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Using open access observational data for conservation action: A case study for birds

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ABSTRACT

Ensuring that conservation decisions are informed by the best available data is a fundamental challenge in the face of rapid global environmental change. Too often, new science is not easily or quickly translated into conservation action. Traditional approaches to data collection and science delivery may be both inefficient and insufficient, as conservation practitioners need access to salient, credible, and legitimate data to take action. Open access data could serve as a tool to help bridge the gap between science and action, by providing conservation practitioners with access to relevant data in near real time. Broad-scale citizen-science data represent a fast-growing resource for open access databases, providing relevant and appropriately scaled data on organisms, much in the way autonomous sensors do so on the environment. Several such datasets are now broadly available, yet documentation of their application to conservation is rare. Here we use eBird, a project where individuals around the world submit data on bird distribution and abundance, as an example of how citizen-science data can be used to achieve tangible conservation science and action at local, regional, and global scales. Our examination illustrates how these data can be strategically applied to improve our understanding of spatial and temporal distributions of birds, the impacts of anthropogenic change on ecological systems, and creative conservation solutions to complex problems. We raise awareness of the types of conservation action now happening with citizen-science data, and discuss the benefits, limitations, and caveats of this approach.

1. Introduction

Ensuring conservation action is informed by the best available science is a fundamental challenge in the face of rapid global environmental change. Importantly, 'conservation science' and 'conservation action' are two different things: conservation science is the scientific process of generating information that leads to knowledge about conservation, whereas conservation action is the process of using that information to make decisions that help conserve species and/or habitats. In ideal situations, the former process informs the latter, and conservation action is implemented using a data-driven approach based on the best available conservation science. However, in many cases a gap exists between newly generated conservation science information and the conservation actions taken by decision-makers (Cook et al., 2013; Knight et al., 2008). Too often, novel scientific information cannot be used effectively in conservation practice: it may not be relevant to the conservation question at hand, it may be difficult to access, results may be too complicated, or suggested implementation may not be practical in a real-world setting (Cook et al., 2013; Sunderland et al., 2009). In order for conservation science to most effectively translate into conservation action, the information generated must be salient (relevant and timely), credible (authoritative, believable, and trusted), and legitimate (developed via a process that considers the values and perspectives of all relevant actors) (Cook et al., 2013).

Open access observational databases could help to close the gap between knowledge and action by providing data resources that allow a broad diversity of potential users to extract the information needed to address a particular conservation challenge. Because some of the fastest-growing contributors to observational databases today are broad-scale citizen-science projects (Theobald et al., 2015), such databases may become increasingly important in the conservation domain. Conservationists are now leveraging new sources of information that provide complementary data to more traditional data gathering approaches, including automated sensor networks that collect real-time earth observations (Turner et al., 2015), and citizen-science projects in which humans collect real-time observations on organism occurrence and abundance. Citizen-science projects such as these effectively leverage the power of the Internet and the "crowd" of observers and collectors to gather or analyze data at volumes, scales, and a level of immediacy not possible through traditional techniques (Bonney et al., 2009, 2014; Miller-Rushing et al., 2012; Theobald et al., 2015). Pimm et al. (2014) suggest that citizen-based observational data currently

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represent the fastest growth in our ability to understand species' distributions, providing substantial opportunities to monitor a broad range of species over long time periods and broad spatial extents. Indeed, more traditional structured forms of citizen science (e.g., projects with structured sampling protocols) have already contributed significantly to the fields of conservation science and conservation action, such as atlases that compare species distributions between two time periods (Fuller et al., 1995), and especially long term survey programs such as Breeding Bird Surveys (e.g., Sauer et al., 2013), which generate information on species population trends across multiple spatial scales and time periods. Importantly, novel analytical techniques are also being developed to discover ecological patterns in these broad-scale observational data sets, identify and overcome inherent limitations and biases (Fink et al., 2010, 2014; Hochachka et al., 2012a), and control for data quality (Sullivan et al., 2014; Kelling et al., 2015). Thus, observational data generated by these broad-scale citizen-science approaches may provide conservation practitioners with a much needed source of salient, credible information that augments information gathered through more traditional approaches.

One such broad-scale citizen-science project that strives to achieve these goals is eBird (Sullivan et al., 2009, 2014), which aims to collect data on all bird species, year-round (i.e., across breeding, migration, and non-breeding periods), from any location on the planet, and make these data openly available for research, education, and conservation. Currently, eBird serves as a major source for observational data on bird occurrence, providing roughly 20% of the data available in the Global Biodiversity Information Facility (GBIF) (www.gbif.org), an open access biodiversity data clearinghouse. In addition to basic occurrence information available through GBIF, eBird allows individuals open access to a richer data set directly through its web interface (www.ebird.org). These data include information on species presence and absence gathered through checklists (lists of all species seen and heard at a location), as well as information on species abundances, search effort, and basic breeding ecology (Sullivan et al., 2014). Access to these data has already been useful in generating novel science across a variety of domains (e.g., Hutchinson et al., 2011; Hurlbert and Liang, 2012; La Sorte et al., 2013, 2015; Taylor et al., 2014), yet little is known of its use in on-the-ground conservation action.

In this paper we report conservation actions resulting from use of observational data collected by volunteers in eBird. We surveyed data users to learn more about their characteristics, why they use eBird data, and to discover conservation products and actions based on eBird data. We provide and utilize a novel conservation action framework adapted from existing frameworks used in conservation biology, classify reported conservation actions, and provide exemplars for each category. We demonstrate how a diversity of conservation actions is resulting from use of one openly available citizen-science data set, and discuss the benefits, limitations, and caveats of this approach to conservation.

2. Methods

2.1. eBird

Our results are based on surveys of individuals who have used eBird data. Developed by the Cornell Lab of Ornithology and Audubon and launched in 2002, eBird is a free, open access global citizen-science project in which volunteer participants submit checklists of the birds they see anytime from anywhere around the world (Wood et al., 2011; Sullivan et al., 2014). Since its inception, growth in eBird participation has been exponential, with more than 300 million observations submitted all-time and more than 70 million in 2015 alone.

eBird currently provides access to its data through the web site in two different ways: 1) web-based tools summarize raw eBird data into visualizations that can be used for simple exploration, decision making, and planning; and 2) a data access gateway that includes four data sets that package eBird's raw data in various forms, from basic occurrence information to a more rigorous and restricted view of the data with hundreds of spatial covariates designed for higher-level science use (Sullivan et al., 2014). All data are freely available for science, education, and conservation use. While eBird's web-based visualization tools are openly available to the online community, eBird's data access gateway requires each user to self-identify, provide contact information, and explain his or her intended use of data prior to access. A data key is then provided for each user request, allowing access to eBird's data download tools for a specified time horizon (typically 30 days). The required provision of contact information in the data access gateway allows for subsequent communication with data users accessing any of the four pre-packaged eBird data sets.

2.2. Surveying eBird data users

Our aim was to survey the eBird data use audience to 1) discover tangible conservation products and actions, and 2) classify reported conservation actions resulting from eBird data use. We define "tangible conservation actions" as those that helped to conserve birds, biodiversity, or key habitats. Examples are protection or creation of habitat, appropriate siting of an energy project, listing/delisting of a species, or a set of management guidelines for a landowner. We used two different surveys: one to explore general data use, and a second to discover conservation products and actions.

In the first survey, questions asked for information about ease of access to eBird data, ratings of data quality, intended use of the data, challenges with using the data, and whether eBird data were being used with other datasets. In addition, a small subset of pilot questions focused on products and outcomes from the data. We administered this survey with SurveyMonkey™ in August 2014, by sending an email invitation to all 2033 individuals who had *requested* a key to download eBird data from November 2012 to August 2014. The survey was completed by a total of 364 participants (17.9% response rate).

The second survey asked questions about geographic region for application of the data, audience affiliation, reasons for choosing eBird data, and products, publications, and conservation actions resulting from the use of eBird data. This survey was sent to a broader audience. In April 2015, it was administered through SurveyMonkey™ to 2108 individuals who had successfully *downloaded* eBird data from November 2012 to April 2015 (including 341 individuals who had taken the first survey), as well as through an open web link provided on the eBird web site. A total of 603 individuals completed this survey: 406 responses came from the email invitation (19% response rate) and 197 from the web link. We included the wider web community in this survey because we realized that tangible conservation actions could result from cases where people did not download raw eBird data, but instead relied on eBird's web-based visualization tools to gather the information they needed to take conservation action. Of the 406 email respondents, 90 individuals had also taken the first survey. For these cases, answers to identical questions from the two surveys were counted only once, and information from the first survey was discarded for that question. The questions from both surveys, associated sample sizes, and data analysis techniques used in this paper are provided in Table 1.

2.3. Classifying conservation actions

For classifying conservation actions we looked to existing frameworks commonly used within conservation biology. For example, Salafsky et al. (2008) described a unified classification of conservation actions, which was built upon and expanded by Kapos et al. (2008) and the Cambridge Conservation Forum (CCF) for evaluating conservation success. In 2015, the Conservation Measures Partnership (CMP) (www.conservationmeasures.org) released a beta version of a framework for action classification that includes ten major categories, each with several subcategories (http://tinyurl.com/CMP-Actions). We

Table 1
Survey questions presented to surveyed eBird data users.

Survey questions	Response type	N	Source	Data analysis
How do you identify your primary research discipline, field of study, or interest area(s)? (Please check all that apply.)	Fixed responses with other	364	Survey 1	Frequency
If the data were used for research, please describe the focus of the research.	Fixed response with other	226	Survey 1	Frequency
Was eBird the primary data set used in your study?	Fixed response	444	Survey 1	Frequency
What region(s) of the world best describes the general location of your analysis or research interest?	Fixed responses with other	457	Survey 2	Frequency
Did you request eBird data to use as a…	Fixed responses with other	710	Survey 1 and 2	Frequency
Why did you decide to use the eBird data set in your analysis?	Open text	617	Survey 1 and 2	Qualitative coding for similar concepts
Can you describe any product resulting from downloading or analyzing the data (e.g., publication, regulatory action, curriculum, etc.)?	Open text	230	Survey 1	Qualitative coding for similar concepts
Please mark any products resulting from downloading or analyzing the data. (Please check all that apply.)	Fixed responses	434	Survey 2	Frequency
If the analysis resulted in a publication, where was your research published? (Please check all that apply.)	Fixed responses with other	191	Survey 1 and 2	Frequency
Please describe any documented conservation outcomes resulting from your use of eBird data or what you hope will result from your eBird data analysis	Open text	115	Survey 1	Qualitative coding for conservation science and action categorization
Did your use of eBird data result in tangible conservation outcomes? We define 'conservation outcomes' as actions resulting from eBird data use that helped conserve birds, biodiversity, or key habitats. Examples could be protection or creation of habitat, better siting of a renewable energy project, listing/delisting of a species, or a set of management guidelines for a landowner.	Open text	426	Survey 2	Qualitative coding for conservation science and action categorization

reviewed all three of these schemes and modified them to create a framework for classifying conservation science and action within citizen science (Fig. 1). We excluded some categories from our analysis (e.g., Awareness Raising; Law Enforcement and Prosecution; Livelihood, Economic, and Moral Incentives; Education and Training; and Institutional Development) because these did not fit our definition of "tangible conservation outcomes" and are difficult to track and measure.

The framework in Fig. 1 presents six categories of conservation science and actions, described below:

- *Research and monitoring*: actions aimed at providing data needed to inform conservation decisions, such as population size or trends, distribution, habitat preferences, and limiting factors. Approaches include survey, inventory, monitoring, remote sensing, mapping, and development of new technologies.
- *Conservation planning*: actions aimed at creating a comprehensive plan to protect species or sites, such as identifying a portfolio of sites for protection or specific actions that can be taken to ameliorate threats limiting populations.
- *Site/habitat management*: actions directly manipulating, managing, or restoring structural and/or floristic features at a particular site or habitat.
- *Species management*: actions directly manipulating populations and/or individuals, such as clutch management or captive breeding.
- *Site/habitat protection*: actions taken to identify, create, designate, or elevate a specific site or habitat to some form of protected status.
- *Law, policy, and regulation*: actions taken to establish frameworks within the processes of government, civil society or the private sector that make conservation goals official or facilitate their accomplishment; may include development, implementation and/or enforcement of legislation, management plans, policy statements for government decision making, and trade regulations, among others.

2.4. Data analysis

In this analysis, we aggregate survey responses from individuals representing academia, governmental agencies, non-profit organizations, corporations, and private citizens who used eBird data. For quantitative and categorical questions asked with fixed responses, we report basic frequencies.

Before coding and quantifying reports of conservation science and action, we first assessed whether a survey response met our criteria for inclusion as a tangible conservation action. For example, we did not include actions that were hoped for, but had not happened, or

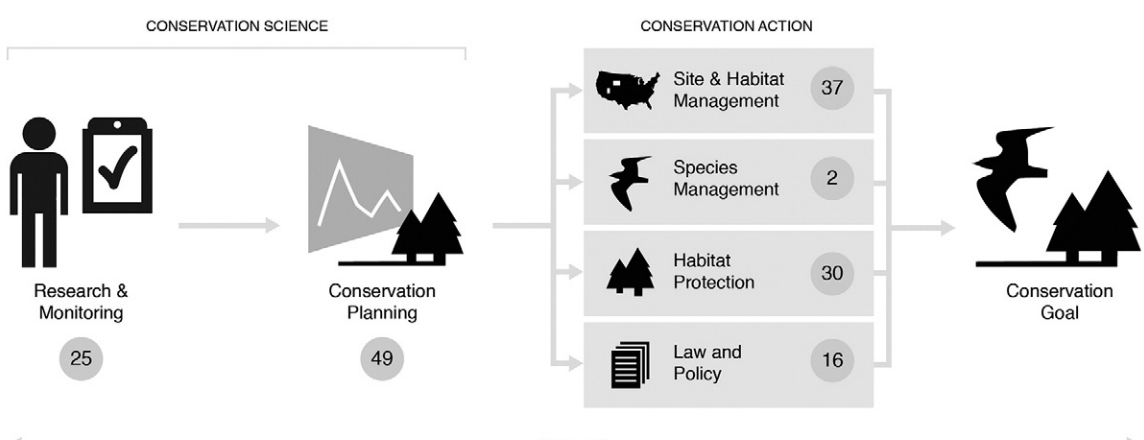

Fig. 1. Framework for classifying conservation science and action resulting from citizen-science, modified from several existing frameworks. Numbers represent conservation actions (N = 159) stemming from the use of eBird data, as reported by survey respondents and classified by the authors.

actions that were not tangible, such as those related to public education or raising awareness of conservation. Some respondents reported multiple actions in the same response; these were separated out and each counted individually. In many cases we wrote to survey respondents for additional information to clarify how eBird data were used. The actions that met our criteria were then classified according to one of the six classification actions listed above. For each reported action, two coders went through each entry. If there was disagreement among coders, a dialogue ensued until consensus on a particular classification was reached. For other qualitative questions with open text responses, we analyzed responses and grouped them into themes, depending on the question. All questions discussed in this paper are listed in Table 1.

3. Results

3.1. Data use audience

Data from the first survey revealed that respondents' field of study was heavily dominated by ornithology and ecology. Nearly all research focused on understanding species distribution, occurrence, and abundance. From Survey 2 we learned that eBird was cited as the primary data set used in 48% of reported research use. Most of the research occurred in North America (77%), followed by South America (9%), and Central America (7%), with the remainder of responses spread across the rest of the world. Respondent affiliations aggregated from both surveys were varied, with 30% stating they used eBird data as private individuals, followed by students (undergraduate, graduate, and post docs — 19%), government employees (16%), NGO employees (14%), academic researchers (12%), and teachers (2%).

When asked why they chose eBird as a data source, respondents from both surveys cited its spatially explicit nature and its comprehensive coverage of all species, year-round, at large scales as being important. eBird's high data volume, open accessibility, and data quality were also cited as benefits (Table 2).

3.2. Data use products/outputs

When asked about products from data use, over a third of respondents entered conservation or management plan as the most common product. Other products, in descending order included: maps or data visualizations, publication, database, environmental assessments, and decision support tools. Several other less common products included posters, checklists, outreach materials, grant proposals, status reports for listing/de-listing species, curriculum materials, mobile software apps, and interactive exhibits. The complete list of products stemming from eBird data use is presented in Table 3. When asked where their research was published (if at all), 30% of respondents reported gray literature, followed by peer-reviewed publications (25%). Another 19% of respondents had submitted something but it was not yet published; 18% reported publishing in popular literature; and 8% used the data in a thesis or dissertation.

Table 2
Eight common themes generated from the question "Why did you decide to use the eBird data set in your analysis?", coded as the count of mentions of each theme across all survey responses (N = 617).

General themes	Count of mentions
Comprehensive (all species/year-round coverage)	170
High data volume	101
Ease of data access	78
Rigorous data quality processes	69
Data currency (timely and relevant)	46
Best/only data source available	44
Geo-referenced data	43
Ease of use (i.e., data format)	24

3.3. Documented conservation actions

Respondents reported 45 tangible conservation actions in the first survey, and 114 in the second survey, resulting in a total of 159 tangible conservation actions. Our framework for describing the process by which citizen-science data are used in both conservation science and conservation action is presented in Fig. 1. The numbers in the figure represent the total number of reported actions (within each category from surveys 1 and 2). Although the framework is presented linearly, we note that there is complexity, variability, and feedback throughout the process, especially as it pertains to how and when data are used. Below we provide an overview of the general patterns for each of the described conservation action categories, along with one reported exemplar for each. Additional exemplars can be found in Appendix A.

3.3.1. Research and monitoring

Research and monitoring include basic and applied research to support biodiversity conservation work. Information on species status and distribution are the building blocks of any conservation assessment or plan. Survey data elicited 25 reported actions fitting this category, including research to describe diversity patterns of avifauna of northeast Mexico, document species distributions for conservation targets under the Agreement on the Conservation of Albatrosses and Petrels (ACAP), and estimate local population extirpations in the northern Andes.

3.3.1.1. Developing the IUCN Red List of Chile's threatened bird species. For the last 30 years, conservation practitioners in Chile have been cataloging the country's flora and fauna into the International Union for Conservation of Nature's (IUCN) conservation categories. However, many species lack assigned categories or have been identified as being Data Deficient (DD) due to lack of data, which precludes them from being considered in conservation plans by the Ministry of Environment of Chile (MMA in Spanish). In 2012, the Centro de Estudios Agrarios y Ambientales and the Red de Observadores de Aves y Vida Silvestre de Chile (Chilean Birding Network) began a project funded by MMA to generate and discover new information on 30 species cataloged as DD. Among these were 7 species of birds: Cinnamon Teal (*Anas platalea*), Short-eared Owl (*Asio flammeus*), Tamarugo Conebill (*Conirostrum tamarugense*), Black Rail (*Laterallus jamaicensis*), Red-legged Cormorant (*Phalacrocorax gaimardi*), Ticking Doradito (*Pseudocolopteryx citreola*), and Rufous-legged Owl (*Strix rufipes*). Updated maps with the distribution and abundance of each species were generated using data from biological collections, published historical records, eBird, and new field data, as well as new biological information (e.g., reproduction, population trends, threats). For the 7 bird species 3364 records were obtained, with 94% of these contributed by eBird. MMA currently uses 'eBird Chile' as one of the main sources of information for classifying bird species'

Table 3
Survey respondents (N = 437) reported a multitude of products that used eBird data.

Product type (N = 434)	Percent of respondents	Response count
Conservation or management plans	31	138
Maps or data visualizations	29	127
Publication	21	92
Database	21	91
Environmental assessments	21	89
Decision support tool	20	86
Poster or presentation	18	78
Publicly available checklists	12	50
Outreach materials	12	50
Policy or regulatory actions	10	42
Grant proposal	8	35
Status reports for listing/de-listing species	8	35
Curriculum materials	7	28
Conservation easement justification	5	23
Mobile software application	2	8
Interactive exhibit	1	6

conservation statuses, requiring researchers who support these processes to include eBird records in every analysis.

3.3.2. Conservation planning

Conservation goals are most effectively articulated and achieved by way of careful, data-driven planning. eBird data are being incorporated into conservation planning processes mainly in the form of information determining species status assessments, both as a primary and supplemental data source. Examples from the 49 reported conservation planning actions in this category include identifying priority areas for conservation in southern Ecuador, setting biological goals, objectives and conservation measures for Gila Woodpecker (*Melanerpes uropygialis*) in California, and informing decisions regarding allocation of conservation funding for waterfowl on the northern Great Plains.

3.3.2.1. Partners in flight species assessment of North American birds. Partners in Flight (PIF) has developed bird conservation plans at state, ecoregional, national, and continental scales (e.g., Rich et al., 2004), all based on a common species assessment process and database (Carter et al., 2000; Beissinger et al., 2000; Panjabi et al., 2001). PIF species assessment ranks species' vulnerability across a set of factors including range size, population trend, and the importance of a given area to the species' overall conservation; until recently these rankings were derived largely using data from the North American Breeding Bird Survey (BBS), a citizen-science data set managed by the U.S. Geological Survey (Sauer et al., 2013). As part of a 10-year revision of the PIF North American Landbird Conservation Plan (Rich et al., 2004), PIF is currently using eBird to develop area importance ranking scores for the non-breeding season for all North American landbirds across Bird Conservation Regions (BCRs: http://www.nabci-us.org/bcrs.htm) and Latin American countries. The eBird analyses allowed, for the first time, the ability to rank regions of highest importance for migratory species during migration seasons and winter. As an example, both BBS and eBird identified the Appalachian Mountains and Piedmont BCRs as having the highest relative breeding densities of Wood Thrush (*Hylocichla mustelina*), while eBird data also made it possible to identify Belize, Guatemala, and the Mexican Caribbean Lowlands BCR as most important for this species in winter.

3.3.3. Site/habitat management

Land protection alone is often not sufficient to ensure the persistence of a species, hence, most conservation initiatives recognize the need to manage or restore specific habitat attributes at important sites. Effective habitat management requires that land managers make informed decisions based on the best available data across a range of scales — from relatively small areas (e.g., a state park) to broad landscapes (e.g., states). eBird data are being used in land management decision-making processes mainly as a source of species occurrence information, especially site-based spatial and temporal occurrence. A total of 37 reported conservation actions fell into this category. Examples included modifying mowing practices to avoid grassland breeding birds, optimizing timing of prescribed burns to reduce avian impacts, and marking powerlines to avoid avian collisions in primary movement corridors for conservation targets.

3.3.3.1. Siting communications infrastructure to minimize potential impacts to birds, USA. The Federal Communications Commission (FCC) is the federal nexus between the communications tower industry and the United States Fish and Wildlife Service (USFWS). In considering effects that communications towers have on endangered species and certain species of migratory birds, the FCC uses online databases, such as the USFWS Information for Planning, and Conservation (IPaC), to provide spatial data on the potential presence of these species. However, the FCC may also need site-specific information to determine if a project may have adverse effects on protected species. eBird serves as a supplementary online database to determine if protected bird species have been observed near a proposed tower site, which can be particularly important when considering species not tracked by IPaC, such as Bald Eagle (*Haliaeetus leucocephalus*), Golden Eagle (*Aquila chrysaetos*), and prairie and sage grouse species (*Tympanuchus*/*Centrocercus* sp.). eBird augments field surveys and federally/state funded online databases, improving the likelihood that the presence of protected bird species would be considered in communications tower siting.

3.3.4. Species management

Species or population management involves actions that directly affect the demography of a specific species. Most of this conservation work involves a hands-on field approach relying on direct human intervention rather than observational data-based decision making, so it is perhaps unsurprising that only two reported conservation actions from eBird data fell into this category, both involving nest box placement for conservation targets.

3.3.4.1. Waterfowl nest box placement in British Columbia, Canada. Nest boxes can help increase the breeding success of many species of cavity-nesting waterfowl. The Rocky Mountain Naturalists club recently used data submitted to eBird when considering duck nest box placements at Elizabeth Lake in Cranbrook, BC. Elizabeth Lake is an eBird Hotspot with more than 339 complete eBird checklists, many of which were generated by the club's regular field trips. eBird data were critical for discovering information on species composition as well as migration and nesting phenology. eBird data helped inform the club about which duck species were present and the right boxes to provide at the most critical times of the year to increase the likelihood of breeding success.

3.3.5. Site/habitat protection

Site and habitat protection is a critical component of any conservation strategy. Conservation work in this category involves actions that legally or formally protect sites, roughly equivalent to the IUCN site categories I–VI (Dudley, 2008). A total of 30 reported conservation actions fell into this category. Most cases involved using species occurrence data used to show the biological and conservation significance of a particular site, thereby allowing it to be identified, elevated, or officially protected. For instance, eBird data were used in the conversion of a former golf course to parkland, land acquisition prioritization by a land trust, and designation of areas as Important Bird Areas (IBAs), as well as elevating the global rankings of several IBAs.

3.3.5.1. Protecting sites of high conservation value, Wellington, NZ. New Zealand's Resource Management Act (1991) requires regional councils to identify "ecosystems and habitats with significant biodiversity values" as part of a wider requirement to promote the sustainable management of each region's natural and physical resources. To this end, the Greater Wellington Regional Council has prepared a Natural Resources Plan, in which 52 sites with significant habitat values for indigenous birds have been listed. The inclusion of these 52 sites is the culmination of 2–3 years' work by a panel of local ornithologists reviewing available data sets describing the distribution and abundance of indigenous birds across the Wellington region. They applied these data against a set of criteria describing thresholds above which a site is deemed to be "significant". Since the launch of eBird in New Zealand in 2008, some 100,000 records have been accumulated for the Wellington region, describing the distribution and abundance of 173 bird species. Using these data, the ornithologists working on Wellington's Natural Resources Plan were able to use the proportions of checklists submitted for particular sites to quantify the diversity of resident and migrant (as opposed to vagrant) bird species using particular sites, and in some cases to estimate the proportion of the regional populations of target species that regularly utilize these sites. In the past, this type of work was often based on a combination of the expert opinions of local ornithologists and relatively sparse survey data. The identification of these 52 sites was accomplished through an evidence-based approach, with a clear link formed between the final list of sites included in the Natural Resources Plan, the criteria used to identify them, and the data used to demonstrate that these sites met the criteria. This enabled ornithologists to identify new sites that had previously been deemed "data deficient" based on evidence in addition to expert opinion. The justification for including many of these sites now can be more readily explained to landowners, developers, and other government agencies than at any time in the past. As a result of this network of 52 sites being listed in the Wellington region's Natural Resources Plan, landowners, companies, or agencies applying for a consent under the Resource Management Act to carry out an activity at any of these sites face much stricter requirements to demonstrate that their activities have minimal adverse effects on the bird values present, before receiving permission to carry out their activities.

3.3.6. Law, policy, and regulation

Developing, implementing, or enforcing laws, policies, and regulations to protect biodiversity also yields conservation impacts. Data can be used to enforce laws that stop development, inform everyday decisions made by conservation practitioners, establish new laws and regulations, and support the listing or delisting of a conservation target. Respondents reported 16 conservation actions in this category, ranging from actions that helped stop proposed local developments, to halting wind energy siting in areas of high potential impacts to birds, to high-level legislative processes involving the listing or delisting of threatened and endangered species.

3.3.6.1. Listing the rufa Red Knot as a threatened subspecies. eBird is one source of data used by the US Fish and Wildlife Service (the Service) to document seasonal patterns of occurrence of a species as part of the listing process for threatened or endangered status. In the case of the *rufa* Red Knot (*Calidris canutus rufa*), data from consistent long-term surveys were available from only a few locations, with most breeding and nonbreeding areas poorly or inconsistently covered. For such areas, eBird data was one of several primary data sources in the Service's effort to use the best available data and science to assess the status of this species. In the final listing rule (Federal Register Vol. 79, No. 238, p. 73731), the Service noted that eBird is based on citizen science, which can be scientifically rigorous, for example by employing data quality control protocols to minimize the risk of mistaken bird identification. Although the Service acknowledged that sampling biases toward more popular bird-watching locations can limit eBird's ability to track long-term population changes, it also recognized that eBird provides the only available data source for Red Knot occurrence information in many parts of the species' range.

4. Discussion

Our study shows that conservation practitioners, as well as private individuals, use broad-scale observational data sets, like eBird, for conservation planning and action. Furthermore, open access to observational citizen-based data sets may reduce the "knowledge to action" gap that is typically prevalent in the conservation arena. The scale, availability, and comprehensive nature of these data provide the flexibility to serve as a primary data source in areas where more standardized data are lacking, as well as supplemental data that fills spatial and temporal gaps around more structured surveys. Projects like eBird offer the conservation community access to salient, credible, broad-scale information that can be used in conjunction with other approaches and applied to everyday conservation problems. eBird's core tenet of providing open and free access to data is key to its conservation use, allowing a broad array of users across many disciplines to use the data however they choose.

4.1. Audience and motivations

eBird participation is heavily skewed toward North America when viewed through a global lens, and this explains why many of our conservation outcome exemplars are from that region. eBird was launched globally in 2010 (Sullivan et al., 2014), and international growth has been rapid (if spatially uneven), with a 70% annual increase in eBird submissions outside of the United States from 2012 to 2014. Bringing eBird to a global scale requires intensive partnership-building and community outreach, and realizing the project's global vision will require time, sustained resources, and institutional support. What seems obvious, however, is that in places around the world where eBird is functioning at a high level (e.g., lots of participation and consistent data quality/review processes), the conservation community is paying attention and beginning to use these data to help solve real world conservation challenges. It will be important to track the geographic spread of conservation actions achieved as the data set becomes increasingly global.

Surprisingly, private individuals downloaded more data than any other audience, typically using the data to inform issues at the local and regional levels. Many of the reported actions had to do with protecting local parks or natural areas or preventing further development in altered landscapes. This is an important finding because grass-roots conservation actions are typically associated with smaller, localized projects, and rarely attributed to large-scale global projects (Wiggins and Crowston, 2011). Additionally, widespread use of data by private individuals suggests that this data set is useful to the layperson, perhaps overcoming the often-cited knowledge to action barrier, and the suggestion that access to the 'best available science' might be overly complicated or impractical (Cook et al., 2013; Sunderland et al., 2009).

eBird is used for conservation because of its quality, accessibility, and comprehensiveness (all species; large geographical scale; year-round). This combination of features has allowed it to be used as the root or as a supporting data set in the conservation actions described in this paper. This list of qualities complements those in the knowledge to action gap literature (i.e., salient, credible, and legitimate; Cook et al., 2013) with its emphasis on the ease of access and usability. Having access to a voluminous and rapidly growing, well-curated set of freely available data on bird distribution and abundance is essential in bird conservation initiatives. eBird is novel in making these kinds of data easily accessible to anyone for any species in any location around the world.

4.2. Products

A diverse range of products has been created using eBird data. They include curriculum and outreach materials, environmental assessments, conservation plans, and interactive exhibits. The dissemination of such diverse products demonstrates the broad utility of the eBird data set and increases exposure of eBird and citizen science to potentially new audiences. Additionally, 60% of publications based on eBird data appeared in either gray or popular literature, further increasing the potential to reach new and diverse audiences. Although outside the scope of this paper, there could be value in tracking and measuring the conservation impacts of products and publications that are disseminated outside of scientific and academic circles.

4.3. Actions

While many citizen-science projects strive to achieve conservation goals, few projects have documented and reported demonstrable conservation actions. Project scope and scale vary widely, ranging from local or regional scale projects designed to answer a specific question or to address an immediate threat, to global scale projects that gather massive amounts of information with no single *a priori* hypothesis, making data available to a broad and diverse constituency of data users. Following broad-scale observation data from collection processes through to conservation action can be a challenge and currently, open access to data generally means that data providers have decreased knowledge about data use and little information about specific conservation actions resulting from use of their data. For example, while GBIF reports more than 22,000 downloads of eBird data, we do not know whether any of these downloads resulted in analyses that led to conservation action. To document the role of data like these in conservation actions, it is critical to follow-up with data users, after the point of data access, to learn about broader impacts.

Our analysis reveals that eBird data are used extensively for building the knowledge base of conservation science, especially through research and monitoring and conservation planning. We were surprised by how often eBird data were used to influence conservation action, mostly through site and habitat management ($n = 37$), habitat protection ($n = 30$), and law and policy ($n = 16$), which are considered to be ultimate, on-the-ground conservation actions. We were not surprised that use directly for species management was less common ($n = 2$), because such actions typically require in-depth knowledge about individuals and population sizes at a very fine scale. Additionally, we saw examples of conservation action that perhaps are unique to use of open-access observational data. For example, we learned of several actions involving private citizens using eBird data to halt building projects such as residential development and wind turbine siting (in local areas). These examples provide preliminary evidence that citizen-science data can have practical utility for individuals, and increase the potential to further democratize science for society.

In addition to providing evidence that citizen-science can yield true conservation actions, we demonstrate how using a framework of categories for classifying conservation science and action within citizen-science is useful for tracking and measuring the impacts of citizen-science data collection efforts. We encourage other projects to conduct their own investigation of conservation actions stemming from data use using this framework, and to publish these findings so that we can better understand how citizen-science does or does not influence conservation more broadly. Furthermore, using a common framework to classify conservation action outside the citizen-science domain would allow for a better understanding of which types of efforts are most effective, the characteristics of those efforts, or predictors of effectiveness. Our results also raise interesting questions about the relative frequency of various categories of conservation actions in the global conservation arena. Such information could provide a useful benchmark for understanding how various types of conservation science knowledge (e.g., citizen-science) contribute to, and complement each other in, influencing conservation impacts and overcoming the knowledge to action gap.

4.4. Caveats for data use

Measuring ecological patterns and predicting their responses to environmental change is not an exercise in curiosity. Today, it is an essential task for understanding the causal effects that human activities have on earth's natural systems, and for developing science-based environmental policies. The data required to inform policy may need to be gathered at continental spatial extents and across the year (Marra et al., 2015). In order to gather data at such scales, eBird uses protocols that may be relatively unstructured in order to engage a larger number of observers (Hochachka et al., 2012a). Because these protocols do not control for several sources of error and bias during the process of data collection, these sources of noise need to be accounted for during data management (Sullivan et al., 2014) and analyses (e.g., Kelling et al., 2015). Failure to account for biases in the data that are collected can lead to inaccurate conclusions.

Based on our own experience in controlling sources of noise within the data from eBird, we have created resources intended for wider use. The results of automated and human screening of the observations (Sullivan et al., 2014) feed into the data that are used internally and publically distributed: only observations that have been validated become part of data products. eBird is a "living" database in which any record can be reviewed and validated or invalidated in light of new information; thus, new versions of the data do not simply add new records, but instead represent a complete re-assembly of the data being distributed. Our own work has shown that variation in the observation process (e.g., duration of observation periods, distances traveled, and time of day) affects the probability that birds will be detected, and thus variation in the observation process needs to be described in the models used to analyze eBird data. All of the factors that we have identified as relevant have their information included in the data that are distributed, and the processes that we use to incorporate this information in models are described in publications based on our uses of the data (e.g., Fink et al., 2010; Johnston et al., 2015). Additionally, we actively work to develop new methods for reducing the effects of noise within eBird's data, and publish descriptions both of specific new methods (e.g., Hochachka et al., 2012a; Johnston et al., 2015; Kelling et al., 2015) as well as more general discussions of using data from eBird and similar sources of data (e.g., Hochachka et al., 2007, 2012b; Munson et al., 2010). Our practices for controlling for noise during analyses are now standardized sufficiently that at the time of writing this paper we are planning the creation of an additional resource: white-paper-style documents describing our recommendations of best practices for use of the data products that we distribute.

5. Conclusion

The aspiration of most well-conceived citizen science efforts is not simply data collection, but rather use and application of data to broader societal issues, education, or environmental management. Here we demonstrate how one well-curated, openly available data set has created a broad array of conservation actions. Citizen-science data are now being used in real-world conservation scenarios to inform management, protection, and legal issues. Further, these data are openly available to anyone on a global scale, providing new opportunities for evidence-based, conservation decision-making. When applied with appropriate care and with data use caveats taken into consideration, citizen-science data can serve as a stand-alone data source or complement more rigorous scientific approaches by filling in spatial and temporal gaps. In many places around the world rigorous data sets do not exist for informed conservation decision-making, and in these cases citizen-science approaches to data collection may offer conservation practitioners the 'best available data' to address a specific conservation need. Although broad-scale surveillance monitoring projects such as eBird have known and documented limitations, we argue that real-time sampling of the world's bird populations by human sensors provides conservationists with a cost-effective way to keep a collective finger on the pulse of bird populations around the world, at a scale never before possible. This approach provides new opportunities for analysis that combine these data with those collected by an increasingly diverse array of autonomous sensors in the environment. As data volume grows and data quality improves, broad-scale, multidisciplinary data use should likewise grow, as will the importance of citizen science in addressing the ever-increasing challenges in biodiversity conservation.

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Appendix A. Additional conservation action exemplars

A.1. Determining species distributions for conservation targets in the Philippines

Hosner et al. (2013) described a new species of *Robsonius* ground-warbler from the Philippine archipelago. *Robsonius* are extremely secretive birds known from few localities (38 unique localities among three species), and the limits of their distributions are poorly understood. Hosner et al. used eBird and museum locality data to model *Robsonius* distributions in order to (1) infer distributional limits and estimate range sizes for each species to inform conservation status assessments, and (2) to identify areas of suitable environmental conditions for future survey effort and formal protection. Hosner et al. made recommendations to the IUCN that the status of *R. rabori* be changed to "endangered" and that the statuses of *R. thompsoni* and *R. sorsogonensis* be set at "vulnerable." Since no protected areas intersected with predicted *Robsonius* distribution NW of the Cordillera Central they further recommended that surveys for *R. rabori* focus on this region, and suggested that *R. rabori* be used as a flagship species to protect forested habitats in this region.

A.2. Status assessment for the endangered Tricolored Blackbird in the Sierra Nevada foothill grasslands of California, USA

Tricolored Blackbird (*Agelaius tricolor*) is a near-endemic California species, suffering both long-term and rapid recent population declines, leading to its listing by the State of California as Endangered in 2014. Many studies of the species have focused on populations and agricultural conflicts in the Central Valley, but much less is known about the population segment that nests in grasslands in the lower Sierra Nevada foothills. Airola et al. (2015) led a citizen-science effort in these grasslands in 2014 and 2015 to determine the breeding population size, habitat requirements, reproductive success, and land use conflicts. Birders and biologists surveyed the 5700 km^2 study area, and found that nearly a third of the statewide Tricolored Blackbird population was nesting, mostly successfully, in the Sierra foothills. eBird provided a mechanism to locate, nearly in real time, aggregations of Tricolored Blackbirds. In several cases, active nesting colonies were reported in eBird that were not known to the survey team. In other cases, reports of foraging flocks drew the teams' attention to areas where nesting colonies were subsequently found.

A.3. Targeting areas of outstanding conservation value in Nova Scotia

The Nova Scotia Nature Trust (NSNT) is a land conservation organization in Nova Scotia, Canada that works with private landowners to protect properties of outstanding conservation value. These private lands are often not well inventoried with regard to biological data relative to government-owned land, despite land ownership in the province being primarily private. NSNT uses eBird data to predict which bird species are likely present on properties of interest for conservation. Volunteers then visit properties of interest and create bird lists, which are added to eBird. NSNT is also notified of new bird data for properties of interest, and these data help contribute to understanding a property's conservation value.

A.4. Updating the Oregon Department of Fish and Wildlife Conservation Opportunity Areas, Oregon, USA

The Oregon Conservation Strategy (OCS) was released in 2006 by the Oregon Department of Fish and Wildlife (ODFW) as part of a US Fish and Wildlife Service effort to have state agencies produce State Wildlife Action Plans (SWAPs). The OCS is a non-regulatory planning document, used by natural resource agencies, conservation organizations, landowners, and others who want to enhance and conserve Oregon's wildlife and habitats. The Strategy prioritizes Strategy Species, Strategy Habitats, Key Conservation Issues, and Conservation Opportunity Areas (COAs), which aim to focus investments in conservation actions onto landscapes where broad fish and wildlife conservation goals can best be met. COAs are delineated through spatial analysis and expert review, and are provided both as maps throughout the OCS and available for download as a GIS spatial data layer. In 2015, ODFW will submit the 10-year revision of the OCS to USFWS, updating it with new science, information, and conservation priorities, and improving COA boundaries using new data sets. The updated COA included observations of Strategy Species, as well as species predicted habitat models, updated Strategy Habitat maps, and a variety of other input data sets that help provide a systematic way to map COAs across Oregon. eBird data provided more than 35,000 new records of Oregon Conservation Strategy Species gathered over the past 25 years. At a time when continued increases in pressures on species and natural resources combine with limited agency resources to undergo intensive monitoring efforts, citizen-based data sources such as eBird play an important role in providing data for statewide conservation applications.

A.5. Determining species of greatest conservation need in Delaware, USA

The Delaware Department of Natural Resources Division of Fish and Wildlife recently completed a ten-year revision of the Delaware Wildlife Action Plan, as required by the US Fish and Wildlife Service. Part of the revision process involved improving prioritization of Species of Greatest Conservation Need (SGCN) identified in the plan. In order to accomplish this objective, SGCN were screened to determine species for which Delaware had high responsibility within the Northeast U.S. region, using the best available data (population estimates, area of occupancy (AOO), or extent of occurrence (EOO)). eBird checklist data and mapping products were used as one of several data sources to evaluate whether the state's responsibility for a given bird species exceeded a set threshold that was based on the relative land area ratio of the state to the region as a whole. eBird mapping tools were especially useful in providing a consistent basis for estimating Delaware's contribution to overall regional AOO and EOO for bird species for which state, regional, and/or continental population estimates were unavailable.

A.6. Optimizing mowing practices for grassland birds, New York, USA

Croton Point County Park is a 504-acre peninsula on the Westchester County Hudson River shoreline in New York, USA. Starting in the 1920s, over 100 acres of this peninsula was converted from tidal marsh to municipal landfill. In the early 1990s this landfill was capped and Saw Mill River Audubon helped convince Westchester County to establish native grassland habitat on the landfill cap. However, over the last two decades proper maintenance of the grasslands has proven to be an ongoing challenge. Croton Point County Park is within the Lower Hudson River Important Bird Area, and as a popular birding spot, the site has good birder coverage and the second highest number of eBird records of any location in the county. eBird data documented that grassland birds otherwise uncommon in the region (e.g., Grasshopper Sparrow (*Ammodramus savannarum*), Savannah Sparrow (*Passerculus* *sandwichensis*), Bobolink (*Dolichonyx oryzivorus*), and Eastern Meadowlark (*Sturnella magna*)) were attempting to nest in the landfill grassland habitat, but were being prevented in doing so by poor mowing practices. Over the last three years, better mowing practices have resulted in eBird-documented nesting success in all four grassland species. In 2014, three nesting pairs of Grasshopper Sparrows were the only nesting records in the Lower Hudson Valley. In 2015, new nest boxes for American Kestrel and new nesting platforms for Osprey were added based on eBird records of high spring numbers of both species visiting this site. Records from eBird have also documented year-to-year migrant use of the landfill grasslands by several other grassland species that are scarce in the region.

A.7. Powerline retrofitting to reduce avian electrocutions in Colorado, USA

Birds are frequently injured or killed when they collide with overhead power lines or contact energized system components. Many power line owner/operators use Avian Protection Plans (APPs) to minimize risk to birds, improve system reliability, and decrease the likelihood of federal prosecution under the Migratory Bird Treaty Act. EDM International Inc. (EDM) develops APPs on behalf of investor-owned utilities, small rural electric cooperatives, military installations, federal agencies, mines, and oil and gas operations across the United States. EDM uses eBird data with habitat and occurrence data from other sources to help identify key use areas for raptors, which are especially vulnerable to electrocution. In preparing field maps, EDM identifies clusters of eBird records within 1/4 mile of one another—clusters are more relevant than isolated observations, and also, multiple observations and observers are more credible than a single record. eBird data help EDM biologists to implement avian mitigation measures in areas that are occupied by at-risk species, where interventions will have maximum conservation benefit. Since 2010, EDM has recommended countless power line retrofits in the vicinity of eBird observation clusters, many of which have prevented, or will prevent, avian mortalities.

A.8. Wind energy siting optimization, Tennessee, USA

eBird records were used to assess relative risk to Bald Eagles (*Haliaeetus leucocephalus*) and Golden Eagles (*Aquila chrysaetos*) from proposed wind farms in Tennessee. Using these eBird data, the US Fish and Wildlife Service was able to generate statewide maps that concisely described Bald and Golden Eagle presence in each county in the state. Once presented with these maps, several project proponents chose to suspend pursuing development of wind farms in counties with high numbers of eagles, while others chose to only pursue development in counties with the least risk of impacting these species.

A.9. Expanding a Ramsar site in the Fraser River Delta, British Columbia, CA

Two citizen science data sets, one of which was eBird, were extensively harvested to obtain maximum species counts at specific locations, as part of an approved proposal that in 2012 resulted in the vast extension of the Alaksen Ramsar Site designation as a Wetland of International Importance from 586 ha to 20,682 ha, becoming the Fraser River Delta Ramsar Site. Specifically, eBird maximum site-count data were used to demonstrate regular bird use exceeding the Ramsar global thresholds for several species of coastal waterbirds, including gulls and sea ducks, especially for the Sturgeon Bank and Boundary Bay portions of this complex site. The area is a major birding destination, with a high proportion of birders who submit observations to eBird; the value of their efforts is brought to bear in this international designation which confers greater urgency on the Government of Canada under the terms of the Ramsar Convention to conserve and sustainably use this major wintering and migratory stopover site, which is also designated as an Important Bird Area and Western Hemisphere Shorebird Reserve Network site of global importance.

A.10. Important Bird Area designations in Chile

In 2009, BirdLife International in conjunction with local partner organizations, released a report highlighting Important Bird Areas (IBAs) for Chile (Soazo et al., 2009). The report is based on a wide amount of published data, including rigorous data collected on seabirds and large waterbirds such as flamingos in the Altiplano region of the country. However, there was a dearth of published information on abundances and occurrences of many species of conservation concern, sites with high concentrations of shorebirds, or information on migratory species in Chile such as Franklin's Gull (*Leucophaeus pipixcan*) and Elegant Tern (*Thalasseus elegans*). The primary source for specific numbers and recent records of these species came from eBird Chile (http://ebird.org/content/chile/; acknowledged on page 133 of the IBA document), and analysis of which provided sufficient data to identify candidate sites that were eventually included as IBAs. A substantial portion of these were new sites that were not previously identified as being important for birds, but were identified as such because local birders and researchers had been diligent in data collection, and in particular in the inclusion of population estimates of birds recorded through eBird. This information has been key in prompting local municipalities to officially preserve these sites due to their high conservation value.

A.11. New law to protect wildlife from disturbance in Florida state parks, Florida, USA

Restored in the mid-1990s, Tomoka State Park marsh restoration area has become a significant stopover and overwintering location for migratory waterbirds and landbirds, as well as an important site for nesting resident birds. The site is actively surveyed by eBirders, and during a survey on 5 October 2014, an observer noted someone flying a drone just a few inches above the marsh. Usually active birds fell silent (e.g., rails), and remained so for several days afterward. Realizing the degree of disturbance caused by this recreational activity, the observer sent documentation to the park manager outlining the concerns. Drones are already banned in US National Parks, and they were already an issue of concern at the state level. Documentation of this event and data verifying the importance of the site for birds collected through eBird, were used to help support the passing of a new law prohibiting drones in all Florida State Parks.

A.12. Listing the Pacific subspecies of Western Screech-Owl as threatened

The coastal subspecies of Western Screech-Owl (*Otus kennecottii kennecottii*) was assessed as Threatened in 2012 by COSEWIC (Committee on the Status of Endangered Wildlife in Canada). COSEWIC is a group of independent scientists responsible for making recommendations to the Canadian Minister of the Environment about species that may qualify for protection under Canada's Species at Risk Act. Questions were raised during the ensuing public review process about evidence for rarity and decline of this species. This triggered further investigation using data from eBird and other lines of evidence. eBird data for British Columbia (BC) confirmed the restricted distribution of this species, with records largely confined to Vancouver Island and the south coast. A comparison with eBird records of Barred Owls confirmed that the absence of records of screech-owls from central and northwestern BC was not simply due to lack of coverage of these regions. This information on distribution was combined with evidence from other citizen-science projects, including the BC Breeding Bird Atlas, BC's Nocturnal Owl Survey, and Christmas Bird Counts in BC and adjacent Washington state. The weight of evidence from these data, combined with targeted surveys, confirmed the Threatened status of this subspecies.

A.13. Brown Pelican status review by Washington Department of Fish and Wildlife, Washington, USA

Brown Pelican (*Pelecanus occidentalis*) reaches the northern extent of its range along the Pacific Coast in Washington and British Columbia, mainly during post-breeding dispersal from southern nesting areas (Shields, 2014). It is currently listed as endangered in Washington. In order to generate an updated status report on this species in Washington (http://wdfw.wa.gov/publications/01693/), eBird data were used to supplement more structured survey data, providing a more comprehensive picture of Brown Pelican's seasonal occurrence in the region. eBird data included the identification of previously unreported roost locations, high counts of pelicans at roost sites, and the timing of occurrence of peak numbers — all of which collectively indicated that Brown Pelicans were more numerous than previously thought and should be removed from the state list of endangered species.

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