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THE AVIAN KNOWLEDGE NETWORK: A PARTNERSHIP TO ORGANIZE, ANALYZE, AND VISUALIZE BIRD OBSERVATION DATA FOR EDUCATION, CONSERVATION, RESEARCH, AND LAND MANAGEMENT

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Abstract. The Avian Knowledge Network (AKN) is an international collaboration of academic, non-government, and government institutions with the goal of organizing observations of birds into an interoperable format to enhance access, data visualization and exploration, and scientific analyses. The AKN uses proven cyberinfrastructure and informatics techniques as the foundation of its development. Data are made available via secure and managed pathways. Additionally, data visualization and exploration tools are made available by a broad and diverse community of developers, analysts, and biologists. Through the development of tools and standardized data organization models, new analysis techniques are being developed that explore data fusion and federation techniques that allow the investigation of patterns of bird occurrence across multiple datasets. Finally, the Avian Knowledge Alliance uses the AKN and consists of a distributed network of nodes that provide regional or thematic access to decision support tools and other applications to support research and bird conservation across a variety of spatial scales.

Key Words: bird occurrence data, data organization management, discovery, access, visualization, exploration, and analysis, internet, information, technologies, informatics, user community.

LA RED DE CONOCIMIENTO DE AVES: UNA ASOCIACIÓN PARA ORGANIZAR, ANALIZAR, Y VISUALIZAR DATOS DE OBSERVACIONES DE AVES PARA LA EDUCACIÓN, CONSERVACIÓN, INVESTIGACIÓN Y MANEJO

Resumen. La Red del Conocimiento de Aves (AKN – por sus siglas en Inglés) es una colaboración internacional de instituciones académicas, gubernamentales y no-gubernamentales con el objetivo de organizar observaciones de aves dentro de un formato que facilite el acceso, visualización, exploración y análisis científico de datos. La AKN usa como base de desarrollo cyber-infraestructuras probadas y técnicas de informática. Los datos se proveen a través de vías seguras y controladas. Además, herramientas para visualización y exploración de datos son proveídas por una comunidad diversa de programadores, analistas y biólogos. Debido a éste avance de herramientas y modelos estándar de organización de datos, nuevas técnicas de análisis están siendo desarrolladas que exploran métodos de fusión y federación de datos, permitiendo la investigación de patrones de ocurrencia de aves en múltiples bases de datos. Finalmente, la Alianza del Conocimiento de Aves usa la AKN y consiste de una red distribuida de nodos que suministran acceso regional o temático a herramientas de soporte de decisiones y otras aplicaciones que fomentan la investigación y conservación de aves en de una variedad de escalas espaciales.

INTRODUCTION

The AKN (http://avianknowledge.net) is an international collaboration of academic, non-government and government institutions focused on understanding the distribution, patterns and dynamics of bird populations across the Western Hemisphere. This collaboration has developed the organizational framework to gather and store existing and new bird observational data

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(hereby referred to as bird data), which includes census, monitoring, banding, and specimen data. The emphasis is to organize this bird data into an interoperable format that enhances application development, access, and exploration. By doing this the AKN provides the opportunity to create information products such as visualizations (via maps, graphs, and tables) and scientific and technical analyses.

The cyberinfrastructure developed for the AKN is a combination of databases, networking protocols, and computational services. This allows a geographically distributed community to participate in the Network, and establishes a new informatics-based paradigm for bird population studies. Specifically, the goal of the AKN is to use broad and diverse data resources and new analysis techniques to make accurate predictions of species occurrence and to identify the factors affecting that occurrence at a variety of spatial and temporal scales. (Hochachka et al. 2007). For example, AKN resources have been used in large-scale analyses to model the occurrence of all birds at continental scales (Fink and Hochachka 2008), to do detailed analyses of a specific species in restricted locations (Nur et al. In Press), and to predict future distributions given climate change projections (http://data.prbo.org/cadc2/index.php?page=climate-change-distribution).

In this paper we first describe how the AKN organizes and provides access to bird observational data. Next we identify the AKN as a collective development group that contributes to the success and scope of this initiative. Finally, we describe a suite of data exploration, analysis, and visualization tools resources that use AKN data resources.

THE DISCOVERY OF BIRD OBSERVATIONS VIA THE AKN

The first step that an individual must take in using the AKN is to determine what data collections are available, where the collections are from, and how the data can be accessed. Descriptive metadata (i.e., "data about data") provide information on the identification, quality, spatial context, data attributes, and distribution of data sets, using a common terminology and definitions that prevents loss of the original meaning and value of the collection resource (Bose and Frew 2005).

The AKN uses descriptive metadata to describe the data collections and provide information on their accessibility. The common terminology used in describing the collections is particularly important because bird data are dispersed throughout the Western Hemisphere and different projects collect data at a variety of scales, using dissimilar protocols for data gathering, and maintain those data in various formats. Thus, without metadata that is based on a common descriptive terminology, it would require a monumental effort to discover what resources exist, how to access them, and what and how the bird data were collected.

The AKN descriptive metadata conforms to the Biological Data Profile, developed by the Biological Data Working Group of the United States' Federal Geographic Data Committee (FGDC) (http://biology.usgs.gov/fgdc.bio/charter.html). The FGDC biological Data Profile is a user-defined, theme-specific profile for describing all biological data with the purpose of increasing compatibility in the development, use, sharing, and dissemination of these data. Through the FGDC Data Profile, the AKN provides an accurate description of the project that collected the bird data and its spatial attributes, which include bounding coordinates for the specific project, how data were gathered, limits of coverage, and how these data are stored. The descriptive metadata also identifies the data structure of the specific bird data collections, with details of how to access the data and/or how to access tools that can manipulate the data (i.e., visualization, statistical processes, and modeling. Presently, over 140 bird data collections have been fully described using the FGDC Biological Data Profile.

The Bird Monitoring Data Registry (BMDR) is an archive of FGDC descriptive metadata and is available at the AKN website (http://www.avianknowledge.net/content/datasets). Each AKN data provider describes their bird data collection, which is posted on the AKN website. Additionally, descriptive metadata are provided to the National Biological Information Infrastructure (NBII) Metadata Clearinghouse.

THE ORGANIZATION OF BIRD OBSERVATIONS IN THE AKN

Once a project has been "discovered" the next step is to determine the means of access to the data. This is challenging, because bird data collections are maintained by a variety of institutions that are widely dispersed, with their resultant data stored in various heterogeneous data architectures. Maximizing efficient use of observational data for exploration, visualization, and analysis requires across-site mechanisms to synthesize these disparate resources into a unified entity—that is, the databases must be made interoperable.

The AKN is spearheading an effort to achieve interoperability of bird data by following

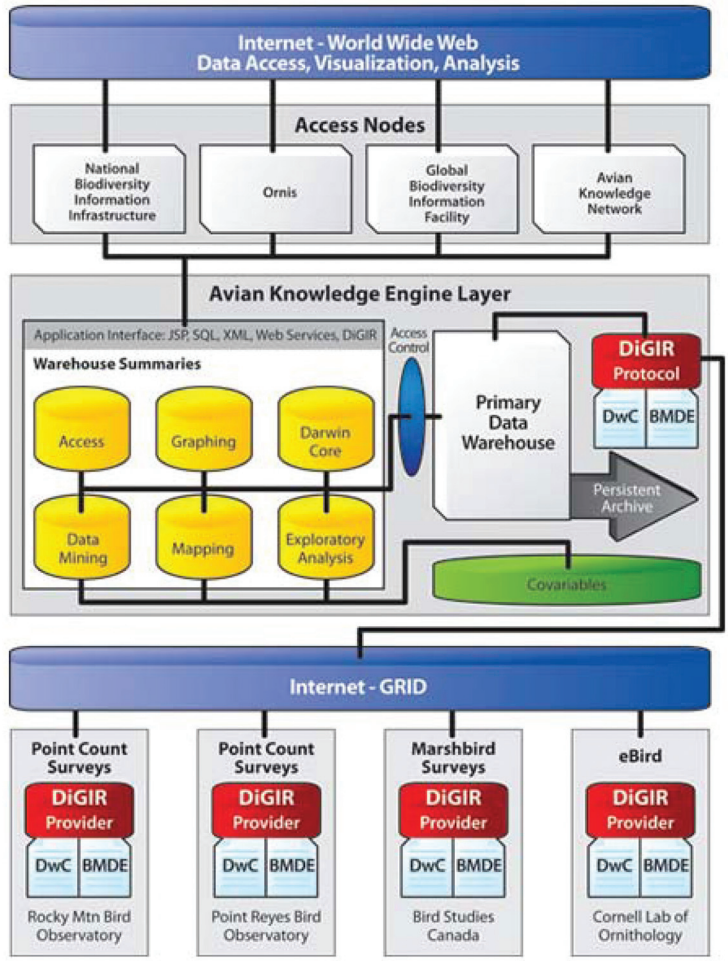

FIGURE 1. The AKN cyberinfrastructure.

standardized data formats being developed for biodiversity data (Kelling 2008). This is being accomplished by adopting existing data organizational standards, external portals, and data harvesting structures. Currently, data exchange schemas, which make data collections interoperable by transforming heterogeneous data into a standardized target format schema, and have been used successfully to organize hundreds of millions of biodiversity observations.

The data exchange schema that the AKN has implemented is a version of the Darwin Core http://www.tdwg.org/activities/darwincore). The Darwin Core schema includes a simple set of data element definitions designed to support the sharing and integration of primary biodiversity data, and is used by multiple biodiversity data clearinghouses. While initially developed to organize museum specimen collections, the Darwin Core schema is extensible. Specifically, the AKN has developed the Bird Monitoring Data Exchange schema (BMDE) (Lepage et al. 2005), which contains additional variables associated with bird data, that includes; fields describing species and taxonomy, count, date and time of observation, locality, survey protocol and effort, bird-banding information, as well as information on the organization and project that provided the data. The BMDE currently holds more than 53 million observations of 5069 taxa provided by 46 different partner organizations.

Data organized in the BMDE are stored centrally at the AKN's primary data warehouse (see Fig. 1 above), which is located at Cornell University. While the AKN is not intended to be a comprehensive data repository that maintains a complete copy of each data collection, the AKN

data management strategy does strive to establish, maintain, validate, and provide access to high quality bird data for long term use. It does this by providing a standard method of sharing bird data to a variety of users. For example, AKN nodes (see The AKN Community below) regularly harvest data specific to their region or protocol of interest. Depending on the level of data access (see Access Control below) data are also regularly shared with other initiatives such as the Global Biodiversity Information Facility (GBIF; http://www.gbif.org), which provides distributional information for all organisms on the planet, or the Ornithological Information System (ORNIS; http://olla.berkeley.edu/ornisnet/) which organizes spatial and temporal information on birds, including observational data and specimen data. In addition, the AKN cooperates with the National Biological Information Infrastructure (NBII; http://www.nbii.gov/portal/server.pt) to organize metadata for bird monitoring projects throughout the Americas.

AKN DATA ENRICHMENT

AKN data represent more than 400 000 distinct geographic locations across North America. These site-specific data are made more useful by AKN's Covariate Spatial Table, which applies multiple habitat, human population, geographic, and climatic variables (i.e., annual rainfall or average temperature) to each location within the United States. By adding remotely-sensed variables at the spatial (e.g., habitat, climatic averages) or temporal (e.g., weather) scales, increased data richness is achieved, allowing for additional analyses and explorations to be performed. Computer models predicting bird distribution based on avian data from the AKN and landscape characteristics from the Covariate Spatial Table are currently being explored. Expansion of the variables contained in the Covariate Spatial Table is ongoing, and will continue to enrich the data within the AKN.

AKN SYSTEM CYBERINFRASTRUCTURE

The AKN uses grid technologies and standard informatics processes to federate disparate bird data resources (Fig. 1). What follows is a brief description of the data flow through the AKN cyberinfrastructure. First, data providers link their existing data to the BMDE. The DiGIR client/portal software federates the distributed data and centralizes it in the primary data warehouse. The primary data warehouse is backed-up offsite, using persistent archive technologies. Environmental co-variables are linked via location and data to locations where bird data have been collected. Depending on the access control requirements and analyses required, subsets of the data are made available as warehouse summaries. An application interface layer allows the development of exploration, visualization, and analysis tools. Anyone can create applications that interact with the AKN data through the application interface and use the data stored in the warehouse summaries.

AKN DATA ACCESS

Data access is controlled by five access levels, and applications used for data exploration and visualization do not connect directly to the AKN primary data warehouse. These access levels are:

1. No access without prior consent.
2. Data can be used in certain publicly available, predefined visualizations.
3. Data can be used for visualizations, and can be provided with permission of the data owner.
4. Data are made available for visualizations, and international biodiversity initiatives such as the Global Biodiversity Information Facility.
5. Data can be accessed directly from the AKN website.

Depending on the permissions provided by the data owner, data view applications are developed to provide access. These applications include:

1. Data for access from the AKN website.
2. Data for harvesting from GBIF and ORNIS.
3. Data for developing new analysis techniques in computer science.
4. Data for developing data mining techniques in modelling of bird distributions.
5. Data for predicting spatial and spatio-temporal patterns of bird populations.
6. Data for web mapping for bird conservation.

THE AKN COMMUNITY

The AKN is a community-driven initiative that includes members and contributors from non-governmental organizations (e.g., PRBO Conservation Science, Bird Studies Canada, Klamath Bird Observatory, Institute for Bird Populations, and Rocky Mountain Bird Observatory), academic institutions (e.g., Cornell Laboratory of Ornithology and the Avian Science Center at the University of Montana), and government agencies (e.g.,

Department of Defense, U.S. Forest Service, and U.S. Geological Survey). These members and contributors support the AKN both directly (through guidance, development, and data contribution) and indirectly (through promotion and community engagement).

An important feature of the AKN is its distributed network of access nodes. AKN access nodes provide a broad spectrum of services that include:

1. Curation of data from original data sets;
2. Integrating original data sets into AKN's BMDE schema;
3. Developing data set-specific visualization or analysis tools that can be adopted more broadly;
4. Providing access to regionally or thematically relevant data and analysis;
5. Providing contact and outreach to the local bird monitoring community.
6. Providing contact and outreach to the local habitat management community.

In addition, the AKN works closely with the Avian Knowledge Alliance. The Alliance promotes and helps design coordinated bird monitoring projects, facilitates data contribution to the AKN, solicits feedback from managers and other stakeholders on what information and data visualization tools are most urgently needed, and helps ensure that important conservation information reaches intended audiences. A major effort of the alliance is to support on-the-ground conservation decision-making by developing decision support tools that allow land-managers, conservationists, scientists and the general public to access the best possible scientific data to make informed decisions. To this end the AKN is working closely with the Alliance to create an adaptive management framework that identifies management challenges and provides access to data-based tools that help resolve them.

AKN DATA EXPLORATION, VISUALIZATION, AND ANALYSIS

The AKN is unique because it does not stop at data curation. It uses data management as a means to develop a community of practice to create tools for exploration, analysis, and visualization. This is possible because the AKN maintains data in the standardized BMDE format and links them to predictive variables through the Covariate Spatial Table. This data-intensive computing strategy is used by a multitude of individuals to study the patterns of bird occurrence across a variety of spatial and temporal scales. For example, this approach can predict the effects of these variables within and across regions (Caruana et al. 2006), can recognize when a region-specific analysis is needed (Fink and Hochachka 2008), and can provide empirical information at a scale relevant to managers and policy makers so they can make informed decisions on bird conservation (Hochachka et al. 2007).

The AKN community is developing new web-enabled tools that allow visualization of data across large geographic areas. The visualization tools enable users to explore data, inspire question-driven critical thinking, and help target conservation action. They help users find out where data exist for a given species, and elucidate and assess simple biological patterns across space and time, such as species occurrence, migration timing, and distribution. Integrated web-mapping technologies provide the opportunity to explore these patterns in relation to a host of outside variables including climate, topography, land-cover, vegetation and more. Ultimately these visualization tools allow us to formulate new questions, and put forth hypotheses for further testing and targeted research.

Additionally, the AKN is developing models for integrated bird monitoring analysis. The AKN manages banding data that are rich with information on biometrics, molt status, sex, age, estimation of productivity, and overall health and condition of the bird (DeSante et al. 2005, Dunn and Ralph 2004, Bart et al. 1999, Baillie 1990). Integrating bird count data (comprising tens of millions of observations annually gathered over broad landscapes) with estimates of life history parameters available from banding data allows the creation of bird population models that can explain the underlying reasons for bird distribution, abundance, and demographic trends (Kendall et al. 2004). Such models would provide further insights into the bio-physical factors affecting bird populations, the life history stages at which these factors become influential, and the strategies that bird populations develop to cope with these factors (see for example Beissinger 1995).

Finally, the AKN takes full advantage of all available data and is developing techniques for data-intensive analysis of bird data. Specifically, the AKN is developing exploratory analyses that are useful when there is insufficient information to specify a single parametric model with confidence. Data mining analyses can model highly complex relationships between predictors and response variables by discovering what these relationships are, instead of requiring the relationships to be hard-wired by the analysis. This technique is useful when mapping various bird

distributions, and in predicting relative abundance of birds in relation to habitat. The exploratory approach may detect new patterns that could generate research hypotheses or create new paradigms in bird conservation.

HOW THE AKN ADDRESSES THE NEEDS OF THE BIRD CONSERVATION COMMUNITY

There is a direct correspondence between the features of AKN and the most important needs identified by the bird science and conservation communities (Kelling and Stewart 2005). The following examples showcase how the AKN can assist the U.S. North American Bird Conservation Initiative (NABCI) with its "high priority needs for bird conservation (Van Horne et al. 2007).

Capacity Building

The fourth goal of the NABCI review (Van Horne et al. 2007) identifies the acute need for a comprehensive data organization strategy. Early attempts to address this need have had marginal success, due to limited access to technology, and networking constraints. This resulted in a multitude of projects that gather bird monitoring data, a diverse array of data management systems, little opportunity for data integration or data reuse, and, ultimately will lead to data degradation and loss (Michener et al. 1997). The AKN supports full and open sharing of a suite of bird data sets for bird conservation, all managed in a standardized data format. The data management architecture has been developed through the coordinated efforts of scientists, managers, and informatics specialists to provide a resource for all aspects of bird conservation, from research to management to education. The architecture allows contributors to select from multiple levels of participation that include to displaying bird data on maps, charts and other visualizations, to making bird data completely available. The AKN is not a comprehensive data archive; that is it does not maintain data sets in their original format (although participating nodes usually do perform this service), and not all data in the original data collections (e.g. information on habitat or other non-bird related variables) are maintained in the AKN primary data warehouse. The AKN has established an easily accessible data archive of bird observational data that is well maintained, validated, and properly described.

Over the next two years the AKN will continue to increase the number of data contributors and volume of data. The goal is to identify and archive all bird data, including nest record data, counts of birds, and the results of behavioral and other studies. Many of these data will be organized within a framework that enhances access for visualization, data exploration and analysis.

Within three to five years we envision a broad community not only contributing data sets, accessing data or visualizations, and doing analyses, but also developing new functionality. These include data collection modules (including those for handheld devices) to allow project managers and researchers to design web-based data collection tools. Additionally, we will develop a suite of data manipulation and analysis tools that will allow the creation of analysis routines, or decision support tools, which will be housed within an AKN features library. These features could include interactive mapping of species occurrence to bird diversity indices for specific regions, or habitat-bird associations.

Education/Communication/Outreach

Bringing data together in one place and archiving it is a modest first step towards extracting the most value from this information. For greatest utility, data must be made available to engage a broad spectrum of users (students, educators, scientists, land managers, and policy makers) in multiple languages.

The Avian Knowledge Alliance is the organization whose main objectives are to identify tools and delivery mechanisms to increase the integration of bird data into conservation, and to make them broadly available. By providing data resources to the Avian Knowledge Alliance, the AKN provides the foundation for creating decision support tools for on-the-ground conservation, while its data management strategy allows anyone to explore and visualize the data through interactive maps, graphs, and analysis. The distributed AKN architecture creates a community of users capable of acquiring and archiving data, as well as developing regional or domain specific functionality that supports sound bird monitoring research and conservation.

Over the next two years the AKN will develop an expanding array of AKN data visualization, exploration, and access features. These will include simple and intuitive visualizations of species occurrence via seasonal histograms and graphs, routines that identify interesting relationships between birds and variables that might impact birds and accurate distribution maps of bird populations across North America. Additionally, all tools and visualization features will be integrated into a variety of on-line education, reference, and scholarly publications such

as the Birds of North America-online (http://bna.birds.cornell.edu/bna), Encyclopedia of Life (http://www.eol.org/), and the Home Study Course on Bird Biology (http://www.birds.cornell.edu/homestudy).

Within three to five years the AKN will increase the scope of these data visualization, exploration, and access features to include the entire western hemisphere. Tools will become more interactive, and applications will enhance new feature development. The AKN will develop education materials that allow students to explore the data resources to develop and test hypotheses via inquiry-based learning exercises.

Public Policy

The AKN consists of a distributed network of nodes that provide regional or thematic access to decision support tools and other applications to support research and bird conservation across a variety of spatial scales. For example, AKN nodes develop web tools that enable habitat managers and conservation planners to derive trends, indices, interactive maps, and other visualizations from individual or collective data sources of participating partners. These data currently represent more than 52 million bird observations with associated habitat, landscape, and land management variables. This resource is used by the nodes for a variety of purposes. The AKN strives to employ open-source, modular, and exportable technologies to the greatest extent possible.

This process is intended to greatly reduce the costs associated with future AKN node-development, since data models and interfaces can be readily copied and shared. For example, the California Avian Data Center (CADC) AKN node (http://data.prbo.org/cadc2/) is maintained by PRBO Conservation Science (http://www.prbo.org/). This node targets California constituents, especially to assist resource managers in county, state, federal, and non-governmental agencies in prioritizing conservation actions. CADC integrates AKN with applications being developed at the node. These applications are then exportable to other nodes, or other data sets.

Over the next two years the AKN will extend the CADC AKN node model for other regional nodes. The AKN will help develop additional thematic nodes that will focus on specific applications such as the interactive mapping of species distributions as they relate to range maps or occurrence models.

Within three to five years, a network of AKN nodes will extend across the western hemisphere.

Research

The AKN is pioneering new concepts in analysis of large data sets consisting of millions of observations and thousands of variables (Caruana et al. 2006, Hochachka et al. 2007, Sorokina et al. 2007, Fink and Hochachka 2008, Saracco et al. 2009, Sorokina et al. 2008 in press). These analyses are exploring the factors that influence bird occurrence over broad geographic landscapes. The AKN is introducing data mining, and other machine learning techniques, to the bird conservation community so that we can identify patterns of bird occurrence in areas where information is lacking. Data mining identifies patterns in the data that would not be found through simple analysis. This is achieved by testing the data against an extremely large set of models to identify which best describe them. The technique allows analysts to identify factors that influence breeding, migration patterns, and relative abundance.

Over the next two years the AKN will analyze data using data mining or other machine-learning methods to identify relationships between some response, such as presence or absence of birds, and predictors of this variation. The intent is to develop processes that lead from exploratory to confirmatory analysis of bird data. For example, in order to explore data thoroughly, we will develop techniques that allow the data to identify the most appropriate models. Then we will use confirmatory analyses to examine very specific details about that model to develop an accurate description of reality.

Within three to five years the AKN will begin to develop new analysis tools that stand at the interface between non-parametric and parametric approaches to modeling bird abundances and distributions. This technique, called hierarchical parametric modeling, will identify confidence limits within a data mining context to increase the predictive value of the analysis techniques.

Inventory/Monitoring

A major challenge to the AKN is to develop new techniques that allow us to bring together diverse bird data so that they can be used for conservation. To this end the AKN's analysis tools and techniques strive to be comprehensive and applicable to many types of data. For example, the AKN is developing accurate models of relative abundance of bird species from data gathered from inventory projects like eBird (http://www.ebird.org). Additionally, it is using the results of monitoring projects such

as the Rocky Mountain Bird Observatory's section survey (http://www.rmbo.org), or PRBO Conservation Science's point count survey (http://data.prbo.org/cadc2/) to identify management strategies from a continental scale to a riparian watershed.

Over the next two years the AKN will complete a continental scale analysis of the factors that influence bird occurrence. This analysis will use the results of several large scale point count surveys conducted during the breeding season to identify environmental requirement profiles for breeding birds across broad physiographic regions.

Within three to five years these techniques will be applied across the western hemisphere. We expect these developments in the AKN will speed and improve the science and conservation of birds. The AKN initiative to will provide better access to bird data for application to priority monitoring and conservation needs. With its unique data organization and access architecture the AKN will succeed and expand to become a major tool for bird conservation in the Western Hemisphere.

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