

The evolving role of zoological parks and aquariums in migratory bird conservation

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As threats to migratory birds in the Western Hemisphere, including North America, intensify and bird populations decline, there is a growing interest among zoo biologists in the conservation and management of these taxa. The purpose of this article is to explore the role that Association of Zoos and Aquariums (AZA)-accredited zoos and aquariums either are playing or could play in the conservation and management of migratory birds. Topics explored include: (1) Public education and advocacy; (2) Captive breeding and reintroduction; (3) In situ conservation; (4) Tracking and monitoring; (5) Research/technology development; and (6) Sustainability/green practices; and (7) Partnerships. Zoos and aquariums could play an important role in increasing the public's access to understanding migratory birds and the threats they face, ultimately helping to protect these remarkable species.

KEYWORDS

education, monitoring, partnerships, propagation, reintroduction, sustainability

"Many of the birds Audubon painted are now extinct, yet we go on killing them, more or less casually with our pesticides and wires and machinery."

John Burnside

1 | INTRODUCTION

Migratory birds are species that make seasonal, often north or south, to and fro movements between their breeding and non-breeding (hereafter wintering) grounds. Typically, these movements north to breeding areas

coincide with increases in food production (e.g., insects) and favorable weather conditions that make energetic expenditures associated with reproduction possible (Lovette & Fitzpatrick, 2016). An estimated 19% of the world's extant 9,856 bird species are considered migratory (Kirby, Stattersfield, Butchart, & Evans, 2008). In just the western hemisphere, an estimated biomass of 30,000 tons of songbirds move from their wintering grounds in the Caribbean and Latin America to their breeding grounds in the United States and Canada each Spring and return in the Fall (Wilcove & Wikelski, 2008). A wide variety of bird species are migratory, ranging from the diminutive ruby-throated hummingbird (*Archilochus colubris*) to the much larger whooping crane (*Grus americana*). North-south migratory flights are often made along general routes called flyways, but smaller songbirds generally move over broad fronts and can be tracked using a variety of tools ranging from genetics to archival GPS tags to Doppler weather radar (Fessenden, 2014).

Here we summarize what Association of Zoos and Aquariums (AZA)-accredited zoos and aquariums, hereafter "zoos," are currently

[†]Deceased.

doing or could do in the future to support migratory bird conservation in North America. This paper is timely for a number of reasons. First, there is a growing concern for conservation efforts focused on the air space (the area above ground used by insects, birds, and bats), which is now being recognized as a key habitat for many species (Davy, Ford, & Fraser, 2017). Second, migratory birds face an ever expanding gauntlet of anthropogenic threats during their journeys, as humans increasingly modify natural habitats (Kirby et al., 2008; Loss, Will, & Marra, 2013a, 2015) or habitats are altered by climate change. As a result, several migratory bird species are now classified by government entities as Endangered, Threatened or of Conservation Concern (Kirby et al., 2008; Wilcove & Wikelski, 2008). Third, there is a growing interest and perceived need among zoos in becoming more involved in migratory bird management and conservation. Recent meetings and discussions by the NASWG (North American Songbird Working Group) of the AZA PaCCT (Passerine and Caprimulgiformes, Coliiformes, Trogoniformes) Taxon Advisory Group (TAG) have begun to explore some of these possibilities. Additionally, some zoos are participating in a North American songbird initiative led by the Conservation Centers for Species Survival (C2S2), which seeks to grow connectivity between *ex situ* and *in situ* populations of songbirds through a One Plan Approach (Byers, Lees, Wilcken, & Schwitzer, 2013; Schwartz, 2017). Lastly, birds are ecologically and economically important. Avifauna are critical parts of functioning ecosystems, and the ecological services they provide in the way of pest control, seed dispersal and pollination are worth billions of dollars to the U.S. and other economies (Sekercioglu, Wenny, & Whelan, 2016). With so many bird watchers investing so much time and spending an estimated \$85 billion annually to see them, losing our native song birds could affect not only our environment but our economy.

Natural threats to migratory birds include severe weather (e.g., hurricanes, tornados), predation, disease, starvation, and intra- and inter-specific competition (Lovette & Fitzpatrick, 2016). Among the major anthropogenic threats—which are growing exponentially—are habitat loss and alteration from development (Runge et al., 2015), illegal hunting (Bairlein, 2016), competition with and predation by invasive species, such as feral cats (Loss, Will, & Marra, 2013a), collisions with buildings, particularly those with glass windows and walls (Loss, Will, & Marra, 2014a), vehicles (Loss, Will, & Marra, 2013b), communication towers (Longcore et al., 2013), wind turbines (Loss, Will, & Marra, 2013a; Smallwood 2013), power lines and towers (electrocutions also) (Loss, Will, & Marra, 2014b), and solar arrays (incineration, also) (Upton, 2014; Walston, Rollins, LaGory, Smith, & Meyers, 2016), and exposure to toxic pesticides (Loss et al., 2015). Climate change is also a major and growing threat to migratory birds (La Sorte et al., 2017). The cumulative impact on bird populations is staggering, resulting in the loss of billions of birds annually (Loss et al., 2015). As a result, many of North America's native birds, including many migratory species, have been in steady decline since the mid 1960's (when records started being kept), with fully one-third now in need of concerted conservation action to ensure their future (North American Bird Conservation Initiative, 2016).

Zoos and aquariums have gone beyond the care and public exhibition of wild animals in captivity and ventured into a wide variety of activities either directly or indirectly supportive of wildlife management and conservation (Conway, 2003; Conde, Flessness, Colchero, Jones, & Scheuerlein, 2011; Hutchins & Conway, 1995; Hutchins & Smith, 2003; Mallinson, 2003; Zimmerman & Wilkinson, 2007). Therefore, it is appropriate to discuss the potential for zoo contributions to migratory bird management and conservation. For the purposes of this paper we focus on migratory birds of the Western Hemisphere but the application of these ideas could be scaled globally.

Zoos have many avenues for contributing to wildlife and habitat conservation, both directly and indirectly. Here in this paper, we summarize how AZA accredited institutions either are contributing to migratory bird management and conservation now or could contribute in the future.

1.1 | Public education and advocacy

One of the key societal roles of zoos is to inform visitors about a wide range of wildlife, including their biology, behavior, habitat, and conservation status (Andersen, 2003; Falk et al., 2007; Hutchins, 2003) and provide them with information about actions they can take to save wildlife (Hallager, Kreger, & Schneider, 2017). This educational role may involve both formal and informal components, ranging from exhibits to interpretative graphics and signage to videos to presentations and classes.

There is much that zoos are doing or could do to inform their visitors about migratory birds and the many threats they face, however, if they are to make a difference for migratory birds with their education programs, they must consider intensifying their efforts. Simply putting basic information about a species' name and geographical location on a sign are not enough. To be effective, they must show what people can do in their own lives to assist migratory birds or to reduce threats, which could involve feeding them (e.g., by planting native food plants), giving them a place to breed (bird houses), keeping their pet cat indoors, using pesticides sparingly, marking windows on their house to prevent collisions, turning off outdoor lights at night, drinking bird-friendly coffee and so forth (ABC, 2017a; Falk et al., 2007).

Smithsonian's National Zoological Park (National Zoo), in collaboration with its Migratory Bird Center, is building an entire exhibit and educational program centered on migratory birds (Marra and Hallager, pers comm., 2017). "Experience Migration" will be a state of the art, 21st century bird exhibit that merges the science of bird migration with excellence in animal care and husbandry on a scale that has never been seen in any North American zoo. The existing Bird House is being redesigned and rededicated to the exhibition, study and husbandry of Western Hemisphere birds, using bird-friendly glass throughout, both inside and outside. Immersive aviaries will emphasize the importance of conserving stopover sites and habitats, breeding grounds and wintering grounds for North American migratory shorebirds, waterfowl and songbirds. Year-round mist netting of wild birds in the National Zoo and in the surrounding Rock Creek National Park will

provide hands on educational experiences for visiting school groups and the public. Behind the scenes, these aviaries will connect zoo-based scientists and animal care staff to collaborate on research on wild and captive populations of migratory songbirds and shorebirds. Experience Migration is designed to inspire zoo visitors to care about birds and help save them, but it is also about understanding and advancing migratory bird science and husbandry.

As our understanding of the husbandry challenges subside, zoos of all sizes can include song birds in exhibit spaces. These can be impactful single exhibit or have songbirds mixed in with tropical exhibits depicting non-breeding habitats for these species. Interpretive material can focus on the challenges song birds face and also on what visitors can do in their own backyard to help declining species.

Advocacy is a bit trickier as it involves zoos pushing for or opposing legislation, regulations or development that may affect birds and their habitats, such as the Farm Bill (Rodewald, 2017). For zoos that are governmental or quasi-governmental entities, taking political action can be difficult. However, commenting on pending legislation or regulations certainly can be and often is done through regional and global zoo organizations worldwide, including AZA (Hutchins, 2003). Indirectly, zoos give guests the tools to advocate on behalf of birds through participation in events celebrating International Migratory Bird Day (Hallager et al., 2017) and interactive bird presentations and guest speakers (Kreger, pers comm., 2017) or more directly in cooperation through not for profit bird conservation organizations, such as Audubon, the American Birding Association, or American Bird Conservancy, all of whom comment actively on legislation and regulations that impact migratory bird conservation.

1.2 | Captive breeding and reintroduction

Captive husbandry and breeding of wildlife are traditional roles of zoos (Hutchins, 2003). Certainly, zoos and aquariums must sustain captive populations for the purposes of education and outreach as described above. Zoos also rely on sustainable captive populations for research, often with applied conservation benefits. These populations can be used to provide a hedge against extinction through building ex situ insurance populations or to provide candidates for reintroduction. This includes establishing and sustaining populations of non-threatened species for use as models for similar threatened species when developing husbandry techniques or studying and promoting behaviors necessary for survival. For example, by learning how to breed “warblers” now, we can gain valuable husbandry insights which will be critical in the future when a population is on the verge of crashing and captive breeding is the only way to save it. Since collection from the wild is becoming less and less feasible, developing sustainable collections is important to the future of zoological institutions (Hutchins, 2003; Hutchins, Dresser, & Wemmer, 1995; Leus, Traylor-Holzer, & Lacy, 2011) interested in exhibiting, studying, and conserving migratory species.

AZA and all professionally managed zoos worldwide accomplish this through careful collection planning and cooperative breeding programs employing appropriate genetic and demographic management (Hutch-

ins, 2003; Hutchins, Sheppard, Lyles, & Casadei, 1995; Leus et al., 2011). However, once the possibility of reintroduction into free-ranging populations is considered, then captive breeding becomes part of an in situ conservation strategy (Beck, Rapaport, Stanley Price, & Wilson, 1994; Gilbert & Soore, 2017; Hutchins, 2003; Stanley-Price & Soore, 2003). However, criteria for reintroduction of captive bred animals into wild populations are difficult and complex and should not be taken lightly (Kleiman, Stanley Price, & Beck, 1994).

Successful captive breeding and reintroduction programs have been focused mostly on larger, longer-lived migratory bird species, including whooping cranes, Mississippi sandhill cranes (*Grus canadensis pulla*) (Lewis, 1990; Zwank & Wilson, 1987) and trumpeter swans (*Cygnus Cygnus buccinator*) in North America (Diebold, Matteson, & King, 1999; Nagendran, Urbanek, & Ellis, 1996; Zwank & Wilson, 1987), and northern bald ibis (*Geronticus eremita*) in Europe (Fritz, Kramer, Hoffman, Trobe, & Unsold, 2017). There are also examples of successful breeding/fostering and reintroduction programs for North American songbirds. For example, the San Diego Zoo's Institute for Conservation Research has produced endangered San Clemente loggerhead shrikes (*Lanius ludovicianus mearnsi*) for release, maintained an insurance population in case of catastrophic loss in the wild, and provided care for abandoned wild eggs and chicks for over 25 years (Wiese, pers com, 2017). In 2009, management protocols were altered to allow the fostering of salvaged wild eggs in captive nests. After two initial successes, these techniques were expanded to include salvaged chicks, which replaced the previous hand-rearing techniques as management protocol for rescued clutches. The result has been a stable or growing population of this endangered subspecies. Eastern loggerhead shrikes (*Lanius ludovicianus migrans*) have also been the subject of large-scale field propagation and release programs in Canada (Nichols et al., 2010) and the U.S. The U.S. participates under the umbrella of C2S2 (Conservation Centers for Species Survival), which includes several AZA facilities and partner organizations (Hallager et al., 2017).

Examples of long-term husbandry and management programs for migratory songbirds are few. Zoos typically obtain their founder birds through rescue and rehabilitation, rather than through direct collection from nature, so opportunities have been severely limited. However, cooperative, scientifically managed breeding programs in North America have been evolving for a few exotic non-migratory passerine species including the fairy bluebird (*Irena puella*) (Singer & Lynch, 2017), red-capped cardinal (*Paroaria gularis*) (Lynch & Snyder, 2017) and Bali mynah (*Leucopsar rothschildi*) (Ross, Thompson, & Ray, 2017). Lessons learned and experience gained could help in the development of programs for native species (Saint Jalme, 1999).

Most zoo-bred animals will never be reintroduced into the wild for a wide variety of reasons (Hutchins, 2003). However, given the conservation status of some migratory birds, it is possible that captive breeding for reintroduction could be a viable, last resort conservation strategy for selected species (Saint Jalme, 1999; Sheppard, 1995a; Snyder et al., 1996). Captive breeding for reintroduction, however, is likely to be of limited utility for many migratory birds, especially smaller taxa, for the following reasons. First, space in zoos is limited and often

inappropriate for breeding (Sheppard, 1995b; Soule, Gilpin, Conway, & Foose 1986), and small, migratory songbird populations, even with sufficient founder stock, are probably going to require a minimum of at least two hundred individuals to remain genetically viable over the long-term, especially since they tend to have short generation times (Lees & Wicklen, 2009; Lynch & Snyder, 2014). Second, reintroduction techniques are poorly developed and, in many cases, may be species-specific (Saint Jalme, 1999). This is especially true since behavioral barriers to successful reintroduction and migration may prove difficult to overcome for captive-bred individuals (Hutchins, Dresser, & Wemmer, 1995; Saint Jalme, 1999; Wallace, 1994). However, training to locate food, fly, avoid dangers, including predators, has substantially improved the success of some avian reintroduction programs (Saint Jalme, 1999). In summary, captive breeding programs with the aim of reintroduction for smaller migratory songbirds may be viewed as an option for species recovery when no other viable alternatives are available. Furthermore, they should always be integrated with recovery objectives for wild populations (Snyder et al., 1996). We emphasize, however, that there is value in developing the husbandry tools for captive breeding, including using common species as surrogates for threatened species, given the declining population trajectory of so many species of migratory birds. In addition, developing sustainable captive populations of migratory birds can be extremely useful for studying a suite of other biologically relevant questions ranging from wind tunnel studies examining aerodynamic performance, to nutritional studies to physiological ecology. Recently, National Zoo animal care staff supported two projects for researchers from the Smithsonian Migratory Bird Center. One was a study looking at migration behavior in wood thrush (*Hylocichla mustelina*) and another was a study using song sparrows (*Melospiza melodia*) to investigate the bill as a thermoregulatory organ. The animal care staff provided critical husbandry advice and daily care to both projects (Marra, pers comm., 2017).

1.3 | Field conservation

Many zoos have been taking a more active role in field or in situ conservation, either directly or indirectly (Gusset & Dick, 2010; Hutchins & Conway, 1995; Zimmerman & Wilkinson, 2007). Conway (2011, p. 27) states that "it is now clear, in terms of limited (housing) capacity as well as genetics, demography, and behavior, that zoological gardens must also focus on supporting parks and wildlife environments." Indirect contributions include raising funds and providing publicity for field conservation projects organized by outside conservationists or partner organizations, while direct contributions include support of national parks and equivalent reserves or related species conservation projects (e.g., surveys) conducted by zoo staff (Gusset & Dick, 2010; Hutchins & Conway, 1995). Studies at the Bronx Zoo and other New York City parks indicate that many zoos have grounds that can or could support resident birds and provide stopover habitat for migratory birds (Seewagen, Sheppard, Slayton, & Guglielmo, 2011). Zoo-based granting programs provide a potential source of funding for field biologists focused on migratory bird conservation

initiatives. For example, the Riverbanks Zoo's Conservation Support Fund (CSF) has provided funding for assessing the connectivity of breeding and wintering habitat for migratory prothonotary warblers (*Protonotaria citrea*) using stable isotope analysis (Diebold, pers comm., 2017).

In the case of migratory birds, we agree that contributions to in situ conservation must be part of the overall zoo strategy because of the key importance of protected areas to conserving migratory birds (Runge et al., 2015). To effect conservation for these species, particular attention should be placed on protecting known wintering, stop-over and breeding sites, and the air space, as conservation of migratory birds means protecting them during their entire life cycle (Faaborg et al., 2010; Mehlman et al., 2005; Runge et al., 2015).

Zoos, for example, could aid in protecting local sites of great importance to migratory birds and/or assist in educating the public about them (see Public Education, below). Furthermore, they could work with partners to assist with the conservation of North America's marine and terrestrial Important Bird Areas (IBAs) (Audubon, 2017c), critical habitats for Threatened and Endangered species as defined by U.S. Fish and Wildlife Service (FWS, 2017), or work with bird conservation organizations like the American Bird Conservancy (ABC) that supports a Latin American Bird and Migratory Bird Reserve Network (ABC, 2009) and Birdscapes. The more than 70 current reserves and easements in this network span the U.S. and 13 other countries in the Americas, supporting more than 2,600 bird species—more than half those recorded in the Americas, including more than a quarter of all threatened bird species in the Americas (Lebbin, pers Comm., 2017). Many of these reserves support avian species that migrate into North America. There are also many opportunities for zoos to partner with national, state, and municipal public land management organizations. These include national parks and wildlife refuges.

1.4 | Tracking and monitoring

Tracking and monitoring of bird populations and their key habitats is critical for conservation and this is especially true of migratory species, which may use a wide variety of geographical locations during their seasonal journeys (Runge et al., 2015). Unfortunately, our detailed understanding of the migratory patterns and connectivity of birds is poor, with the study of the movements of small-bodied species being a major research priority (Faaborg et al., 2010; Marra, Norris, Haig, Webster, & Royle, 2006). Zoo staff and their volunteers could play an important role in filling gaps in our knowledge. With precious little known about the details of bird migration, this has placed conservationists at a huge disadvantage when evaluating planned developments that could potentially alter or destroy key habitats (Faaborg et al., 2010). The more we learn about how the various stages of migratory bird lifecycles are connected geographically and biologically for specific species, the better we will be at making strategic decisions about where to develop versus where not to develop.

The Smithsonian's Conservation Biology Institutes' Migratory Connectivity Project's (<http://www.migratoryconnectivityproject.org>)

sole focus is to identify where breeding populations migrate and winter, to better understand ecological and evolutionary links throughout the year. Two recent examples include studies of the migratory connectivity of the declining wood thrush (*Hylocichla mustelina*) (Stanley et al., 2014) and the endangered Kirtland's warbler (*Dendroica kirtlandii*) (Cooper, Hallworth, & Marra, 2017). Both species winter in the Caribbean or Central America and breed in the northern U.S. and boreal forests of Canada. Better knowledge of these connectivity patterns, including wintering and stopover locations and migration routes could help understand when during the annual cycle populations of these species are limited. This information could, for example, help to inform the siting of wind turbines around the Great Lakes, one of the world's largest confluences of migratory birds and bats (Hutchins, 2017). It could also assist in contingency planning for the impacts of climate change, which will impact many aspects of zoo operations and their in situ conservation efforts (Junhold & Oberwemmer, 2011).

Zoo staff and volunteers are already making important contributions to our understanding of bird migration by doing occasional events or hosting equipment to monitor migratory birds. They are doing this by participating in nation-wide bird counts, such as Audubon's Christmas and Great Backyard Bird Counts (Audubon, 2017a, 2017b), participating in the Cornell Laboratory of Ornithology's eBird by recording observations of birds on site (Cornell Lab of Ornithology, 2017), and by erecting Motus towers at their locations to help monitor avian migratory behavior (Taylor et al., 2017). Motus Wildlife Tracking System, a program of Bird Studies Canada, is an automated radio telemetry system that includes a network of receiving towers that allows researchers to track the movements of radio-tagged birds and other animals through a coordinated hemispheric program (<http://birdscanada.org/research/motus/>). Towers at zoos could add to the network of over 375 stations across the hemisphere operated by more than 75 collaborators and help grow our understanding of bird migration. Some zoos, such as the Columbus Zoo and Aquarium, The Wilds, and Riverbanks Zoo are tracking birds through Motus program and are planning their own migratory bird studies using nano-transmitters (Diebold, Kreger, pers comm., 2018). Many other zoos have started or are in the process of participating in the program (Diebold & Kreger, pers comm., 2017; Hallager et al., 2017).

1.5 | Research and technology development

Zoos are excellent places to test conservation-related technologies for their efficacy prior to their application in the field (Hutchins & Conway, 1995). For example, Riverbanks Zoo and Botanical Garden spearheaded a satellite telemetry project used in trumpeter swan recovery in Wisconsin (Diebold et al., 1999; Diebold, Matteson, Koontz, Koontz, & Manthey, 2008). Analysis of satellite data helped identify the migratory routes and habitat use of this restored migratory population. Captive swans were used to determine the best methods for attachment of the telemetry units. The Zoo conducted trials with Teflon ribbon back packs before deciding on using more effective neck-collar mounts.

Zoos and aquariums conduct a wide variety of research, both on their animal collections and in the field, often in collaboration with universities and other institutions, thus contributing to our knowledge of wild animals' basic biology (Fernandez & Timerlake, 2008; Hutchins, Sheppard, Lyles, & Casadei, 1995; Macek, 2014). Zoo-based research covers a wide variety of relevant topics such as reproductive biology, behavior, husbandry and care, physiology, nutrition, growth and development, disease and pathology, reintroduction, animal welfare, and veterinary care (Hutchins, Dresser, & Wemmer, 1995; Macek, 2014).

The knowledge gained by zoos on migratory birds not only contributes to husbandry and breeding in captivity (e.g., Fidgett & Gardner, 2014), but also assists in providing a deeper understanding of an animal's basic biology in nature, often contributing both directly and indirectly to in situ conservation efforts (Hutchins, Sheppard, Lyles, & Casadei, 1995). For example, our understanding of piping plover (*Charadrius melodus*) biology and conservation have been advanced through studies conducted by AZA zoos and partners (Powell, Cuthbert, Wemmer, Doolittle, & Feirer, 1997) using a population established with rescued chicks and eggs. The enhanced understanding of the species' breeding biology and behavior, as well as techniques for raising piping plover chicks and eggs, has proven useful for enhancing small populations of this endangered migratory species, both in captivity and in the wild (Roche et al., 2008).

Understanding the role migratory birds play in the spread of emerging infectious diseases will be a major area of priority research in the coming years (Vitali, Reiss, & Eden, 2011), as climate change exacerbates the spread of mosquitoes and other disease vectors (Macek, 2014). Avian malaria and West Nile virus are two known pathogens that can and do impact bird populations (Atkinson, Woods, Dusek, & Sileo, 1995; Nemeth & Oesterle, 2014). The latter was discovered in North America by a pathologist at the Wildlife Conservation Society's Bronx Zoo in New York City (Lanciotti et al., 1999).

What is essential for the zoological community to give careful consideration to is not only to which species might be the focus of their captive breeding programs, but to also which research priorities that will develop. For example, with developing successful husbandry, zoos should decide on priority taxa, reintroduction strategies, and to address those priorities systematically across institutions (Hutchins & Thompson, 2008).

1.6 | Sustainability/green practices

Many AZA-member institutions have been working towards sustainability (green practices) in their own operations (Townsend, 2009), which could help declining populations of migratory birds in many ways—including by simply education the public about these practices. The adoption of green building and other operational practices, such as limiting fuel consumption, could also help to reduce greenhouse gasses and aid in reducing the impacts of climate change (Houck & Plunkett, 2010).

Bird-friendly building design for animal exhibits and other structures (e.g., office buildings) could also save the lives of many

migratory birds by minimizing collisions (ABC, 2017a, 2017b). The National Zoo's new Experience Migration Exhibit will, for example, use bird-friendly glass in its design to reduce collisions both on the exterior of the building and on the interior in the aviaries (Marra and Hallager, pers comm.). Similarly, many zoos have adopted bird friendly design or glass in order to reduce bird collisions on site (Sheppard, 2017).

As zoos move towards using renewable energy, such as wind and solar, they should be aware of the impacts of poorly sited projects and their associated infrastructure, notably power lines and towers, on migratory birds and adopt bird smart wind and solar energy, or purchase energy from developers and utilities that are sited away from large concentrations of birds, reduce bird kill to the extent possible, and provide compensatory mitigation for unavoidable mortality (Hutchins, Parr, & Schroeder, 2016). Power lines and towers on zoo grounds or nearby could be mitigated to reduce bird loss using techniques recommended by the Avian Power Line Interaction Committee (APLIC, 2012).

Habitat loss, on both temperate breeding areas and on tropical wintering grounds is the primary driver of population declines of migratory birds. Direct habitat preservation is ideal but not always possible. On innovative example of a program that helps protect essential habitat for migratory song birds is the Smithsonian Migratory Bird Center's Bird friendly coffee certification. The Migratory Bird Center developed a science-based criteria for when coffee grown under a shade canopy provides good habitat for migratory and resident species. Known as the Smithsonian Bird Friendly Coffee certification, it is considered the gold standard of environmental certifications and is also 100% USDA organic. Selling Smithsonian Bird Friendly Coffee is an easy way for all AZA institutions and its members to support migratory bird conservation.

1.7 | Partnerships

Zoos maintain many partnerships that help them to fulfill their important missions of education, science, and conservation (Hutchins & Smith, 2003). Many partnerships that focus on the conservation and management of migratory birds that could benefit from zoo involvement and vice versa. The Bird Conservation Alliance (BCA) is a communication network of some 200 organizations focused on bird conservation that share information and resources on relevant topics (ABC, 2017b). The Alliance for Zero Extinction (AZE) is an organization which targets the most endangered birds for conservation action. Partners in Flight is an organization that focuses on the conservation priorities for migratory birds in the Americas and which, despite some criticism (Faaborg, 2002), has had great success in identifying habitat, species priorities and identifying research needs (Carter, Hutcer, Pashly, & Rosenberg, 2000; Fitzgerald, 2003). Many zoos also have strong partnerships with colleges and universities (Fernandez & Timerlake, 2008). These mutually beneficial partnerships can leverage the resources of each for the benefit of migratory birds. These range from veterinary medicine to avian ecology to placement of Motus towers.

AZA member institutions already collaborate with government wildlife agencies that have programs focused on migratory birds,

including the U.S. Fish and Wildlife Service, National Oceanographic and Atmospheric Administration (NOAA), and U.S. Department of Agriculture's Natural Resources Conservation Service. These partnerships extend to state and local environment and wildlife agencies. They also partner with non-governmental conservation organizations, such as the American Bird Conservancy and Audubon. One example of this kind of partnership is that members of the AZA North American Songbird Working Group are working with a coalition of government and non-government organizations in the North American Bird Conservation Initiative (NABCI), particularly in NABCI's Human Dimensions Working Group. Discussions and collaborative projects focus on how zoos can best present bird conservation priorities identified by NABCI. The goals are to educate and inspire the visitor to make a difference by taking positive actions on behalf of migratory birds (Hallager & Kreger, pers comm., 2018).

2 | CONCLUSION

As evident from the ideas and examples presented here, zoos could make substantial contributions to migratory bird conservation in North America and beyond. In our opinion, this could be accomplished primarily and most effectively through several explicit contributions including: 1) direct and indirect support for in situ conservation (identifying and protecting key wintering, stopover and breeding habitat); 2) assisting in the tracking and monitoring of migratory bird populations; 3) adoption of green practices, including bird-friendly building design; 4) developing and implementing targeted educational programs and advocacy efforts; and 5) developing effective husbandry, release and translocation methods through systematic research now, rather than waiting until species become threatened or endangered

Zoos should move towards bird-friendly building design, ensuring that best practices for reducing bird mortality are adopted during both renovation and new construction. To address climate change, they should also adopt sustainable practices, limiting fossil fuel use and greenhouse gas emissions to every extent possible. At the same time, in moving towards renewable energy, zoological institutions should purchase energy from developers that use bird- (and bat-) smart principles (Hutchins et al., 2016). Wind and solar energy have the potential to harm migratory birds, especially when poorly sited in areas of high bird use, such as key migratory routes and stopover sites, and major foraging and breeding areas.

Captive breeding/fostering for reintroduction has only limited potential to contribute to migratory bird conservation, at least in the case of smaller species, such as passerines. However, there may be a few carefully selected cases in which captive breeding/fostering for reintroduction could be a viable, last resort conservation strategy. Such efforts will depend first on developing the art and science of husbandry of more common migratory birds in human care.

Deciding which avian species should be the focus of zoo attention must be done strategically (Balmford, Mace, & Leader-Williams, 1996; Diebold & Hutchins, 1991; Hutchins, Willis, & Wiese, 1995; IUCN,

2002). The development of husbandry, care and reintroduction techniques should be accompanied by appropriate and scientifically valid research; with research priorities developed through careful and systematic planning (Hutchins & Thompson, 2008). This will help ensure that the knowledge gained fills existing information gaps in husbandry, care and conservation of migratory birds in captivity and in nature. Developing this knowledge base is critical *before* species become seriously endangered. While precognition is not always possible because of rapidly changing circumstances, this should be kept in mind.

With over 183 million visits annually (AZA, 2017), the more than 230 AZA-accredited zoos and aquariums (AZA, 2017) have a huge potential for developing educational outreach programs focused on migratory birds and educating the public about their value including the ecological services they provide. Migratory birds like all animals also provide visitors with unique access to the amazing biology and splendor of these species. Programs emphasizing the beauty of migratory birds and their conservation needs could have great appeal to zoo and aquarium visitors, especially since many of them are likely bird-watchers or could be in the future.

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