, Environment Canada, Ottawa, ON, Canada.
Environment Canada (2014). Management Plan for McCown's Longspur (*Rhynchophanes mccownii*) in Canada. Species at Risk Act Management Plan Series, Environment Canada, Ottawa, ON, Canada.
Environment Canada (2015). Recovery Strategy for Eastern Whip-poor-will (*Antrostomus vociferus*) in Canada [Proposed]. Species at Risk Act Recovery Strategy Series, Environment Canada, Ottawa, ON, Canada.
Environment Canada (2016a). Recovery Strategy for the Olive-sided Flycatcher (*Contopus cooperi*) in Canada. Species at Risk Act Recovery Strategy Series, Environment Canada, Ottawa, ON, Canada.
Environment Canada (2016b). Recovery Strategy for the Common Nighthawk (*Chordeiles minor*) in Canada. Species at Risk Act Recovery Strategy Series, Environment Canada, Ottawa, ON, Canada.
Erskine, A. J. (1978). The first ten years of the co-operative Breeding Bird Survey in Canada. Canadian Wildlife Service Report Series No. 42.
Evans, S. G., and M. D. Potts (2015). Effect of agricultural commodity prices on species abundance of U.S. grassland birds. Environmental and Resource Economics 62:549–565.
Faaborg, J., R. T. Holmes, A. A. Anders, K. L. Bildstein, K. M. Dugger, S. A. Gauthreaux, Jr., P. Heglund, K. A. Hobson, A. E. Jahn, D. H. Johnson, S. C. Latta, et al. (2010). Conserving migratory land birds in the New World: Do we know enough? Ecological Applications 20:398–418.
Faber-Langendoen, D., J. Nichols, L. Master, K. Snow, A. Tomaino, R. Bittman, G. Hammerson, B. Heidel, L. Ramsay, A. Teucher, and B. Young (2012). NatureServe Conservation Status Assessments: Methodology for Assigning Ranks. NatureServe, Arlington, VA, USA.
Farmer, R. G., M. L. Leonard, J. E. Mills Flemming, and S. C. Anderson (2014). Observer aging and long-term avian survey data quality. Ecology and Evolution 4:2563–2576.
Farnsworth, G. L., K. H. Pollock, J. D. Nichols, T. R. Simons, J. E. Hines, and J. R. Sauer (2002). A removal model for estimating detection probabilities from point-count surveys. The Auk 119:414–425.
Finch, D. M., and P. W. Stangel (Editors) (1993). Status and management of Neotropical migratory birds: September 21–25 1992, Estes Park, Colorado. USDA Forest Service General Technical Report RM-229.
Flather, C. H., and J. R. Sauer (1996). Using landscape ecology to test hypotheses about large-scale abundance patterns in migratory birds. Ecology 77:28–35.
Forcey, G. M., J. T. Anderson, F. K. Ammer, and R. C. Whitmore (2006). Comparison of two double-observer point-count approaches for estimating breeding bird abundance. The Journal of Wildlife Management 70:1674–1681.
Gibbons, D. W., P. F. Donald, H.-G. Bauer, L. Fornasari, and I. K. Dawson (2007). Mapping avian distributions: The evolution of bird atlases. Bird Study 54:324–334.
Gorzo, J. M., A. M. Pidgeon, W. E. Thogmartin, A. J. Allstadt, V. C. Radeloff, P. J. Heglund, and S. J. Vavrus (2016). Using the North American Breeding Bird Survey to assess broad-scale response of the continent's most imperiled avian community, grassland birds, to weather variability. The Condor: Ornithological Applications 118:502–512.
Griffiths, E. H., J. R. Sauer, and J. A. Royle (2010). Traffic effects on bird counts on North American Breeding Bird Survey routes. The Auk 127:387–393.
Handel, C. M., and J. R. Sauer (2017). Combined analysis of roadside and off-road breeding bird survey data to assess population change in Alaska. The Condor: Ornithological Applications 119:557–575.
Heink, U., and I. Kowarik (2010). What are indicators? On the definition of indicators in ecology and environmental planning. Ecological Indicators 10:584–593.
Hill, J. M., J. F. Egan, G. E. Stauffer, and D. R. Diefenbach (2014). Habitat availability is a more plausible explanation than insecticide acute toxicity for U.S. grassland bird species declines. PLoS ONE 9:e98064.
Houston, C. S., and J. K. Schmutz (1999). Changes in bird populations on Canadian grasslands. In Ecology and Conservation of Grassland Birds of the Western Hemisphere (P. D. Vickery and J. R. Herkert, Editors). Studies in Avian Biology 19: 87–94.
Jacobs, B., and J. D. Wilson (1997). Missouri Breeding Bird Atlas, 1986–1992. Natural History Series No. 6, Missouri Department of Conservation, Jefferson City, MO, USA.
Johnson, D. H. (2008). In defense of indices: The case of bird surveys. The Journal of Wildlife Management 72:857–868.
KDFWR (Kentucky Department of Fish and Wildlife Resources) (2013). Kentucky's Comprehensive Wildlife Conservation Strategy. Kentucky Department of Fish and Wildlife Resources, Frankfort, KT, USA. http://fw.ky.gov/WAP/Pages/Default.aspx
Kendall, W. L., B. G. Peterjohn, and J. R. Sauer (1996). First-time observer effects in the North American Breeding Bird Survey. The Auk 113:823–829.
Kennedy, J., E. Krebs, and A. Camfield (2012). A Manual for Completing Bird Conservation Strategies in Canada

(Abridged Version). Canadian Wildlife Service, Environment and Climate Change Canada, Gatineau, QC, Canada. http://www.ec.gc.ca/mbc-com/default.asp?lang=En&n=7EC65236-1
Kleen, V. M., L. Cordle, and R. A. Montgomery (2004). The Illinois Breeding Bird Atlas. Illinois Natural History Survey, Champaign, IL, USA.
Kullenberg, C., and D. Kasperowski (2016). What is citizen science? – A scientometric meta-analysis. PLoS ONE 11: e0147152.
Leston, L., N. Koper, and P. Rosa (2015). Perceptibility of prairie songbirds using double-observer point counts. Great Plains Research 25:53–61.
Link, W. A., and J. R. Sauer (1994). Estimating equations estimates of trends. Bird Populations 2:23–32.
Link, W. A. and J. R. Sauer (1998). Estimating population change from count data: Application to the North American Breeding Bird Survey. Ecological Applications 8:258–268.
Link, W. A., and J. R. Sauer (2002). A hierarchical model of population change with application to Cerulean Warblers. Ecology 83:2832–2840.
Link, W. A., and J. R. Sauer (2007). Seasonal components of avian population change: Joint analysis of two large-scale monitoring programs. Ecology 88:49–55.
Link, W. A., and J. R. Sauer (2016). Bayesian cross-validation for model evaluation and selection, with application to the North American Breeding Bird Survey. Ecology 97:1746–1758.
Link, W. A., J. R. Sauer, and D. K. Niven (2008). Combining Breeding Bird Survey and Christmas Bird Count data to evaluate seasonal components of population change in Northern Bobwhite. The Journal of Wildlife Management 72: 44–51.
Lipsey, M. K., K. E. Doherty, D. E. Naugle, S. Fields, J. S. Evans, S. K. Davis, and N. Koper (2015). One step ahead of the plow: Using cropland conversion risk to guide Sprague's Pipit conservation in the northern Great Plains. Biological Conservation 191:739–749.
Machtans, C. S., K. J. Kardynal, and P. A. Smith (2014). How well do regional or national Breeding Bird Survey data predict songbird population trends at an intact boreal site? Avian Conservation and Ecology 9:art.5.
Mahon, C. L., E. M. Bayne, P. Sólymos, S. M. Matsuoka, M. Carlson, E. Dzus, F. K. A. Schmiegelow, S. G. Cumming, and S. J. Song (2014). Does expected future landscape condition support proposed population objectives for boreal birds? Forest Ecology and Management 312:28–39.
Martin, T. E., and D. M. Finch (Editors) (1995). Ecology and Management of Neotropical Migratory Birds: A Synthesis and Review of Critical Issues. Oxford University Press, New York, NY, USA.
Matsuoka, S. M., E. M. Bayne, P. Sólymos, P. C. Fontaine, S. G. Cumming, F. K. A. Schmiegelow, and S. J. Song (2012). Using binomial distance-sampling models to estimate the effective detection radius of point-count surveys across boreal Canada. The Auk 129:268–282.
Meyer, S. W., J. W. Ingram, and G. P. Grabas (2006). The Marsh Monitoring Program: Evaluating Marsh Bird Survey Protocol Modifications to Assess Lake Ontario Coastal Wetlands at a Site-Level. Technical Report Series 465, Canadian Wildlife Service, Ontario Region, Toronto, ON, Canada.
Millsap, B. A., G. S. Zimmerman, J. R. Sauer, R. M. Nielson, M. Otto, E. Bjerre, and R. Murphy (2009). Golden Eagle population trends in the Western United States: 1968–2010. The Journal of Wildlife Management 77:1436–1448.
Mineau, P., and M. Whiteside (2013). Pesticide acute toxicity is a better correlate of U.S. grassland bird declines than agricultural intensification. PLoS ONE 8:e57457.
Minister of Justice (2015). Species at Risk Act S.C. 2002, c. 29. http://laws-lois.justice.gc.ca/eng/acts/S-15.3/FullText.html
NABCI (North American Bird Conservation Initiative) (2016). The State of North America's Birds 2016. http://www.stateofthebirds.org/2016/
NABCI-C (North American Bird Conservation Initiative Canada) (2012). The State of Canada's Birds, 2012. Environment Canada, Ottawa, ON, Canada.
NABCI-US (North American Bird Conservation Initiative U.S. Committee) (2009). The State of the Birds, United States of America 2009. U.S. Department of the Interior, Washington, DC, USA.
NABCI-US (North American Bird Conservation Initiative U.S. Committee) (2014). The State of the Birds 2014, United States of America. U.S. Department of Interior, Washington, DC, USA.
Nichols, J. D., L. Thomas, and P. B. Conn (2009). Inferences about landbird abundance from count data: Recent advances and future directions. In Environmental and Ecological Statistics, volume 3: Modeling Demographic Processes in Marked Populations (D. L. Thomson, E. G. Cooch, and M. J. Conroy, Editors). Springer, New York, NY, USA. pp. 201–235.
Niemuth, N. D., M. E. Estey, and C. R. Loesch (2005). Developing spatially explicit habitat models for grassland bird conservation planning in the Prairie Pothole Region of North Dakota. In Bird Conservation Implementation and Integration in the Americas: Proceedings of the Third International Partners in Flight Conference (C. J. Ralph and T. D. Rich, Editors). USDA Forest Service General Technical Report PSW-GTR-191. pp. 469–477.
Niemuth, N. D., F. R. Quamen, D. E. Naugle, R. E. Reynolds, M. E. Estey, and T. L. Shaffer (2007). Benefits of the Conservation Reserve Program to Grassland Bird Populations in the Prairie Pothole Region of North Dakota and South Dakota. Report prepared for the United States Department of Agriculture Farm Service Agency Reimbursable Fund Agreement OS-IA-04000000-N34. https://www.fsa.usda.gov/Internet/FSA_File/grassland_birds_fws.pdf
NMDGF (New Mexico Department of Game and Fish) (2006). Comprehensive Wildlife Conservation Strategy for New Mexico. New Mexico Department of Game and Fish, Santa Fe, NM, USA. http://www.wildlife.state.nm.us/conservation/comprehensive-wildlife-conservation-strategy
O'Connell, T. J., J. A. Bishop, and R. P. Brooks (2007). Subsampling data from the North American Breeding Bird Survey for application to the Bird Community Index, an indicator of ecological condition. Ecological Indicators 7:679–691.
Pacifici, K., B. J. Reich, D. A. W. Miller, B. Gardner, G. Stauffer, S. Singh, A. McKerrow, and J. Collazo (2017). Integrating multiple data sources in species distribution modeling: A framework for data fusion. Ecology 98:840–850.
Pardieck, K. L., and J. R. Sauer (2007). The 1999–2003 summary of the North American Breeding Bird Survey. Bird Populations 8: 28–45.
Pardieck, K. L., D. J. Ziolkowski, Jr., M.-A. R. Hudson, and K. Campbell (2016). North American Breeding Bird Survey

Dataset 1966–2015, version 2015.1. U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, MD, USA. www.pwrc.usgs.gov/BBS/RawData/

Peterjohn, B. G., and J. R. Sauer (1999). Population status of North American grassland birds from the North American Breeding Bird Survey, 1966–1996. In Ecology and Conservation of Grassland Birds of the Western Hemisphere (P. D. Vickery and J. R. Herkert, Editors). Studies in Avian Biology 19: 27–44.

PIFSC (Partners in Flight Science Committee) (2012). Species Assessment Database, version 2012. Rocky Mountain Bird Observatory, Fort Collins, CO, USA. http://rmbo.org/pifassessment

Potter, B. A., G. J. Soulliere, D. N. Ewert, M. G. Knutson, W. E. Thogmartin, J. S. Castrale, and M. J. Roell (2007). Upper Mississippi River and Great Lakes Region Joint Venture Landbird Habitat Conservation Strategy. U.S. Fish and Wildlife Service, Fort Snelling, MN, USA.

Raftovich, R. V., S. C. Chandler, and K.A. Wilkins (2016). Migratory bird hunting activity and harvest during the 2014-15 and 2015-16 hunting seasons. U.S. Fish and Wildlife Service, Laurel, MD, USA. http://www.fws.gov/birds/surveys-and-data/reports-and-publications.php

Rich, T. D., C. J. Beardmore, H. Berlanga, P. J. Blancher, M. S. W. Bradstreet, G. S. Butcher, D. W. Demarest, E. H. Dunn, W. C. Hunter, E. E. Iñigo-Elias, J. A. Kennedy, et al. (2004). Partners in Flight North American Landbird Conservation Plan. Cornell Lab of Ornithology, Ithaca, NY, USA.

Robbins, C. S., and W. T. Van Velzen (1967). The Breeding Bird Survey, 1966. Special Scientific Report – Wildlife 102, U.S. Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife, Washington, DC, USA.

Robbins, C. S., D. Bystrak, and P. H. Geissler (1986). The Breeding Bird Survey: Its First Fifteen Years, 1965–1979. Resource Publication No. 157, U.S. Fish and Wildlife Service, Washington, DC, USA.

Robbins, C. S., J. R. Sauer, R. S. Greenberg, and S. Droege (1989). Population declines in North American birds that migrate to the Neotropics. Proceedings of the National Academy of Sciences USA 86:7658–7662.

Rodewald, P. G., M. B. Shumar, A. T. Boone, D. L. Slager, and J. McCormac (Editors) (2016). The Second Atlas of Breeding Birds in Ohio. Penn State Press, University Park, OH, USA.

Rosenberg, K. V., P. J. Blancher, J. C. Stanton, and A. O. Panjabi (2017). Use of North American Breeding Bird Survey data in avian conservation assessments. The Condor: Ornithological Applications 119:594–606.

Rosenberg, K. V., J. A. Kennedy, R. Dettmers, R. P. Ford, D. Reynolds, C. J. Beardmore, P. J. Blancher, R. Bogart, G. S. Butcher, A. F. Camfield, A. Couturier, et al. (2016). Partners in Flight Landbird Conservation Plan: 2016 Revision for Canada and Continental United States. Partners in Flight Science Committee. https://www.partnersinflight.org/resources/the-plan/

Rushing, C. S., T. B. Ryder, and P. P. Marra (2016). Quantifying drivers of population dynamics for a migratory bird throughout the annual cycle. Proceedings of the Royal Society B 283:20152846.

Ruth, J. M., D. R. Petit, J. R. Sauer, M. D. Samuel, F. A. Johnson, M. D. Fornwall, C. E. Korschgen, and J. P. Bennett (2003). Science for avian conservation: Priorities for the new millennium. The Auk 120:204–211.

Saracco, J. F., D. F. Desante, and D. R. Kaschube (2008). Assessing landbird monitoring programs and demographic causes of population trends. The Journal of Wildlife Management 72: 1665–1673.

Sauer, J. R. (1999). Marsh birds and the North American Breeding Bird Survey: Judging the value of a landscape level survey for habitat specialist species with low detection rates. In Proceedings of the Marsh Bird Monitoring Workshop (C. A. Ribic, S. J. Lewis, S. Melvin, J. Bart, and B. Peterjohn, Compilers.) U.S. Fish and Wildlife Service and U.S. Geological Survey, Laurel, MD, USA. p. 43.

Sauer, J. R., and S. Droege (1992). Geographic patterns of population trends of Neotropical migrants in North America. In Ecology and Conservation of Neotropical Migrant Landbirds (J. M. Hagan, III and D. W. Johnson, Editors). Smithsonian Institution Press, Washington, DC, USA. pp. 26–42.

Sauer, J. R., and W. A. Link (2002). Hierarchical modeling of population stability and species group attributes from survey data. Ecology 83:1743–1751.

Sauer, J. R., and W. A. Link (2011). Analysis of the North American Breeding Bird Survey using hierarchical models. The Auk 128: 87–98.

Sauer, J. R., D. D. Dolton, and S. Droege (1994a). Mourning Dove population trend estimates from call-count and North American Breeding Bird surveys. The Journal of Wildlife Management 58:506–515.

Sauer, J. R., J. E. Fallon, and R. Johnson (2003). Use of North American Breeding Bird Survey data to estimate population change for Bird Conservation Regions. The Journal of Wildlife Management 67:372–389.

Sauer, J. R., J. E. Hines, J. E. Fallon, K. L. Pardieck, D. J. Ziolkowski, Jr., and W. A. Link (2012). The North American Breeding Bird Survey, Results and Analysis 1966–2011. Version 07.03.2013. USGS Patuxent Wildlife Research Center, Laurel, MD, USA. http://www.mbr-pwrc.usgs.gov/bbs/bbs.html

Sauer, J. R., J. E. Hines, J. E. Fallon, K. L. Pardieck, D. J. Ziolkowski, Jr., and W. A. Link (2014). The North American Breeding Bird Survey, Results and Analysis 1966–2013. Version 01.30.2015. USGS Patuxent Wildlife Research Center, Laurel, MD, USA. http://www.mbr-pwrc.usgs.gov/bbs/

Sauer, J. R., W. A. Link, J. E. Fallon, K. L. Pardieck, and D. J. Ziolkowski, Jr. (2013). The North American Breeding Bird Survey 1966–2011: Summary analysis and species accounts. North American Fauna 79:1–32.

Sauer, J. R., W. A. Link, W. L. Kendall, and D. D. Dolton (2010). Comparative analysis of Mourning Dove population change in North America. The Journal of Wildlife Management 74: 1059–1069.

Sauer, J. R., D. K. Niven, J. E. Hines, D. J. Ziolkowski, Jr., K. L. Pardieck, J. E. Fallon, and W. A. Link (2017b). The North American Breeding Bird Survey, Results and Analysis 1966–2015. Version 2.07.2017. USGS Patuxent Wildlife Research Center, Laurel, MD, USA. https://www.mbr-pwrc.usgs.gov/bbs/

Sauer, J. R., K. L. Pardieck, D. J. Ziolkowski, Jr., A. C. Smith, M.-A. R. Hudson, V. Rodriguez, H. Berlanga, D. K. Niven, and W. A. Link (2017a). The first 50 years of the North American Breeding

Bird Survey. The Condor: Ornithological Applications 119: 576–593.

Sauer, J. R., B. C. Peterjohn, and W. A. Link (1994b). Observer differences in the North American Breeding Bird Survey. The Auk 111:50–62.

SCDNR (South Carolina Department of Natural Resources) (2005). Comprehensive Wildlife Conservation Strategy. South Carolina Department of Natural Resources, Columbia, SC, USA. http://dnr.sc.gov/cwcs/

Schaub, M., and F. Abadi (2011). Integrated population models: A novel analysis framework for deeper insights into population dynamics. Journal of Ornithology 152 (Suppl. 1): S227–S237.

Schmidt, P., G. Myers, and D. Pashley (1998). A Proposed Framework for Delineating Ecologically-based Planning, Implementation, and Evaluation Units for Cooperative Bird Conservation in the U.S. Commission for Environmental Cooperation, Montreal, QC, Canada. http://digitalmedia.fws.gov/cdm/ref/collection/document/id/214/

Schneider, T. M., G. Beaton, T. S. Keyes, and N. A. Klaus (Editors) (2010). The Breeding Bird Atlas of Georgia. University of Georgia, Athens, GA, USA.

Seamans, M. E. (2016a). Mourning Dove Population Status, 2016. U.S. Fish and Wildlife Service, Division of Migratory Bird Management, Washington, DC, USA. https://www.fws.gov/migratorybirds/pdf/surveys-and-data/Population-status/MourningDove/MourningDovePopulationStatus16.pdf

Seamans, M. E. (2016b). Band-tailed Pigeon Population Status, 2016. U.S. Fish and Wildlife Service, Division of Migratory Bird Management, Washington, DC, USA. https://www.fws.gov/migratorybirds/pdf/surveys-and-data/Population-status/Band-tailedPigeon/Band-tailedPigeonPopulationStatus16.pdf

Simons, T. R., M. W. Alldredge, K. H. Pollock, and J. M. Wettroth (2007). Experimental analysis of the auditory detection process on avian point counts. The Auk 124:986–999.

Smith, A. C., M.-A. R. Hudson, C. M. Downes, and C. M. Francis (2014). Estimating Breeding Bird Survey trends and annual indices for Canada: How do the new hierarchical Bayesian estimates differ from previous estimates? The Canadian Field-Naturalist 128:119–134.

Sólymos, P., S. M. Matsuoka, E. M. Bayne, S. R. Lele, P. Fontaine, S. G. Cumming, D. Stralberg, F. K. A. Schmiegelow, and S. J. Song (2013). Calibrating indices of avian density from nonstandardized survey data: Making the most of a messy situation. Methods in Ecology and Evolution 4:1047–1058.

Somershoe, S. G., D. J. Twedt, and B. Reid (2006). Combining Breeding Bird Survey and distance sampling to estimate density of migrant and breeding birds. The Condor 108:691–699.

Stem, C., R. Margoluis, N. Salafsky, and M. Brown (2005). Monitoring and evaluation in conservation: A review of trends and approaches. Conservation Biology 19:295–309.

Stephens, P. A., L. R. Mason, R. E. Green, R. D. Gregory, J. R. Sauer, J. Alison, A. Aunins, L. Brotons, S. H. Butchart, T. Campedelli, and T. Chodkiewicz (2016). Consistent response of bird populations to climate change on two continents. Science 352:84–87.

Stewart, R. L. M., K. A. Bredin, A. R. Couturier, A. G. Horn, D. Lepage, S. Makepeace, P. D. Taylor, M.-A. Villard, and R. M. Whittam (Editors) (2015). Second Atlas of Breeding Birds of the Maritime Provinces. Bird Studies Canada, Environment Canada, Natural History Society of Prince Edward Island, Nature New Brunswick, New Brunswick Department of Natural Resources, Nova Scotia Bird Society, Nova Scotia Department of Natural Resources, and Prince Edward Island Department of Agriculture and Forestry, Sackville, NB, Canada.

Stralberg, D., S. M. Matsuoka, A. Hamann, E. M. Bayne, P. Sólymos, F. K. A. Schmiegelow, X. Wang, S. G. Cumming, and S. J. Song (2015). Projecting boreal bird responses to climate change: The signal exceeds the noise. Ecological Applications 25:52–69.

Stralberg, D., S. M. Matsuoka, C. M. Handel, F. K. A. Schmiegelow, A. Hamann, and E. M. Bayne (2016). Biogeography of boreal passerine range dynamics in western North America: Past, present, and future. Ecography. doi:10.1111/ecog.02393

Sullivan, B. L., C. L. Wood, M. J. Iliff, R. E. Bonney, D. Fink, and S. Kelling (2009). eBird: A citizen-based bird observation network in the biological sciences. Biological Conservation 142:2282–2292.

Taylor, C. M., and B. J. M. Stutchbury (2016). Effects of breeding versus winter habitat loss and fragmentation on the population dynamics of a migratory songbird. Ecological Applications 26:424–437.

Tucker, G. M., M. F. Heath, L. Tomialojc, and R. F. A. Grimmett (Compilers) (1994). Birds in Europe: Their Conservation Status. BirdLife Conservation Series No. 3, BirdLife International, Cambridge, UK.

U.S. Congress (1998). Neotropical Migratory Bird Conservation Act. Calendar No. 521, 105th Congress Report, Senate 2d Session 105 284. https://www.congress.gov/congressional-report/105th-congress/senate-report/284/1

USFWS (U.S. Fish and Wildlife Service) (2004). Blueprint for the Future of Migratory Birds: Migratory Bird Program Strategic Plan 2004–2014. U.S. Fish and Wildlife Service, Migratory Birds and States Programs, Arlington, VA, USA. http://digitalmedia.fws.gov/cdm/ref/collection/document/id/1256

USFWS (U.S. Fish and Wildlife Service) (2006). Endangered and Threatened Wildlife and Plants; 12-Month Finding on a Petition to List the Cerulean Warbler (*Dendroica cerulea*) as Threatened with Critical Habitat. Notice of a 12-month petition finding. Federal Register 71:70717–70733.

USFWS (U.S. Fish and Wildlife Service) (2008). Birds of Conservation Concern 2008. U.S. Fish and Wildlife Service, Division of Migratory Bird Management, Arlington, VA, USA. https://www.fws.gov/migratorybirds/pdf/grants/BirdsofConservationConcern2008.pdf

USFWS (U.S. Fish and Wildlife Service) (2009). Eagle Permits; Take Necessary to Protect Interests in Particular Localities. Final rule. Federal Register 74:43836–46879.

USFWS (U.S. Fish and Wildlife Service) (2011). Endangered and Threatened Wildlife and Plants; Withdrawal of the Proposed Rule to List the Mountain Plover as Threatened. Proposed rule; withdrawal. Federal Register 76:27756–27799.

USFWS (U.S. Fish and Wildlife Service) (2013). Endangered and Threatened Wildlife and Plants; Determination of Endangered Status for the Taylor's Checkerspot Butterfly and Threatened Status for the Streaked Horned Lark. Final rule. Federal Register 78:61452–61503.

USFWS (U.S. Fish and Wildlife Service) (2014). Endangered and Threatened Wildlife and Plants; Determination of Threatened Status for the Western Distinct Population Segment of the

Yellow-billed Cuckoo (*Coccyzus americanus*). Final rule. Federal Register 79:59992–600338.

USFWS (U.S. Fish and Wildlife Service) (2016a). Waterfowl Population Status, 2016. U.S. Department of the Interior, Washington, DC, USA. https://www.fws.gov/migratorybirds/pdf/surveys-and-data/Population-status/Waterfowl/WaterfowlPopulationStatusReport16.pdf

USFWS (U.S. Fish and Wildlife Service) (2016b). Endangered and Threatened Wildlife and Plants; Removing the Black-capped Vireo from the Federal List of Endangered and Threatened Wildlife. Proposed rule and 12-month petition finding; request for comments. Federal Register 81:90762–90771.

USFWS (U.S. Fish and Wildlife Service) (2016c). Leveraging Funds for Effective Conservation in the Americas: The Neotropical Migratory Bird Conservation Act. U.S. Fish and Wildlife Service, Falls Church, VA, USA. https://www.fws.gov/migratorybirds/pdf/grants/neotrop-overview.pdf

USFWS (U.S. Fish and Wildlife Service) (2016d). Eagle Permits; Removal of Regulations Extending Maximum Permit Duration of Programmatic Nonpurposeful Take Permits. Final rule. Federal Register 81:8001–8004.

USFWS (U.S. Fish and Wildlife Service) and Environment Canada (1986). North American Waterfowl Management Plan: A Strategy for Cooperation. U.S. Department of the Interior, Washington, DC, USA, and Environment Canada, Canadian Wildlife Service, Canada. http://nawmp.wetlandnetwork.ca/Media/Content/files/NAWMP%20Original.pdf

USSCPP (U.S. Shorebird Conservation Plan Partnership) (2016). Shorebirds of Conservation Concern in the United States of America – 2016. http://www.shorebirdplan.org/science/assessment-conservation-status-shorebirds/

Van Wilgenburg, S. L., E. M. Beck, B. Obermayer, T. Joyce, and B. Weddle (2015). Biased representation of disturbance rates in the roadside sampling frame in boreal forests: Implications for monitoring design. Avian Conservation and Ecology 10: art.5.

Walker, J., and P. D. Taylor (2017). Using eBird data to model population change of migratory bird species. Avian Conservation and Ecology 12:art.4.

Waples, R. S., M. Nammack, J. F. Cochrane, and J. A. Hutchings (2013). A tale of two acts: Endangered species listing practices in Canada and the United States. BioScience 63: 723–734.

Wilkins, K. A., and E. G. Cooch (1999). Waterfowl Population Status, 1999. U.S. Fish and Wildlife Service, Washington, DC, USA. https://www.fws.gov/migratorybirds/pdf/surveys-and-data/Population-status/Waterfowl/WaterfowlPopulationStatusReport99.pdf

Williams, B. K. (2011). Adaptive management of natural resources—Framework and issues. Journal of Environmental Management 92:1346–1353.

Wilson, S., S. L. Ladeau, A. P. Tottrup, and P. P. Marra (2011). Range-wide effects of breeding- and nonbreeding-season climate on the abundance of a Neotropical migrant songbird. Ecology 92:1789–1798.

Zimmerman, G. S., J. R. Sauer, K. Fleming, W. A. Link, and P. R. Garrettson (2015). Combining waterfowl and Breeding Bird Survey data to estimate Wood Duck breeding population size in the Atlantic Flyway. The Journal of Wildlife Management 79:1051–1061.

Ziolkowski, D. J., Jr., K. L. Pardieck, and J. R. Sauer (2010). The 2003–2008 summary of the North American Breeding Bird Survey. Bird Populations 10:90–109.