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Special Section: Celebrating Waterfowl Conservation

The Migratory Bird Treaty and a Century of Waterfowl Conservation

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ABSTRACT In the final decades of the nineteenth century, concern was building about the status of migratory bird populations in North America. In this literature review, we describe how that concern led to a landmark conservation agreement in 1916, between the United States and Great Britain (on behalf of Canada) to conserve migratory birds shared by Canada and the United States. Drawing on published literature and our personal experience, we describe how subsequent enabling acts in both countries gave rise to efforts to better estimate population sizes and distributions, assess harvest rates and demographic impacts, design and fund landscape-level habitat conservation initiatives, and organize necessary political and regulatory processes. Executing these steps required large-scale thinking, unprecedented regional and international cooperation, ingenuity, and a commitment to scientific rigor and adaptive management. We applaud the conservation efforts begun 100 years ago with the Migratory Bird Treaty Convention. The agreement helped build the field of wildlife ecology and conservation in the twentieth century but only partially prepares us for the ecological and social challenges ahead.

KEY WORDS conservation history, habitat management, harvest management, human populations, Migratory Bird Treaty, population estimation, waterfowl management, wetlands.

Our goal in this commentary is to briefly describe the creation of the Migratory Bird Treaty and the main foundational developments in waterfowl science and conservation that followed. The treatment is not complete but rather illustrative, with a focus on places and initiatives where major conservation investments have been made. We conclude with thoughts on challenges that lie ahead.

Early European explorers to North America recognized the remarkable abundance of wildlife. As settlers pushed westward, however, the conversion of native forests, prairies, and wetlands for agricultural and industrial uses took a toll on many species. By the mid-1800s, naturalists, such as J. J. Audubon, J. Burroughs, and G. P. Marsh, were outspoken in their beliefs that wildlife, especially migratory birds, were declining rapidly and needed protection from excessive exploitation. G. B. Grinnell, editor of *Forest and Stream*, and President T. Roosevelt advocated for protection and helped generate public support. Together with the Boone and Crockett Club, they launched a campaign to end spring shooting and commercial market hunting that was supplying birds to restaurants and the millinery trade (Trefethen 1975).

Grinnell and Roosevelt understood the need for federal legislation because state wildlife laws were inconsistent and not uniformly enforced. The Lacey Act in 1900 was the first United States federal legislation passed to prohibit interstate commerce of illegally taken birds (Dorsey 1998), but the act was not sufficient because states still regulated the take of birds. Congressmen George Shiras III (PA) introduced a bill (H. R. 15601) in 1904 to place migratory birds under federal control, but the bill was strongly opposed by states' rights

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advocates and failed. In 1912, Senator G. P. McLean (PA) and Congressman J. W. Weeks (MA) sponsored broader federal migratory bird legislation that included non-game species and gained support from agricultural interests, bird watchers, and sportsmen. Finally, in 1913, following nearly a decade of lobbying by conservation leaders, the Weeks–Mclean Act was passed by Congress, signed into law by President W. H. Taft, and became known as the first Migratory Bird Act (Dorsey 1998). Lack of funding and enforcement undermined the act, however, and questions arose regarding its constitutionality. In 1914, it was successfully challenged in United States District Court (AR) on the basis that the federal government was assuming control of an international resource without a treaty.

In Canada, similar concerns regarding declines in migratory birds were being expressed by the conservation community. After passage of the Weeks–Mclean Act, Canadian conservationists saw an opportunity to work with the United States to create an international agreement. They perceived the main threat to be spring shooting, which disrupted the breeding cycle, but until America demonstrated a willingness to protect migratory birds, Canada's lone efforts were regarded as futile. An international migratory bird treaty was proposed explicitly by Senator E. Root (NY) in 1913, anticipating that the Weeks–Mclean Act would not withstand review by the United States Supreme Court. A resolution based on Root's proposal was approved by President W. Wilson in 1914, directing Secretary of State, W. J. Bryan, to begin diplomatic negotiations with Canada and Mexico (Dorsey 1998). At the time Mexico was unstable politically and declined to join the bird conservation discussions. Drafting of the treaty began in 1914 under the leadership of C. G. Hewitt of Canada and E. W. Nelson of the United States, but its completion was delayed until 1916 by the outbreak of World War I. Diplomatic negotiations between the 2 countries proved to be less contentious than the struggles within each country. The Convention for Migratory Birds or the Migratory Bird Treaty (MBT) was signed by President Wilson for the United States and by King George V of Great Britain for Canada, with formal ratifications exchanged on 7 December 1916 (Dorsey 1998).

Canada quickly passed the Migratory Bird Convention Act (MBCA) in 1917, but the United States Congress struggled for 2 years before passing enabling legislation, the Migratory Bird Treaty Act (MBTA), in 1918. The constitutionality of both laws was soon challenged. In Canada, provinces questioned MBCA jurisdiction over previous wildlife policy, but the Supreme Court of Canada refused to hear the case of *The King v Russell C. Clark* and upheld federal protection. In the United States, a legal challenge in *Missouri v Holland* (case 252 U.S. 416) was based on states' rights, but the United States Supreme Court upheld the constitutionality of the MBTA, ruling that wild birds that traverse large areas are not in the possession of anyone. Thus a 30-year struggle by dedicated individuals, influential organizations, and skilled politicians seeking federal protection of migratory birds succeeded, and the first broadly effective wildlife conservation treaty in North America was in place (Dorsey 1998). The MBCA and MBTA prohibited take or possession of all listed migratory birds unless specifically allowed by regulations or permits. Hunting of designated game species was limited to specified open seasons between 1 September and 10 March after due consideration of population status and other criteria.

Conservationists built upon the MBT to broaden bird protection with other international agreements (Bean and Rowland 1997). In 1936, a treaty was negotiated to protect birds that migrated between the United States and Mexico. In 1972, a treaty was signed between the United States and Japan, protecting additional migratory bird species and covering other subjects such as habitat enhancement, sharing research data, and regulation of hunting. A treaty with the Soviet Union was concluded in 1976 to protect birds along common flyways. In 1997, the United States and Canada amended their original 1916 MBT to allow managed aboriginal hunting of migratory birds in certain areas of Alaska and Canada. This enabled traditional harvesting to occur legally in spring and summer during the closed-season period of the MBT. In 2004, President G. W. Bush signed the Reform Act to amend the MBTA to distinguish between protected native species and non-native or human-introduced species, which are not protected (U.S. Department of the Interior 2013).

The most enduring legal legacy of the 1916 MBT is recognition that migratory birds are held in public trust throughout North America and oversight responsibilities fall to the federal governments. Environmentalists and government agencies continue to use the MBCA and MBTA as bases for conservation actions (Dorsey 1998). Importantly, the MBT also precipitated the development of scientific foundations for management.

FOUNDATIONS FOR WATERFOWL MANAGEMENT

Concerns about the vulnerability of waterfowl stocks (Phillips and Lincoln 1930) were amplified in the 1930s as extended drought affected key breeding areas and waterfowl numbers declined. A. Leopold among others (Hawkins et al. 1984) recognized that research and information-gathering were needed to design successful wildlife management policies.

Estimating Waterfowl Population Size and Distribution

One of the earliest and most enduring developments in waterfowl research was the North American Bird Banding Program. Begun in the 1920s with an emphasis on determining species' distributions and migration patterns (Crissey 1955), the banding effort quickly grew in scope. This required a central system for standardizing and storing information, such as the time and place of marking and recoveries, a service currently provided by the United States Geological Survey's Bird Banding Laboratory. As of May 2017, >19.4 million ducks, geese, and swans have been banded and added to this valuable database (U.S. Geological Survey 2017). An important early result from banding was recognition that most populations travel roughly north-south through their annual cycle, providing a biological basis for coordinated management among political jurisdictions.

In 1935, F. Lincoln, a biologist with the Bureau of Biological Survey, conducted the first mid-winter inventory of waterfowl using aircraft (Hawkins et al. 1984). From 1935 through the late-1940s, the mid-winter survey was the primary source of information upon which hunting regulations and other policies requiring population status information were established. From 1946 into the early 1950s, crews from the United States and Canada tested the feasibility of a comprehensive aerial breeding ground survey for waterfowl across the north-central United States and southern prairie Canada. This survey, known as the Waterfowl Breeding Population and Habitat Survey, became operational in 1955 and currently covers >5.18 million km^2 of habitat, including since 1990, vast areas of eastern North America (Blohm et al. 2006*b*). Since 1986, data from this survey also have been used to establish and monitor progress towards population objectives under the North American Waterfowl Management Plan (Canada Ministry of the Environment et al. 2014).

Besides being a seminal figure in waterfowl banding and survey design, Lincoln (1930) first recognized the potential of using banding data for population estimation. Lincoln (1930) proposed that the size of waterfowl populations (N) could be estimated if the fraction of the population that was harvested (h) was known as well as the total harvest (H). Lincoln's straightforward estimator for abundance ($\hat{N} = H/h$) was developed explicitly for continental waterfowl populations, and combined with C. G. J. Petersen's work (Le Cren 1965) became the basis for a wide body of work on estimation of population size for many animals (Pollock et al. 1990).

The size and composition of the annual harvest was of early interest to managers. A United States waterfowl hunter activity and harvest survey was implemented in 1952 based on a questionnaire mailed to a sample of federal duck stamp purchasers. Beginning in 1961, some hunters were asked to provide waterfowl wings or other feathers to enable estimation of species, sex, and age composition of the annual harvest. Canada initiated a similar national harvest survey in 1967. In Alaska, a separate survey for subsistence hunter harvests has been conducted since 1985 (Padding et al. 2006). A new harvest survey, the Harvest Information Program (HIP), has been in place in the United States since 1998, designed to provide a more reliable estimate of the harvest of migratory birds (Padding et al. 2006).

Estimating Harvest Rates and Survival Rates

Before concepts about additive and compensatory mortality were formulated (Anderson and Burnham 1976), the predominant view was that waterfowl harvest likely had a strong effect on subsequent population size. The use of individually banded birds became a critical tool for helping to address the potential impacts of harvest on survival and population change. Building on Lincoln's (1930) insights, Hickey (1952) recognized that the temporal distribution of band recoveries contained information about annual survival rates. Subsequently, band recovery data became useful for understanding waterfowl population dynamics (Martin et al. 1978). The method that Brownie et al. (1978, 1985) formalized became the standard for analysis of band recoveries in North America for numerous species (Rice et al. 2010), although the alternative parameterization by Seber (1970) is also useful. The proportion of banded birds recovered within a year of being marked can estimate harvest rate if the proportion of bands recovered by hunters that are also reported can be estimated using reward bands (Bellrose 1955, Nichols et al. 1995*b*). A review by Nichols (2004) of the development of quantitative methods for the study of populations illustrated how studies of waterfowl populations (Anderson 1975, Brownie et al. 1978) contributed importantly to the evolution of methods for estimation of population parameters in ecology broadly.

The ability to estimate both harvest and survival made it possible to explore the extent to which harvest mortality is additive to other sources of mortality (Anderson and Burnham 1976). In general, evidence suggests that, except at very low harvest rates (<1%), harvest is largely additive in geese (Rexstad 1992, Gauthier et al. 2001, Sedinger et al. 2007, Alisauskas et al. 2011), whereas the situation is less clear in ducks (Rice et al. 2010, Péron et al. 2012, Nichols et al. 2015, Arnold et al. 2016).

Band recovery rates, adjusted for hunter reporting rates, also have been used recently with Lincoln estimators and suggest that waterfowl populations are substantially larger than inferred from traditional aerial surveys (Otis 2006; Alisauskas et al. 2011, 2014). The Lincoln estimator also has the potential to estimate abundance of each age and sex class separately, thereby providing an estimate of late summer sex and age ratios (Munro and Kimball 1982), which may have implications for harvest management.

Lincoln's estimator of abundance requires information about total harvest from the population, for which operational estimation did not begin until 1961 in the United States and 1967 in Canada. In the absence of that information, the May aerial survey became, and remains, the primary method of estimating abundance and trends of duck numbers for management purposes. Although application of Lincoln's estimator suggests that aerial surveys may underestimate abundance, uncertainty exists about the magnitude of the underestimate because of potential bias in the estimate of harvest (Padding and Royle 2012).

Any bias in estimates of abundance has implications for harvest management. For example, concepts about sustainable harvest and yield curves rely on valid estimates of breeding population size and carrying capacity (Runge et al. 2006). As another example, Alisauskas et al. (2011) demonstrated that the size of the midcontinent lesser snow goose (*Anser caerulescens caerulescens*) population had been substantially underestimated, which provided a possible explanation for the lack of effectiveness of harvest as a tool to reduce population size. Use of Lincoln's estimator for monitoring abundance offers a complementary approach to existing surveys, or an alternative where counts may not be feasible (e.g., wood ducks [*Aix sponsa*]; Bowers and Martin 1975). Further comparisons of Lincoln's method with aerial count data for inferences about waterfowl population dynamics seem desirable and may influence future conservation activities.

A significant development in the setting of United States regulations for waterfowl harvest was implementation of Adaptive Harvest Management (AHM; U.S. Fish and Wildlife Service [USFWS] 2016*a*) in 1995. The goal was to provide objective prescriptions for mallard (*Anas platyrhynchos*) harvest regulations while acknowledging multiple sources of uncertainty pertinent to inferences about a population under exploitation (Williams and Johnson 1995). Uncertainty exists from environmental variation in habitat, ability to affect harvest, ability to estimate population attributes, and the structure of biological processes that influence population change (Nichols et al. 1995*a*). Thus, an additional goal of AHM is to reduce these uncertainties through an iterative annual cycle that starts with monitoring, whereby estimated population size is compared to that predicted from 4 competing models (contrasting compensatory vs. additive mortality, and strong vs. weak density dependence in reproduction) built from prior information. Weights are assigned to each model depending on the differences between predicted and estimated population size. Optimization then determines the selection of hunting regulations for the next season, and the cycle begins anew with an estimate of spring population size the following year. The evolution of model weights from 1995 to 2014 appears to favor additive mortality with weak density dependence in reproduction for mid-continent mallards (Cooch et al. 2014, Nichols et al. 2015). There has also been a tendency for predicted populations to be below that observed, regardless of model type. Imprecise ability to affect harvest rates has also emerged as a larger factor than anticipated at the onset of AHM (Johnson et al. 2015). Other developing concerns include the simplicity of the original recruitment models and new thoughts about fundamental objectives. These have motivated agencies to undertake a double-loop planning process (USFWS 2016*a*) whereby objectives, model structures, and other adjustments are being considered for revision, given what has been learned from the initial iterative phase. Adaptive Harvest Management remains an example of linking research and management in a structured way (Roberts et al. 2018) consistent with the earliest charge of the MBT (section 704) requiring that "due regard" be given to bird abundance and distribution before authorizing hunting seasons.

New technology and modeling approaches may further improve our understanding of waterfowl population dynamics (Blohm et al. 2006*a*). Innovative approaches to studying the relationship between harvest rate and survival rate have appeared recently (Sedinger et al. 2010, Péron et al. 2012, Arnold et al. 2016). Combining banding and capture-mark-recapture analyses with new technologies (e.g., geolocators) and stable isotope studies (Clark et al. 2006) may improve our understanding of the effects of habitat conditions or large-scale conservation actions on waterfowl populations (Sedinger and Alisauskas 2014), as may the use of integrated population models (Arnold et al. 2018).

Creating Management Policies for Multiple Jurisdictions

The Flyway System.—In 1935, F. Lincoln presented a flyway management concept based on band recovery data that revealed north-south travel corridors used by waterfowl populations, thus linking breeding, migration, and wintering habitats (Lincoln 1935, 1939; Hawkins et al. 1984). In 1947, a flyway management system was adopted by the USFWS for administrative purposes (Blohm 1989). Coordinating bodies, known as Flyway Councils, were comprised of states and provinces in each flyway. The councils worked with federal agencies to help develop the annual framework for regulating harvests of migratory game birds. With input from flyway members and the public, regulatory frameworks are now developed by the USFWS regulations committee and forwarded for approval to the Secretary of the Interior. In Canada parallel actions are taken by the Canadian Wildlife Service (CWS) regulations committee for approval by the Minister of Environment and Climate Change.

The North American Waterfowl Management Plan.—The catalyst for much of the wetland habitat conservation work in North America for more than 30 years has been the North American Waterfowl Management Plan (NAWMP), a strategy for cooperation signed by Canada's Minister of the Environment and the United States Secretary of the Interior in 1986 (U.S. Department of the Interior and Environment Canada 1986). Mexico joined the pact in 1994. The Plan offered a vision for continental-scale conservation of waterfowl habitats based on assessments of biological needs, human desires for hunting and other recreational use, and a principle of shared responsibility for the stewardship of waterfowl and their habitats. It called for an unprecedented habitat conservation effort to be led by Joint Ventures (JVs). The idea was to foster voluntary regional partnerships of government and private interests galvanized by a desire to help achieve the common continental goals of the NAWMP (Williams and Castelli 2012).

The strategy of pooling resources for common regional priorities proved effective; habitat JVs presently span most of the continent (USFWS 2014) and several affiliated science groups have arisen focused on species of special concern. The JVs vary considerably in organization, range of partners represented, sources of funds, focus, and progress towards objectives (Paulin et al. 2007). Most have morphed into JVs for all migratory birds, although the core of the work in most JVs remains waterfowl habitat because waterfowl advocates still provide the majority of funds, science support, and infrastructure.

The NAWMP has been successful in part because it continues to evolve. In 2012, a comprehensive revision re-examined for the first time the NAWMP's fundamental goals (Canada Ministry of the Environment et al. 2012). Recognizing many social and ecological changes since the 1980s, planners considered what issues were most germane to sustaining waterfowl conservation, and a consensus emerged about 3 interrelated goals: waterfowl populations sufficient to sustain human use, habitats sufficient to support those populations and other human needs, and growing engagement and support for conservation from people. Progress toward these multiple goals has been challenging but promising (Humburg et al. 2018).

DEVELOPING HABITAT CONSERVATION

Public Funding for Conserving Waterfowl Habitat

Following the MBT, 3 developments during the 1930s proved to be of particular long-term value for waterfowl habitat conservation: creation of duck stamps used to fund habitat conservation projects and expansion of the United States National Wildlife Refuge system, emergence of non-government organizations (NGOs) dedicated to waterfowl conservation, and growth of habitat-related research.

One hundred years ago, few public lands were managed for waterbirds. The first migratory bird sanctuary on the continent was established by Canada at Last Mountain Lake, Saskatchewan in 1887. The first United States refuge, Pelican Island National Wildlife Refuge, was established in 1903 to protect habitat for colonial waterbirds. In the western United States, Klamath Lake Reservation was protected by Executive Order in 1908. Gradually, other lands were added across the United States by state and federal entities through Executive Order, purchase, or other agreements. The Migratory Bird Conservation Act of 1929 authorized the establishment of a system of migratory bird refuges, easements, and fee title conservation areas. Biologists (e.g., F. Uhler, C. Sperry, N. Hotchkiss) of the Bureau of Biological Survey traveled the United States looking for key waterfowl areas for possible acquisition (Perry 1984). A few years later, the appropriation of $8.5 million in emergency funds, along with enactment of the United States Federal Migratory Bird Hunting and Conservation Stamp (duck stamp) in 1934, provided support to boost the acquisition of waterfowl habitat. The first duck stamp sold for $1 and served as a federal permit to hunt waterfowl. In 1984, Canada's national Migratory Bird Hunting Permit was initiated as a mechanism for funding Wildlife Habitat Canada. Today, United States public lands include 560 federal refuges covering 61 million ha and state lands and other land protection programs within the United States Department of Agriculture. A substantial addition to the refuge system occurred in 1980 with passage of the Alaska National Interests Lands Conservation Act (Digest of Federal Resource Laws of Interest to the USFWS 1988). Following the 1971 settlement of Alaska native claims, and developed over 3 administrations and 5 sessions of Congress, this act designated nearly 4 million ha to the National Wildlife Refuge System, and even more land to National Parks, National Recreation Areas, and National Forests (Digest of Federal Resource Laws of Interest to the USFWS 1988). Between 1934–2015, sales of United States federal duck stamps alone generated more than $866 million, which was used to purchase or lease >2.4 million ha of wetland habitat in the United States (USFWS 2016*c*), including the protection of some 7,000 Waterfowl Production Areas (>273,000 ha) in the Prairie Pothole Region. In recent years, annual revenue from United States and Canadian federal stamps has averaged about $24 million (Wildlife Habitat Canada 2014, USFWS 2016*c*).

Beginning with California (1971) and Iowa (1973), individual states issued their own stamps as a fund-raising mechanism and an additional requirement for waterfowl hunters. By the 1990s, all 50 states were participating (Scott Publishing Company 2012). Funds from state stamps are used mostly for conservation within state boundaries or to match federal contributions under the North American Wetlands Conservation Act (see below) for transfer to projects on breeding grounds in Canada.

An important complementary program, the Federal Aid in Wildlife Restoration Act, also known as the Pittman-Robertson Act, was signed into United States law in 1937. It imposed a 10–11% excise tax on sporting arms, ammunition, and other hunting gear that is collected by the federal government and made available to cooperating states on a cost-shared basis (Digest of Federal Resource Laws of Interest to the USFWS 2013).

The single largest source of federal funds for habitat work since 1989 has been grants by the United States Congress under the North American Wetlands Conservation Act (NAWCA). Created mainly as a means to fund NAWMP, the program was broadened in 2002 to help support conservation of all wetland-dependent migratory birds. Sources of funding for the NAWCA include interest generated when Pittman-Robertson funds are held in trust temporarily by the federal government, fines levied under the MBTA, and annual appropriations. The NAWCA mandated that a substantial portion of the funds be directed outside the United States for migratory bird habitat needs in Canada and Mexico, enhancing the geographic reach and effectiveness of NAWCA investments. The NAWCA also required that every dollar of federal funding be matched by at least another dollar of non-federal United States funds. That leverage provision became an incentive for states and NGOs to find matching funds for every proposed project. Furthermore, for funds transferred to Canada, NAWCA established an expectation of additional match from Canadian sources. Through March 2014, approximately $1.3 billion United States federal dollars engaged more than 5,000 partners in 2,421 projects and leveraged $2.7 billion in non-federal matching funds, affecting 11.1 million ha of habitat accomplishments (USFWS 2015). For funds granted to NAWCA projects in Canada, totalling $1.93 billion in 1990–2012, Canadian partners matched United States revenues essentially 1:1 (North American Waterfowl Management Plan [Canada] 2016). Although a wide array of partners have provided match funds for NAWCA projects, the most common sources are state governments, mainly through fees charged to waterfowl hunters, and NGOs such as Ducks Unlimited and others.

Emergence of NGOs Dedicated to Waterfowl Conservation

Around the time of the MBT, a growing private constituent base also was advocating for sustainable use of wildlife (Mahoney and Jackson 2013). Such interests combined with the drought of the 1930s and associated declines in waterfowl numbers, stimulated private-sector actions for waterfowl in Canada (Tennyson and Leitch 1977, Leitch 1978). A group of American businessmen sponsored reconnaissance trips to waterfowl breeding grounds, published their findings, and ultimately launched a new private conservation organization, Ducks Unlimited, which was incorporated in the United States (1937) and Canada (1938). By 2013, those organizations had conserved nearly 2.6 million ha and delivered 9,400 conservation projects in Canada, nearly 2 million ha in the United States, and 770,000 ha of habitat protection in Mexico (Anderson and Padding 2015). Several state hunter-based NGOs and individual landowners have made additional substantive contributions to habitat conservation (Anderson and Padding 2015).

RESEARCH TO INFORM CONSERVATION ACTIONS

Waterfowl biologists have contributed to the now commonplace idea of strongly linking research and management (Williams and Castelli 2012, Roberts et al. 2018). We offer 4 diverse examples of how research programs supported by international cooperation subsequent to the MBT informed conservation actions.

Wetland Management

Although the general characteristics of most waterfowl species were described before the twentieth century, information regarding life-cycle events and their relationship to ecological processes took longer to develop. Thus, early in the twentieth century, managers had little understanding of the locations of important habitats, and the ecological and abiotic factors affecting wetland productivity, and little or no training in wetland management. Growth of the United States refuge system during the 1930s coincided with the creation of the Civilian Conservation Corps (CCC). The expertise of engineers and laborers in the CCC program was well-suited to building physical infrastructure to capture water, but sometimes these modifications inadvertently compromised natural processes and the sustainability of altered habitats. At this same time, most biologists with an interest in waterfowl held positions in the Biological Survey, then a division of the United States Department of Agriculture, and their research was largely on diseases and food habits. Eventually, government program leaders like D. Darling and I. Gabrielson recognized the need for research dealing directly with habitat, and in 1936, the Patuxent Research Refuge developed out of their vision (Perry 2001). Scientists stationed at Patuxent (e.g., F. McGilvrey, F. Uhler, C. Webster) initiated studies on impoundment management, nest-box construction, green-tree reservoirs, and moist-soil management in hopes of improving waterfowl populations. In time, information helpful to managers was generated by federal research centers, state wildlife research programs, Cooperative Fish and Wildlife Research Units, and a growing academic community with interests in wildlife management. The Delta Waterfowl Research Station in Manitoba, the Illinois Natural History Survey, and other NGOs also added key findings.

Biologists at Patuxent in the 1960s, in combination with scientists in academia, contributed to a developing understanding of physiology, energetics, and avian biology in general. Of particular influence was new thinking about avian energetics (Paynter 1974, Carey 1996) that began to link life-history needs with wetland dynamics and underlying abiotic conditions. Field researchers began to map the distribution and dynamics of submersed aquatic vegetation in major waterfowl wintering areas such as Chesapeake Bay, Maryland, USA (Stewart 1962, Perry and Deller 1995) and Currituck Sound, North Carolina, USA (Perry and Uhler 1982). Other research revealed the importance of invertebrates in the diets of several waterfowl species (Swanson and Bartonek 1970, Perry and Uhler 1988), thus broadening management objectives in wetland ecosystems.

Wetland managers, however, needed biological insights about many waterbird species over a broad geographic range, and confronted rapidly changing land use. Little process research in wetlands was conducted before the 1970s, and a host of abiotic conditions such as soils, ground water, and biogeochemical conditions that affect wetland productivity were little studied until late in the twentieth century (Good et al. 1978, Saucier 1994, Murkin et al. 2000). Research gradually helped move wetland management from focusing on single species, single wetlands, and simple life-history requirements to an integrated view of wetland functions influenced by abiotic conditions, watershed features, plant and animal life cycles, and bioenergetics. This fundamental change in land management thinking hopefully positions today's management teams to provide more useful advice in changing climates and landscapes.

For habitat management on non-breeding areas where waterfowl tend to occur at high densities, an important development has been bioenergetics modeling of waterfowl needs and the productive capacity of various habitats (Williams et al. 2014). Based on assumptions that waterfowl during the non-breeding period are limited mainly by food availability, this growing body of work has enabled objective linkage between regional population objectives and habitat conservation planning, and is now central to NAWMP JV management (Paulin et al. 2007).

Other notable research on non-breeding waterfowl and their habitats, beginning in the 1970s, included studies of canvasback (*Aythya valisineria*) migration on the Mississippi River (Serie et al. 1983), wintering canvasbacks on Chesapeake Bay (Haramis et al. 1986, Perry and Uhler 1988), mid-continent and Pacific Flyway Canada geese (*Branta canadensis*; Raveling 1979), mallards in the Mississippi Alluvial Valley (Reinecke et al. 1987, Heitmeyer 1988), and northern pintails (*Anas acuta*) in California (Miller 1986, Miller and Newton 1999, Fleskes et al. 2007) and the Gulf Coast (Cox et al. 1998, Ballard et al. 2004).

Among the important contributions of this work were hypotheses about cross-seasonal effects of body condition on demographic processes (Heitmeyer and Fredrickson 1981, Sedinger and Alisauskas 2014). Connecting annual life-cycle events has also been aided by development of satellite telemetry, which has helped elucidate migratory movements and habitat connections of several seaduck species (Perry et al. 2006, de la Cruz et al. 2009), northern pintails (Miller et al. 2005), and mallards (Krementz et al. 2012). Collectively, this body of research has begun to facilitate large-scale modelling of waterfowl population processes and habitat selection, with the potential to inform multiple management decisions (Osnas et al. 2014).

Lead Poisoning and the Advent of Non-Toxic Shot

Poisoning from ingesting lead shotgun pellets was formerly a major mortality factor for several species of waterfowl. It took decades for this to be fully appreciated, however, because unlike in major epizootics, affected birds did not die synchronously en masse. F. Bellrose from the Illinois Natural History Survey was the first researcher to forcefully alert managers to the seriousness of the problem (Bellrose 1959). Factors such as feeding habits, substrate firmness, water depth, and shooting pressure affected the risk of ingestion. Birds that prey on or scavenge ducks can be sickened too. Attempts to bury lead shot with tillage operations showed mixed results (Fredrickson et al. 1977, Peters 1992). Despite strong initial opposition to steel or other non-toxic shot (USFWS 1976), research on the efficacy of alternative shot (Sanderson and Bellrose 1986) enabled the development of reasonable substitutes, and in 1991 lead shot was banned for waterfowl hunting nationwide in the United States. Although evidence of lead-poisoned birds in Canada was limited, a parallel ban there followed in 1999 (Environment and Climate Change Canada 2017). Follow-up studies (Anderson et al. 2000) demonstrated substantial reductions in lead pellet ingestion in the Mississippi Flyway, although exposure risk remained, especially for bottom-feeding species (Hohman et al. 1990, Havera et al. 1992).

The Unexpected Challenge of Over-Abundant Arctic Geese

Scientists studying breeding snow geese in the arctic and subarctic began to notice apparent deterioration in the quality of goose habitat near expanding breeding colonies (Cooch et al. 1989, 1991; Cooke et al. 1995; Ankney 1996). A task force assembled to examine the issue concluded that lesser and greater snow geese (*Anser caerulescens atlanticus*) increased in numbers to the point that they were damaging their habitat and the habitat of many associated species (Batt 1997, 1998). Exhaustive consultations with the USFWS, CWS, and the Flyway Councils, exploring options for population reduction, eventually resulted in 2008 in a special conservation order to allow the take of these geese outside the normal season envelope provided by the MBT (U.S. Code of Federal Regulations 2008). This was done to engage hunters to help manage burgeoning numbers of geese. The hope was that hunting with fewer restrictions on methods of take and closed seasons would result in a reduction in population size. Although harvest increased substantially, so far it has been insufficient to create a negative growth rate in lesser snow goose populations (Alisauskas et al. 2011) or to reverse habitat degradation (Leafloor et al. 2012).

These population management efforts were possible only because long-term demographic research on northern geese enabled researchers and managers to agree on the extent of the problem and to model possible solutions. In general, these long-term studies of breeding geese have resulted in deeper insights about demographic processes and sources of variation in vital rates than for any other species of waterfowl. Particularly productive programs have focused on black brant (*Branta bernicla*) and cackling geese (*B. hutchinsii*) on the Yukon-Kuskokwim Delta (Lindberg et al. 1998, 2013; Sedinger et al. 2008, 2011, 2016); lesser snow goose colonies at La Pérouse Bay (Cooch et al. 1989, 1991, 2001; Cooke et al. 1995); lesser snow geese and cackling geese at McConnell River (MacInnes et al. 1974, Ankney and MacInnes 1978, Prevett and MacInnes 1980); Ross's (*Anser rossii*), lesser snow, and white-fronted geese (*Anser albifrons*) at Queen Maud Gulf (Alisauskas et al. 2006*a*, *b*; Wilson et al. 2016; Ross et al. 2017); greater snow geese on Bylot Island (Reed and Plante 1997, Menu et al. 2002, Bêty et al. 2003); lesser snow geese, cackling geese, and Atlantic brant on Southampton Island (Abraham and Ankney 1986, Nissley 2016, Nissley et al. 2016); Canada geese (*B. canadensis*) on Akimiski Island (Leafloor et al. 1998) and the Hudson Bay Lowlands (Sheaffer et al. 2004); and several other populations in Eurasia. Despite the remoteness of these colonies, the presence of philopatric geese breeding in high densities has allowed successful long-term marked-bird studies that have been very difficult to accomplish with more dispersed breeding ducks.

Changing Paradigms for Prairie Habitat Conservation

Habitat management for mid-continent breeding ducks provides a particularly instructive case study of scientific investments and shifting management paradigms. On 2 occasions over the past 75 years, the direction of prairie duck conservation changed markedly spurred by scientific discoveries, public policy changes, natural events, and new technologies.

Paradigm 1: We need to drought proof the prairies to secure the future for ducks.—The first efforts to conserve prairie ducks were focused almost completely on securing wetlands that had been altered dramatically by severe drought during the late 1920s–1930s. Waterfowl conservation leaders concluded that wetland loss due to drought had caused many waterfowl populations to decline to unprecedented low levels. Protecting existing wetlands and restoring those that had been drained or degraded by drought or by human development became the primary focus of these first initiatives.

The main approach on the prairies in the United States was to secure wetlands through the federal Duck Stamp Act. Ducks Unlimited initiated extensive wetland restoration work in Canada in 1938 and in the United States in 1984

(Batt 2012, Furtman 2012). Many of the restorations focused on large marshes that were used by birds during the spring, summer, and fall, which were perceived to be of greatest biological significance and thus would yield the greatest return on investment.

While this work was under way, the scientific study of breeding waterfowl and wetland ecology, and the technical training of biologists expanded greatly providing new insights for waterfowl managers. Among the key developments were the founding of the private Delta Waterfowl Research Station in Manitoba in 1938 led by H. A. Hochbaum, the USFWS Northern Prairie Wildlife Research Center in North Dakota in 1965 with Director H. K. Nelson, and the CWS Prairie and Northern Wildlife Research Centre in Saskatchewan in 1966 with waterfowl researchers including B. J. Gollop, A. Dzubin, and L. Sugden. Other federal, state, and provincial agencies also became engaged in waterfowl management, wetland conservation, and development of related public policies.

Paradigm 2: Intensive management of wetlands and uplands is necessary to restore duck populations.—The waterfowl conservation community was shaken when, during 1979–1985, continental duck populations declined by 33% and it became evident that decades of wetland restoration and protection efforts had been insufficient to prevent this downturn. Moreover, the destruction of upland and wetland habitats was accelerating in the United States and Canada (Greenwood et al. 1987). At the same time, new technologies to assess the breeding performance of individual birds (e.g., radio-telemetry) and new methods to estimate nest and female survival rates (the Mayfield method; Johnson 1979) were implemented. The findings were alarming; upland-nesting ducks were experiencing low nest success and high female mortality rates across the prairies. New population models predicted negative growth rates (Cowardin et al. 1985) and some biologists were concerned that populations would not recover even when better water conditions returned. The consensus in the waterfowl management community was to shift resources to intensively manage habitat to improve duck recruitment, particularly nest success. This marked a major paradigm shift for prairie duck management.

Initial research suggested that hatch rates and female survival rates could be increased through intensive management of mammalian predators that were destroying nests or killing nesting females (Sargeant et al. 1993). Practices included the creation of secure nesting sites within fences, on constructed islands, with nesting structures, and by trapping predators. Land-use studies provided guidance on the use of prescribed fire (Higgins et al. 1988), livestock grazing (Barker et al. 1990), forage management (Higgins et al. 1992), and the development of guidelines (Duebbert et al. 1981, Morgan et al. 1995) for plant species selection and establishment practices that could be used on managed nesting plots or across larger geographic areas (e.g., the U.S. Department of Agriculture Conservation Reserve Program). Partner agencies used model-based planning to geographically target these management practices, and both of the prairie habitat JVs incorporated certain of these techniques in their implementation plans. While these planning exercises were underway, however, a geographically widespread multi-year increase in precipitation contributed to upending this second paradigm for prairie duck management while it was still gaining momentum.

Paradigm 3: Conserve habitat to set the table so birds can rebound during wet periods.—During 1990–1997, moisture conditions improved dramatically on prairie breeding areas (USFWS 2016*b*) and prairie duck populations increased 72%. The conservation community interpreted this unexpected result as evidence that duck populations could still achieve NAWMP goals when moisture conditions were favorable, provided that the existing wetland and upland habitat base remained intact. At about the same time, evaluations to determine the efficacy of intensive management techniques were revealing mixed results; some showed promise, whereas others failed to increase duck recruitment (Lokemoen and Woodward 1993, Howerter et al. 1996). Moreover, the initial costs for installation of structures like predator-proof fences, and the recurring expenses for operation and maintenance were causing concern. Research also showed that the wetland and upland habitats that enabled the rebound were being lost at an accelerating rate. This precipitated discussions about the need to prioritize perpetual habitat protection to secure existing habitat. Program objectives, now addressing entire landscapes, shifted from intensive management to securing the best of the best habitat in perpetuity (Prairie Pothole Joint Venture 2005, Prairie Habitat Joint Venture 2014).

In the United States, a stratified sample of 10.36-km^2 plots was used to develop spatial models that predicted duck breeding densities based on wetland characteristics contained within the National Wetlands Inventory database (Reynolds et al. 2006). A similar spatial planning tool was developed for prairie Canada using remotely sensed wetland data, information on duck abundance derived from the May surveys, and a data-based recruitment model (Prairie Habitat Joint Venture 2014). This approach targeted habitat protection and other management actions to landscapes that had the highest densities of breeding ducks. Later, land cover information and risk-of-conversion models were added to further refine the selection of landscapes.

Perpetual protection of wetlands and grasslands was achieved through fee acquisition, land donation, and purchased or donated easements. New public policies in the United States and Canada made easements one of the most cost-effective tools. Sparse federal, state, and provincial laws (e.g., Clean Water Act in the U.S.) helped maintain the wetland habitat base, and agricultural policies and programs emerged that complemented those developed by the waterfowl community. In the United States, the Conservation Reserve Program was particularly important for providing restoration and protection of habitats (Reynolds et al. 2006).

Today's approaches involve many partners and attempt to work closely with the agricultural community to focus on long-term conservation of the best habitats. Wetland restoration and intensive management practices are still elements of prairie duck conservation, but emphasis is now placed on the restoration of complexes of small wetlands, and the list of intensive management practices has been reduced to a few cost-effective techniques with proven efficacy. In the United States and Canada, curtailing wetland drainage through public policy initiatives remains a critically high priority.

Looking ahead, unexpected results, natural events, new land-use policies, or agricultural changes may motivate further paradigm shifts. For example, after decades of wetland and grassland loss in the region, and the abrupt loss recently of millions of hectares of nesting habitat provided by the United States Conservation Reserve Program, the annual May survey estimates that prairie duck populations are as large as they have been since 1955. This seems counterintuitive. Do the surveys adequately monitor populations in today's changed landscapes? Further, our predictive models and conservation programs are based on the premise that prairie moisture conditions and temperature regimes vary around a stable mean value. How might our management need to change if climate change imposes a directional shift in moisture and temperature regimes? A willingness to consider these and other questions, and if warranted to alter management approaches yet again, will be critical to the continuing conservation of prairie ducks.

CHALLENGES FOR A SECOND CENTURY UNDER THE MBT

Waterfowl conservation in North America has a long history of accomplishments, but much about the world has changed since 1916. Most notably, the current human population of 7.4 billion (Oct 2016) compares to <2 billion when the MBT was established (United Nations 2015). Remarkably, human numbers have increased by about 40% just since the NAWMP was signed in 1986. Global demand for food, fiber, and biofuels already affects the availability of land for conservation (Trauger et al. 2003), and more people will bring even greater challenges of agricultural expansion and intensification, expanded energy extraction, and water depletion and degradation (Brown 2009). The Global Footprint Network (World Wildlife Fund 2016) estimates that humans presently consume on an annual basis the regenerative capacity of approximately 1.6 earths. Such ecological overshoot is possible, temporarily, only by depleting natural capital, overharvesting renewable resources, causing unsustainable ecological damage, and overloading the environment with waste products. Ecological changes, including climate disruption, are affecting wetland ecosystems and avian biology. Continuing urbanization and social change are creating citizens who are disconnected from the outdoors (Louv 2008, U.S. Department of the Interior et al. 2011), which may weaken the motivation to preserve wildlife and wild places, or cause the public to undervalue goods and services provided by healthy ecosystems. These global issues may matter greatly for sustaining the habitats and the social cohesion on which twenty-first century waterfowl conservation will depend.

For instance, global climate change has begun to affect many ecosystems vital for people and waterfowl (Intergovernmental Panel on Climate Change [IPCC] 2014). Sea-level rise with accompanying loss of coastal wetlands is one example. Although estimates of sea-level rise vary greatly with different assumptions about the rate of glacial melting, there is high confidence that it will continue for centuries (IPCC 2014). Precipitation patterns are changing as sea and land temperatures rise, affecting in variable ways the agricultural potential of much of the planet, freshwater availability, and very likely the abundance and hydroperiod of wetlands. Yet another impending challenge for wildlife managers is that most of our population models are based on assumptions of long-term equilibrium in ecological factors affecting demographic properties. But if the burgeoning demands of human populations and emerging effects such as climate change result in non-stationarity of average conditions, significantly greater uncertainty about system dynamics will prevail (Williams and Jackson 2007, Williams and Brown 2013).

Moving Ahead

As we celebrate the MBT, our responsibility is to ensure that this legacy continues by managing migratory birds and their habitats wisely for future generations. Waterfowl conservationists have overcome many obstacles and achieved important progress in science and management during the last century. With creativity and determination they forged a legacy of wildlife regulation, research, and conservation, and their impact has been continental in scope. Management approaches have evolved repeatedly in response to new circumstances and scientific progress. Most waterfowl populations have shown remarkable resilience (USFWS 2016*b*) and our stakeholders have been generously supportive of conservation actions. But the scale of our present challenges is greater than ever before; human population growth and associated effects such as climate change could become existential threats to many natural resources and our system of migratory bird management.

Waterfowl conservation will be challenged to remain relevant in a world beset by these planetary-scale alterations. If other generations are going to celebrate the successes of conservation at the 200th anniversary of the MBT, then our generation needs to address these challenges successfully. This will be difficult; we face different problems than our predecessors and at larger scales. We will need to expand who we consider to be partners in this broader conservation enterprise. One obvious strategy may be to connect better important societal issues (e.g., clean water, flood amelioration) to habitats and conservation actions that also sustain migratory birds.

With these challenges in mind, building on Inkley et al. (2004), we urge conservation professionals to 1) anticipate even greater climatic disruption than we have observed in the first century of the MBT; 2) recognize that the past may not be prologue because of human resource demands, ongoing social change, and uncertainty about system stationarity; 3) manage for resilience in all the systems we can influence; 4) encourage cross-jurisdictional planning among our existing institutions (e.g., states, JVs, nations) and be open minded about ways to improve those structures; and 5) recognize that growing uncertainty demands a durable commitment to adaptive management, and work to ensure that adaptive capacity is in place as we move forward.

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