A MEXICAN CASE STUDY ON A CENTRALISED DATA BASE FROM WORLD NATURAL HISTORY MUSEUMS

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ABSTRACT

The present contribution is a case study of the possibilities of using data from world scientific collections to understand the distribution and conservation of Mexican birds. Information was gathered on specimens from Mexico housed in 40 scientific collections in Mexico, the United States, Canada, and Europe. This information was compiled in a centralized database and various analyses were developed to address historical patterns of ornithological investigations in Mexico: current and potential distribution areas of the species; patterns of species richness, endemism and seasonality; and conservation applications.

Keywords: Biological surveys, scientific collections, predictive modeling, birds, Mexico.

1 Introduction

Mexico holds an astonishing biological diversity, ranking among the so-called megadiversity countries (Mittermeier, Robles-Gil & Mittermeier, 1997). This richness originates in the geographic location of the country, between two major biogeographic regions, Nearctic and Neotropical, that intermix broadly in Mexico. Perhaps more important, the complex topography--coastal plains, mountain ranges, high plateaus and islands--and geological history of the region produce a wide array of ecological conditions, and favour development of isolated populations and the action of *in situ* evolutionary processes. Thus, a high proportion of the biota of the country is endemic (Ramamoorthy, Bye, Fa & Lot, 1993).

In recent years, interest in surveying the biological resources of the country has increased greatly, with the goal of creating a national strategy to preserve biodiversity. Inventories and analyses of geographic, ecological, taxonomic and genetic diversity are key issues towards this goal (Soberón, Llorente & Benítez-Díaz, 1996). Birds form important components of ecosystems, and are widely used as examples of what biodiversity studies *could* achieve because they are excellent ecological indicators and are well-known taxonomically and distributionally.

To achieve these goals, the enormous quantity of information scattered across the world in the literature and scientific collections must be assembled. Our goal was to create a database aggregating data from Mexican bird specimens worldwide, and to develop analyses that illustrate the potential increase in understanding of biogeography, systematics, and conservation of the birds of Mexico. We see this effort as a prototype for even broader efforts, eventually encompassing the entire world and all taxa, developed by the entire community of systematic biologists and biodiversity scientists in a massive collaborative effort.

1.1 The ornithological framework

Mexico is favoured with great bird diversity. Species richness is usually estimated at about 1074 species, 107 of which are endemic to the country (Escalante, Navarro & Peterson, 1993; American Ornithologists' Union, 1998). Some of the endemic forms belong to ten endemic genera (e. g. *Philortyx*, *Rhynchopsitta*, *Deltarhynchus, Rhodothraupis,* and *Xenospiza)*. This richness is distributed in the country in very interesting patterns (Peterson, Flores-Villela, León, Llorente, Navarro, Torres & Vargas, 1993; Escalante et al., 1993; Peterson, Escalona-Segura & Griffith, 1998a). Whereas species richness is concentrated in tropical regions in the southeast, endemism is highest in the islands, southwestern tropical dry lowlands, and the mountains (Peterson & Navarro, 1999).

Information about this biological diversity constituting a basic tool for a variety of analyses for knowledge, use, and conservation of natural resources, is scattered across a multitude of sources (Peterson, Navarro & Benítez, 1998b). Moreover, this information is often not available to researchers, especially those in developing countries. Scientists and conservationists require information including geographic locations of species' occurrences, ecological characteristics, and conservation status, among others, to develop research. The scientific literature is an important source, although biased by the fact that most formal publications on Mexican birds have appeared in foreign journals, and in other languages (Rodríguez-Yáñez, Villalón & Navarro, 1994). A second, and more widely distributed resource is that of field guides; these, however, are also generally in English, and only provide generalities of the geographic range and ecology of species. Third, observations by birdwatchers and ornithologists would provide a rich resource, but are seldom published and organized in a useful fashion.

The most important sources of information are scientific collections (Peterson et al., 1998b). The specimens that have accumulated through decades in many institutions worldwide constitute a critical baseline data set for biodiversity studies. Indeed, the role of museums as caretakers and disseminators of this information, too often overlooked or underestimated recently, is gaining importance for several reasons. One is that the specimen record was obtained across diverse ecological and historical conditions. These specimens hold information relevant to identification, geographic location, and historical distribution that can be *verified* by subsequent researchers. This basic reference and historical material for studies in avian systematic, ecology, evolution, genetics, biogeography, biodiversity, and conservation research and planning, thus have a diversity of potential uses that is enormous.

The history of ornithological investigations in Mexico through time was reviewed by Navarro (1989) and Escalante et al. (1993), and is summarized here. Knowledge of the Mexican avifauna started with the indigenous cultures that inhabited the country. At the time of the arrival of the Spanish *conquistadores*, the people of different regions in Mexico had discovered most of the diversity of Mexican birds, because birds played important roles in their daily activities, foods, and religion (Alvarez del Toro, 1985). The Spanish made further expeditions in the 17th and 18th centuries, and French, German, British, and Italian naturalists in the 19th century. On these trips, specimens were accumulated (as well as field notes and paintings) that are now housed in Paris, Vienna, Berlin, Cambridge, Italy, and elsewhere. The end of the 19th century saw the beginning of intensive exploration of Mexican biodiversity, particularly by English and U.S. scientists. Osbert Salvin and Frederic Godman coordinated the *Biologia Centrali-Americana*, a multi-volume description of Central American flora and fauna, of which four volumes are dedicated to birds (Salvin & Godman, 1879-1904). The collections amassed were product of fieldwork by themselves, purchases of collections, and by many collectors that they hired in the region. Most of these specimens are now housed at the Natural History Museum in the United Kingdom.

Edward Nelson and Edward Goldman, from the United States National Museum in Washington, D. C., explored Mexico's natural resources as part of the United States Biological Survey. Thousands of bird specimens were accumulated and updated information on ecology and biogeography of the species and communities was assembled (Goldman, 1951). Their work started an intense interest in the Mexican avifauna in the first half of the 20th century. In this period, several professional collectors (e. g. Chester Lamb, Wilmot W. Brown, Mario del Toro Avilés) and researchers from many institutions in the United States and Canada visited different regions within the country and made important collections. The most important collections are those at the Moore Laboratory of Zoology, American Museum of Natural History, Field Museum, Museum of Vertebrate Zoology, Museum of Comparative Zoology, University of Michigan, and Louisiana State University.

More recently, several Mexican or Mexico-based researchers, particularly at the National Autonomous University (UNAM), have further improved knowledge of Mexican birds. Today, a young and active ornithological community is developing at many institutions, adding to the ecological, systematic and geographical knowledge of Mexican birds. Centers of ornithological research with important collections are located in Mexico City (UNAM and Instituto Politécnico Nacional), Monterrey (Universidad de Nuevo León), Morelia (Universidad Michoacana), and Chetumal and Tuxtla Gutiérrez (ECOSUR and Instituto de Historia Natural), among others. Given this history, the scattered nature of information about Mexican birds is very clear, often not available to local researchers, students, and conservationists. The need for such information is enormous, as many conservation-related initiatives are taking place in Mexico as part of regional and international efforts, as well as for basic research.

2 Methods

We obtained data from 40 scientific collections in Mexico, United States, Canada, and Europe (Appendix; Figure 1) with the assistance of curators at each institution, often by direct visits. Data were obtained in different forms, depending on the collection. We were able to obtain electronic copies of the holdings of 21 collection databases that were already computerized in various formats (Dbase, Excel, ACCESS, or ASCII files). In very large and uncomputerized collections, we consulted the original collection catalogs, and checked data against the actual specimens. A few collections were surveyed through the scientific literature, especially those for which catalogs of extinct, type or all specimens had been published. Most commonly, however, we captured data directly from the specimens, allowing checks of identification, locality, sex, and age of the specimens. For each record, taxonomy was updated to a recent nomenclature under the biological (American Ornithologists' Union, 1998) and phylogenetic species concepts (Peterson & Navarro, 1999).

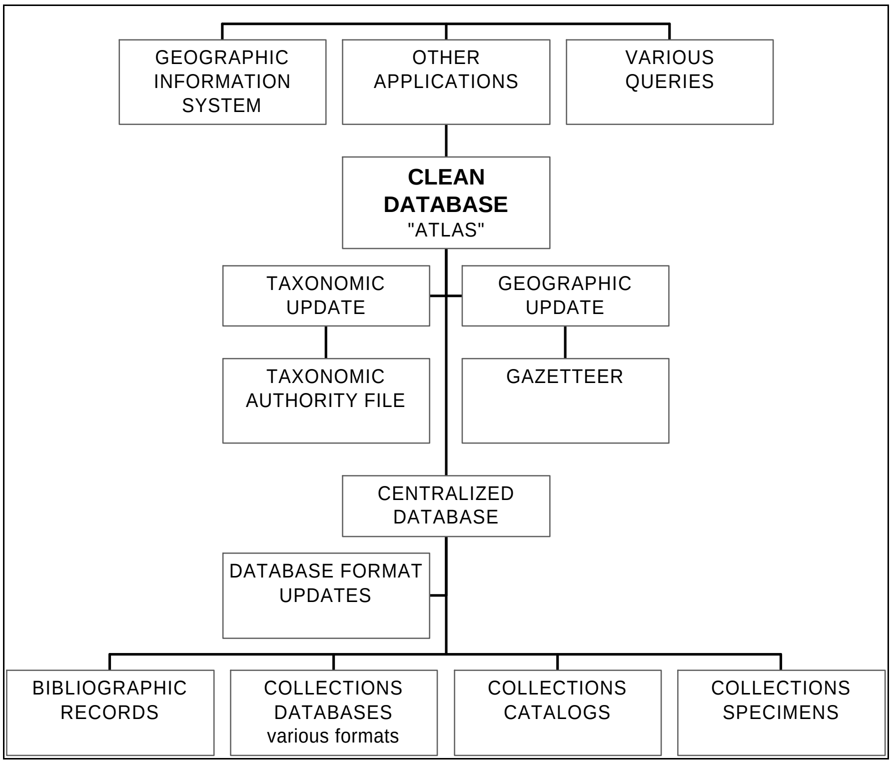

Figure 1. Sources and information flux in the Atlas database: raw data input is shown at the bottom, and updated and edit ascending in the middle; the resulting clean database and applications are shown at the top.

Once records were captured, an extract of unique localities was performed to obtain a gazetteer or geographic authority file. This file included all unique combinations of state, locality, and elevation. Latitude and longitude coordinates (degrees, minutes and seconds) for each unique locality were obtained using 1:250,000 maps of the country (INEGI, 1982). Correct locations of localities for which multiple sites had the same name in a state were determined with the help of published gazetteers (e.g. Paynter, 1955) or original field notes. Of an initial total of plus 36,600 unique localities, 94% were successfully georeferenced.

Once the database was constructed, a selection of records (248,000 of 250,000) for which identification and locality was not doubtful was used to develop the analyses that follow. To visualize general geographic patterns we used ArcView (ESRI, 1999). Digital cartography was made available by the Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO, http://www.conabio.gob.mx). Analyses involving predictive distributional areas were performed using the Biodiversity Species Workshop, and the program called GARP (Stockwell & Peters, 1999; Peterson, Soberón & Sánchez-Cordero, 1999).

3 Results

3.1 Representativeness of collections

How well represented are the birds of Mexico in each scientific collection? Biodiversity analyses require abundant information that is rarely available from a single data source. Particular collections specialize on a particular region (e.g., Universidad Michoacana), or have broader coverage (e.g., Moore Collection, Figure 2). No single collection contains sufficient geographic or taxonomic representation to develop a full analysis (Peterson et al., 1998b). However, accumulation of localities across the 40 data sets included in our studies leaves few areas unsampled, providing much denser ornithological information. These specimen data can be complemented with observational data from the literature to provide further detail (Figure 3).

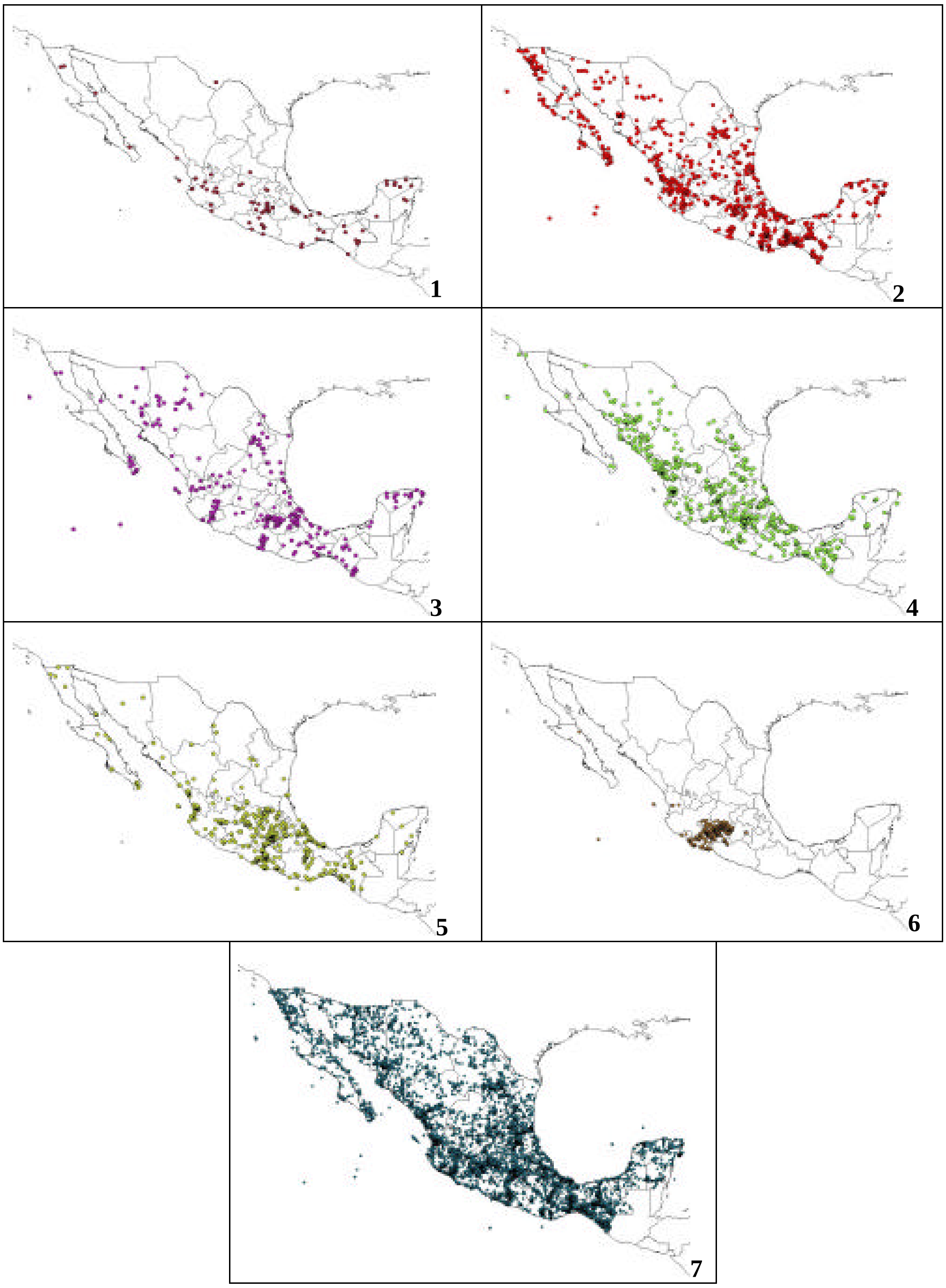

Figure 2. Geographical distribution of specimen data from selected scientific collections. (1) Muséum Nationale d'Histoire Naturelle, Paris; (2) American Museum of Natural History, New York; (3) Natural History Museum, Tring; (4) Moore Laboratory of Zoology, California; (5) Museo de Zoología, Facultad de Ciencias, UNAM, Mexico; (6) Universidad Michoacana, Morelia, Mexico; (7) Sum of locality data from 40 institutions in the Atlas database.

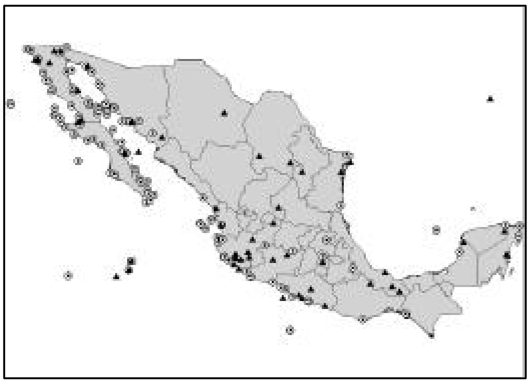

Figure 3. Comparison of different sources of locality data, for a suite of aquatic birds (Procellariiformes, Gaviiformes and Pelecaniformes). Circles indicate specimen records, whereas triangles indicate visual records from the literature.

Although this analysis may suggest that the avifaunal inventory of Mexico is satisfactorily complete, we plotted localities for which more than 100 specimens (an arbitrary measure) are available (Navarro, Peterson & Gordillo-Martínez [2002], in press; Figure 4). The resulting pattern is interesting because the gaps are much wider, and many areas of Mexico are clearly still poorly represented in collections.

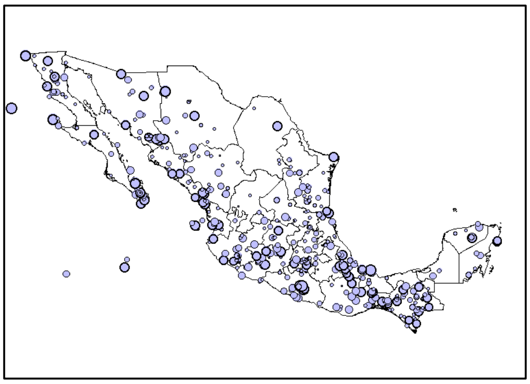

Figure 4. Localities from which more than 100 specimens have been collected, with different sizes of circles indicating increasing numbers of specimens (100 to 4800).

3.2 Distributional patterns

Georeferenced data can easily be retrieved into commercial geographic information systems, permitting association of biological data with geographic and ecological information available in digital formats. This analytical format offers a series of opportunities for understanding basic distributional phenomena, particularly with regard to predicting geographic distributions. For example, correlating known occurrence points of species with ecoregions (CONABIO, 1999) provides a first idea of potential geographic distributional areas.

More complex methodologies for estimating distributional areas from occurrence data vary widely (Udvardy, 1969) both in approach and in results (García-Trejo, Ríos-Muñoz & Navarro, 1999). Most methods depend overmuch on dense point coverage of known distributions for reconstructing areas. Given the paucity of records available for most species (Peterson et al. 1998a), alternative methods that allow predictions of distributions based on incomplete knowledge are needed.

A powerful tool for extrapolating potential distributional areas from primary point occurrences (data placing a species at a point in space) has been developed by D. R. B. Stockwell (Stockwell & Peters, 1999; Stockwell & Noble, 1992), and is called the *Genetic Algorithm for Rule-set Prediction* (GARP). This software uses an artificial intelligence approach (the genetic algorithm) to produce an abstraction of the ecological niche of a species, based on physical and ecological attributes available in digital formats.

3.3 Species richness, endemism and conservation

The predictive approaches of GARP can be applied to more complex challenges, combining results for suites of species. For example, Figure 5. illustrates an overlay of the distributional areas of 16 species endemic to the dry forests of western Mexico. Here, peaks and valleys of in richness of endemic species can be detected, and incorporated in conservation efforts (Kluza & Peterson, in prep.). Figure 6 illustrates the critical need for modeling individual species' distributions, showing how one species of concern in Mexico (Muscovy Duck, *Cairina moschata*) is left out of present conservation prioritizations (Arizmendi & Márquez, 2000).

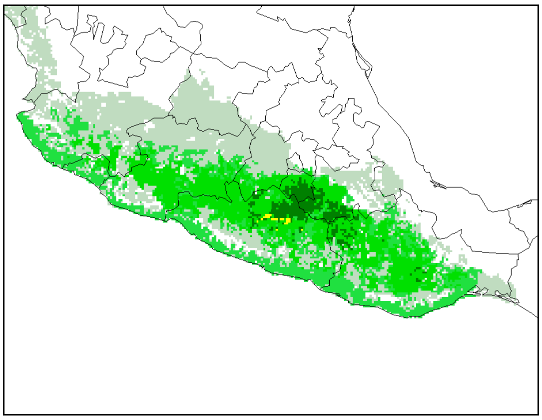

Figure 5. Overlay of potential distributional areas of 16 species endemic to southwestern Mexico. Yellow areas indicate primary concentration of endemic species (14 species); areas in dark green are secondary concentrations of endemics (4 species). Data from Kluza & Peterson, unpubl. data).

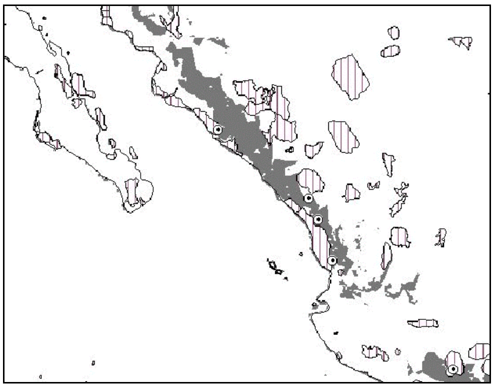

Figure 6. Predicted distributional area (solid gray) of the Muscovy Duck (*Cairina moschata*) in northwestern Mexico (solid gray). Dots indicate the museum records used to build the prediction. Polygons with vertical lines are Important Bird Areas (IBA's).

4 Discussion

The principal source of information on the systematic and distribution of the Mexican avifauna as a whole is Friedmann, Griscom & Moore (1950) and Miller, Friedmann, Griscom & Moore (1957). Although a recent publication (Howell & Webb, 1995) updates the distributional overview, it is largely directed at birdwatchers and does not provide detailed geographic information. The vast data set assembled in our work, including specimens, bibliographic records, and some field observational data, forms the basis for the *Atlas of Mexican Birds*, presently in preparation for publication by us, in collaboration with specialists around the world. This publication is based on a modern taxonomic treatment of the whole avifauna, and presents an analysis of the distribution of each species, and a summary of general patterns of species diversity, endemism, conservation status, and correlations with environmental and geographic features of the country.

To illustrate the importance of complete biodiversity information, we have made reference to the avian data set for Mexico under preparation as the *Atlas of Mexican Birds* (Peterson et al. 1998b). The largest single collection held only 16% of the total, so the emergent properties of the large data set were not realized until the contents of numerous collections were aggregated. Since its assembly, however, this data set has been instrumental in advances both in conservation and in basic biology.

Hence, the present condition of the biodiversity information world is woefully inefficient. Data, although existing in quantity for many taxonomic groups, are not accessible, and so are rarely incorporated into biodiversity studies. Large-scale biodiversity conservation studies, although focusing on exactly the information in question, are often based only minimally, or secondarily, on biodiversity data. For this reason, such studies lack analytical power and information completeness, and the results often reflect this failing.

The data network, called *The Species Analyst* (Vieglais, 2002), is a set of software extensions that enable searches from applications such as Microsoft Excel and ESRI's ArcView GIS application. Users may query multiple collection databases simultaneously, and, in a matter of seconds, obtain information directly into a client application in a form suitable for further analysis. An additional component of the data network is access to high-performance computing facilities at the San Diego Supercomputer Center (SDSC) for prediction of species' distributions from ecological models. The suite of capabilities provided by the TSA to biological collections and taxonomic authority systems provides an infrastructure that allows seamless search, retrieval, and analysis of a wealth of biodiversity data that has hitherto been impossible.

The principle objective of the TSA project is to spark collaboration and cooperation among biodiversity scientists across the World via open access to biodiversity data. The project will effectively end the present compartmentalized system, in which access to information is on an institution-by-institution basis, and move the field towards worldwide integration—a virtual "world museum," in which barriers information access disappear. Information taken from countries over several centuries will become openly accessible to all, effectively constituting repatriation of information. Pairing improved access to information with open sharing of expertise and software will lead to a qualitative leap forward in ability to use biodiversity information effectively. This work will serve as a model of how national biological surveys can be made, and the potential uses of the information.

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7 Appendix

Distribution of species and specimens in scientific collections included in the Atlas of Mexican birds to 1999. Abbreviations: UK, United Kingdom; USA, United States of America.

Institution	country	species	specimens
Moore Laboratory of Zoology	USA	806	43297
Museum of Comparative Zoology, Harvard University	USA	958	21261
British Museum (Natural History), Tring	UK	700	19275
Louisiana State University Museum of Zoology, Baton Rouge	USA	949	17808
Delaware Museum of Natural History, Willmington	USA	891	16711
American Museum of Natural History, New York	USA	907	15803
University of Michigan Museum of Zoology	USA	800	13312
Western Foundation of Vertebrate Zoology	USA	858	12597
Field Museum of Natural History, Chicago	USA	889	12067
Bell Museum of Natural History, University of Minnesota	USA	734	11636
Museo de Zoología, Facultad de Ciencias, UNAM	Mexico	672	10431
Museum of Vertebrate Zoology, University of California, Berkeley	USA	314	9221
University of Kansas Museum of Natural History	USA	762	8504
United States National Museum, Washington	USA	672	8296
Universidad Michoacana, Morelia	Mexico	413	8296
Carnegie Museum of Natural History, Pittsburgh	USA	783	8192
California Academy of Sciences, San Francisco	USA	611	6655
San Diego Natural History Museum	USA	451	6518
University of California, Los Angeles	USA	459	5560
Laboratory of Ornithology, Cornell University	USA	657	5068
Canadian Museum of Nature, Ottawa	Canada	534	4643
Peabody Museum, Yale University	USA	654	4298
Muséum Nationale d'Histoire Naturelle, Paris	France	633	4016
Los Angeles County Museum of Natural History	USA	633	3364
Southwestern College, Windfield	USA	557	2549
Florida Museum of Natural History	USA	535	2326
Royal Ontario Museum, Toronto	Canada	551	2188
Academy of Natural Sciences, Philadelphia	USA	547	2084
University of British Columbia Museum of Zoology, Vancouver	Canada	267	2016
University of Arizona, Tucson	USA	450	1657
Texas Cooperative Wildlife Collections	USA	324	1347
Denver Museum of Natural History, Denver	USA	166	675
Museo Nacional de Ciencias Naturales, Madrid	Spain	186	470
Natuurhistorische Museum, Leiden	Holland	137	327
University Museum of Zoology, Cambridge	UK	112	148
Fort Hays State College, Hays, Kansas	USA	75	120
University of Nebraska	USA	55	87
Iowa State University, Ames	USA	9	22