Bird conservation and biodiversity research in Mexico: status and priorities

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ABSTRACT. Mexico holds a megadiverse avifauna that includes many endemic elements, as well as rich sets of species from both farther north and farther south in the Americas. This avifauna, nonetheless, has suffered considerable losses as a consequence of long-term, intensive human activity across the landscape. We review what is known about the Mexican avifauna, specifically its diversity and endemism, and how that knowledge has and has not turned into effective conservation measures to assure the long-term integrity of the avifauna.

RESUMEN. **Conservación e investigación de biodiversidad sobre las aves de México: Estatus y prioridades**

México tiene una avifauna megadiversa que incluye muchos elementos endémicos, además de muchas especies que provienen de más al norte o más al sur en las Américas. No obstante, esta avifauna ha sufrido pérdidas considerables debido a la actividad humana intensa a largo plazo a través del país. En esta contribución, resumimos el estatus de conocimiento de la avifauna de México, en particular su diversidad y endemismo, y como estos conocimientos se ha traducido (o no) en medidas eficaces hacia su conservación para asegurar su integridad a largo plazo.

Key words: birds, diversity, endemism, conservation

Mexico is considered among the ‘megadiverse’ countries of the Earth by a number of ranking schemes and prioritization efforts (e.g., Myers et al. 2000). As regards birds, Mexico has an impressive number of over 100 endemic taxa, ranging from restricted-range microendemics (e.g., Short-crested Coquette, *Lophornis brachylophus*) to broadly distributed species that are similarly confined entirely or almost entirely to the country (e.g., Eared Quetzal, *Euptilotis neoxenus*) (Stattersfield et al. 1999, González-García and Gómez de Silva 2003). Of this rich avifauna, however, several species have already been lost entirely, including the Guadalupe Storm-Petrel (*Oceanodroma macrodactyla*), Guadalupe Caracara (*Caracara lutosus*), Socorro Dove (*Zenaida graysoni*, extinct in the wild), Imperial Woodpecker (*Campephilus imperialis*), Slender-billed Grackle (*Quiscalus palustris*), and possibly the Cozumel Thrasher (*Toxostoma guttatum*), as well as a number of distinct populations that may or may not have qualified for species status (e.g., Guadalupe Red-shafted flicker, Colaptes "auratus" rufipileus; Sweet et al. 2001). Besides, numerous endemic and non-endemic species inhabiting the country are catalogued from threatened to critically endangered, e.g., Horned Guan (*Oreophasis derbianus*), Blackpolled Yellowthroat (*Geothlypis speciosa*), Rose-bellied Bunting (*Passerina rositae*), and Sierra Madre Sparrow (*Xenospiza baileyi*) (IUCN 2015) As such, bird conservation efforts in Mexico represent a crucial priority for global-scale bird conservation initiatives; if not executed effectively, a major component of global bird diversity would be lost.

Bird conservation priority setting in Mexico began in the 1960s, under a wide array of criteria, particularly high species diversity and vulnerability to habitat destruction (e.g., Álvarez del Toro 1968). However, most of the prioritization schemes developed were not actually used by government authorities to implement any real-life conservation efforts. Rather, it was only after the Earth Summit of Rio de Janeiro in 1992 that the Mexican government took this challenge seriously; over recent decades, Mexico has revamped its protected areas system

rather profoundly via deep analyses of biodiversity and its current status in the country. An important step was the creation, in 1992, of the national biodiversity commission, CONABIO (Comisión Nacional para el Uso y Conocimiento de la Biodiversidad; CONABIO 2012), a government agency responsible for compiling and analyzing primary biodiversity data, creating a much needed bridge between academia, government, and society, and supplying biodiversity information for research, conservation, and sustainable use. Another important step was the creation, in 2000, of the national protected areas commission, CONANP (Comisión Nacional de Áreas Naturales Protegidas; http://www.conanp.gob.mx/quienes_somos/historia.php), a federal agency tasked with designation, coordination, and administration of protected natural areas in the country.

Thanks in part to the activities of these agencies, Mexico created a number of prioritization schemes for unprotected sites of importance for biological conservation in the country based on different sets of criteria (e.g., Arriaga Cabrera et al. 2009), in which bird diversity and endemism were important factors. Regarding efforts particularly devoted to birds, perhaps most notable is the designation of the Áreas de Importancia para la Conservación de las Aves (AICAS; Arizmendi-Arriaga and Márquez-Valdelamar 2000), a nationwide directory of important areas for bird conservation in the country parallel to the global network of Important Bird and Biodiversity Areas [IBAs] (Birdlife International 2015). Finally, since 1994, Mexico has maintained and published officially a national endangered species list (SEMARNAT 2010; called "NOM," based on "Norma Oficial Mexicana") that provides guidance about which species are of particular importance for immediate protection. The list produced and updated based in a standard set of biogeographic, ecological, and biological criteria for assigning threat levels to species, following a methodology termed *Método de evaluación del riesgo de extinción de especies silvestres en México* (“MER”) (Tambutti et al. 2001). These steps signal a clear national priority on preserving biodiversity resources in the country for future generations.

Our objective with this review is to provide an overview and illustration of one facet of the current state of areas for conservation of birds in Mexico. Our thinking framework is rather explicitly in terms of species diversity, such that we focus on the degree to which avian species diversity, and particularly that portion of avian species diversity that is endemic to the country, is correlated with a robust network of protected areas in the country. We perhaps neglect somewhat other dimensions of ecological distribution, biological attributes, abundance, and population health of species inside and outside of protected areas (e.g., González-Jaramillo et al. 2016). Although those considerations are certainly relevant and important, detailed data remain generally scarce generally, and are treated at better depth elsewhere (Ceballos and Márquez-Valdelamar 2000, Gómez de Silva and Oliveras 2000).

GET THE PRIORITIES RIGHT

Units of conservation: species concepts and taxonomy. An early, but important and ongoing challenge was to assemble a basic list of the bird species of Mexico. In the 1950s, Mexico was the focus of a detailed avifaunal check-list (Friedmann et al. 1950, Miller et al. 1957) and was later added to the North American check-list of the American Ornithologists' Union (AOU 1998). However, it was not until 2003 that a review of the taxonomy was developed from an evolutionary and phylogenetic point of view, resulting in revision of species limits in 135 taxa and recognition of 122 additional endemic species (Navarro-Sigüenza and Peterson 2004). Clearly, though, the job is still not done, as additional species are documented from Mexico each year (e.g., Maley and Brumfield 2013, Arbeláez-Cortés and Navarro-Sigüenza 2013), but at least taxonomic levels are now roughly comparable across the Mexican avifauna (Navarro-Sigüenza et al. 2014).

At present, the NOM offers a list of Mexican bird species that are under some protection category, including 393 species and subspecies, of which 54 are endemic species and 74 are endemic subspecies (most of rather unknown or ambiguous biological significance). However,

the list still faces important gaps, related to unprotected taxa, erroneously assigned protection categories, and misunderstandings of geographic distributions that persist thanks to lack of detailed information and differences between taxonomic viewpoints (Rojas-Soto et al. 2010). Therefore, continuous updating of the list becomes a crucial task for authorities and ornithologists in the country.

Distributional information about species. Once the list of species taxa is in place, and a conservation relevance category is assigned to each, a next-most-crucial element is knowing where those taxa occur; this information gap is commonly known as the Wallacean Shortfall (Bini et al. 2006), and it has been a major impediment to progress in much of biodiversity science in the world. For Mexican birds, however, this problem may be generally less than in other taxa and in many other regions because the country's birds have been the focus of numerous projects centered on information assembly (see Conabio; http://www.conabio.gob.mx/web/proyectos/resultados.html). Although, in some sense, earlier monographic treatments (Friedmann et al. 1950, Miller et al. 1957) were also distributional summaries, they contained inaccuracies. Hence, here we recap four more modern projects and data sets that are most relevant to the focus of our review. The geographic distribution of records in each of these data sets can be appreciated in Fig. 1.

A first attempt at large-scale compilation of distributional information for Mexican birds was the *Atlas of Mexican Bird Distributions* (Navarro-Sigüenza 2002, Navarro-Sigüenza et al. 2003b). The *Atlas* database comprises 362,259 records in 73 scientific collections of all Mexican bird species, with 344,611 of the records georeferenced. Besides being a primary source for many publications dealing with Mexican bird diversity, the *Atlas* database allowed development of detailed distributional maps for each species of bird in Mexico (available at http://www.conabio.gob.mx/informacion/gis/) that helped also to provide detailed views of the geography of species richness and richness of endemic and endangered species across the country (Fig. 2; Navarro-Sigüenza et al. 2014).

A second major step in development of adequate information resources for Mexican birds was the work of CONABIO, which invested massively in development of open-access biodiversity resources for the country. For birds, CONABIO not only supported development of the *Atlas* database, but also provided data records from many bird collections in Mexico on its *Red Mundial de Información Sobre Biodiversidad* (World Biodiversity Information Network; REMIB http://www.conabio.gob.mx/remib/doctos/remib_esp.html) that add important, newer, and more data-rich specimens to the overall digital accessible knowledge of the country, complementing nicely the older, if more numerous, specimens held in collections in the rest of North America and Europe.

VertNet (and its precursor ORNIS) offers another data-gathering initiative, developed with funding from the U.S. National Science Foundation, that provides access to specimen-based holdings of North American museum collections of birds (Fig. 2). Indeed, for Mexican birds, VertNet holds 314,683 records, of which 180,428 (~57%) are georeferenced. A special feature of VertNet is that 80,720 of these records include uncertainty information regarding the georeferencing, which indicates considerable care given to data quality and fitness for use. Another large-scale biodiversity data portal, the Global Biodiversity Information Facility (GBIF) offers access to a much-larger data storehouse, with 2,417,534 specimen and observational records, including 2,231,030 (92%) with associated geographic coordinates (Fig. 2). GBIF draws data both from VertNet (see above) and aVerAves (see below), which leads to the large numbers of data records. However, only 76 data records in the GBIF-derived dataset had non-zero uncertainty radii, reflecting a long-term neglect of data fitness for use that has been pointed out in previous publications (Beck et al. 2014, Yesson et al. 2007, Chapman 2005, GBIF Review Committee 2005, GBIF 2014).

Finally, aVerAves (the Mexican version of E-bird; http://ebird.org/content/ebird/about/) represents a recent, large-scale data stream for birds. Impressively, aVerAves (http://www.averaves.org/) has already accumulated more than a million records of birds from

Mexico (Fig. 2), and most are georeferenced because geographic coordinates are required for data submission (although uncertainty measures are not available for these data). However, the spatial distribution of these records appears to correspond closely to the distribution of tourism and perhaps of tourists from regions where birdwatching is more common than among the general populace of Mexico (although birdwatching is growing rapidly in popularity in Mexico; Gómez de Silva and Alvarado Reyes 2010).

The existence of such masses of "Digital Accessible Knowledge" (DAK; Sousa-Baena et al. 2013) about Mexican birds (i.e., digital data that are in digital formats, openly available, and integrated into global biodiversity information networks), however, does not mean that work does not remain. Large gaps and geographic unevenness remain in the spatial extent of knowledge about Mexican birds (see, e.g., the recent maps in Peterson et al. 2015). Perhaps more challenging is the task of quality-controlling and cleaning these data, as illustrated in Fig. 3 for the two species of an endemic genus (*Hylorchilus*) in urgent need of conservation attention (Toribio and Peterson 2008). Indeed, although many approaches to the challenge of data-cleaning have been explored (Chapman 2005), including some that take special advantage of the dense DAK that exists for Mexican birds (Peterson et al. 2004), this task remains significant as an impediment to deep understanding of biodiversity patterns.

CONSERVATION IMPLEMENTATION

Numerous positive steps have been and are being taken for understanding Mexican bird diversity. At this point, then, the question is one of prioritization and effective implementation of conservation measures. Fig. 4 illustrates and compares the spatial coverage of the national scheme of priority areas for Mexican bird conservation (AICAS; http://conabioweb.conabio.gob.mx/aicas/doctos/aicas.html) with that of areas currently protected by the federal government (http://www.conanp.gob.mx/que_hacemos/). At the national level, what emerges clearly from this comparison is that some regions (e.g., Baja

California and Yucatán peninsulas, offshore insular systems, and the mountains and rain forests of the southeast) are fairly well-covered by federal protected areas. However, the need for large-scale protection of sites that cover biologically important regions and habitats is evident, such as the largest tract of pristine rain forest in Mesoamerica at the Chimalapas region in Oaxaca-Chiapas (Peterson et al. 2003), the dry woodlands along the Balsas River Basin (Castro-Torreblanca et al. 2014), and the mountains and lowlands of northern Oaxaca, where the highest bird diversity of the country is found (Navarro-Sigüenza et al. 2003a) to mention a few. These gaps are most evident in the western and southwestern sectors of the country, which are well-known and documented as a center of Mexican bird endemism (Escalante-Pliego et al. 1998), particularly in montane areas as the taxonomy has been updated (Peterson and Navarro-Sigüenza 1999, Peterson and Navarro-Sigüenza 2000).

A more in-depth analysis of this same sort is provided by Navarro-Sigüenza et al. (2011), who analyzed 12 conservation prioritization schemes (global and national) for Mexican birds in a geographic context. They demonstrated that the regions most clearly presenting high conservation priorities tended too frequently not to coincide with protected natural areas. For example, the most important conservation gaps are in the Sierra Madre del Sur in Guerrero and Oaxaca, which were consistently detected as a main protection priority in all prioritization schemes. These areas still lack a federal or provincial natural protected area that cover its high bird species richness and elevated endemism, mostly associated with the region's endangered cloud and pine-oak forests (e.g., Oaxaca Hummingbird, *Eupherusa cyanophrys*; White-throated Jay, *Cyanolyca mirabilis*). Another example is the need for protected areas in the central and southern sections of the Sierra Madre Occidental, which holds impressive bird endemism and endangered taxa (e.g., Eared Quetzal, *Euptilotis neoxenus*; Thick-billed Parrot, *Rhynchopsitta pachyrhyncha*, as well as the extinct Imperial Woodpecker, *Campephilus imperialis* (Lammertink et al. 2012, Medina-Macías et al. 2010, Kobelkowsky-Vidrio et al. 2014).

Even with a fully implemented protected areas network, incomplete scientific knowledge about species present within protected areas and their population status is the norm, with a few recent exceptions (mostly in the Mayan Region), such as the Sierra de la Laguna of Baja California Sur (Arriaga-Cabrera and Ortega 1988), the Yaxchilán region of Chiapas (Puebla-Olivares et al. 2002), the Ría Lagartos area of the Yucatan Peninsula (Ibañez-Hernández and Álvarez-Solorzano 2007), Palenque in Chiapas (Patten et al. 2011), and Calakmul in Quintana Roo (González-Jaramillo et al. in prep.). On the contrary, many of the AICAS were designated based on having available rather complete avifaunal inventories (http://avesmx.conabio.gob.mx/lista_region), such that more complete information frequently exists for those areas.

Another significant concern is the integrity of the areas that have been set aside for protection. The decree of a national park or a biosphere reserve and a park sign on the road may mean little or nothing if the natural ecosystems are being degraded and destroyed (see, e.g., Ramirez-Bastida et al. 2008). Fig. 5 illustrates an example of this situation and set of concerns for the Calakmul Biosphere Reserve, taking advantage of a published analysis of land use conversion in the Yucatan Peninsula (Colchero et al. 2005). Although the Calakmul Biosphere Reserve is clearly seeing less degradation and conversion from forest to anthropogenic habitats (Fig. 5), significant foci of conversion do exist within the reserve, particularly along its eastern border and northern extreme. Note also, as a complication to our previous point about prioritization of areas, that the priority areas for birds around the biosphere reserve (AICAS; Fig. 5) are subject to much-higher rates of deforestation than the protected areas.

Concerns about the integrity of protected areas do not end with protection from human incursions because climate change also has considerable potential to degrade otherwise effective protected areas. (Peterson et al. 2002) used ecological niche modeling approaches to forecast the potential for species' distributions to shift across Mexican landscapes in response

to climate change, showing a differential response for each of the species analyzed. More recently, we have erected detailed comparisons of bird species' distributions between the middle twentieth century and the present (Peterson et al. 2015), and have demonstrated such distributional shifts concretely. For example, new detections of endemic species were rather few, whereas endemic species losses were detected across the Mexican Plateau, Transvolcanic Belt, Isthmus of Tehuantepec, and in eastern Tabasco, and overall endemic species turnover suggested major avifaunal changes across the country (Peterson et al. 2015). Perhaps of greatest concern, however, is that, at least at coarse spatial resolutions, the only significant factor explaining the pattern of these shifts was temperature change.

Recent analyses (Prieto-Torres et al. 2015) have focused on one conservation priority habitat—deciduous tropical forest—a hotspot for avian diversity and endemism in Mesoamerica (Ceballos et al. 2010, Ríos-Muñoz and Navarro-Sigüenza 2012). This work has highlighted possible effects of climate change that should be considered in the design of protected areas and biological corridors, as changes in humidity and temperature in the future will likely reduce or eliminate these forest types in two regions of high avian endemism: the Cape Region (Baja California) and the Balsas River Basin (Prieto-Torres et al. 2015).

A perhaps more dramatic example is that of humid montane forests in eastern and southern Mexico (Rojas-Soto et al. 2012). These areas hold an important level of avian diversity and endemism, as well as several globally endangered species: Resplendent Quetzal, *Pharomachrus* mocinno; Horned Guan, *Oreophasis derbianus*; and Tuxtla Quail-Dove *Zentrygon carrikeri*. Forecasts of distributional changes under coming scenarios of climate change anticipate total disappearance of crucial habitats within currently designated biological reserves (i.e., El Triunfo and Los Tuxtlas Biosphere Reserves) by 2050. Hence, Mexico's protected areas network needs to be revisited in the context of likely climate change effects on geographic distributions of species, especially those holding many endemic and/or threatened

species, and perhaps redesigned to assure that it will be as robust as is possible to these large-scale degrading effects (Hannah et al. 2007).

RESEARCH PRIORITIES AND FUTURE CHALLENGES

We see Mexican bird conservation as a simultaneous success and ongoing challenge. Birds in Mexico face an array of threats that affect differentially populations, species, and complete avifaunas, such as illegal pet trade, introduction of exotic species, habitat transformation, pollution, and climate change, among others (Iñigo-Elías and Enkerlin 2003, Álvarez-Romero et al. 2008, MacGregor-Fors and Schondube 2012). A first attempt to compile an overview of the different approaches of Mexican bird conservation is assembled in Silva and Ita (2003) and the chapters therein. There, the many faces and complexities of the problem of bird preservation from a scientifically mature Mexican viewpoint become clear, from bird diversity patterns to behavior, and from evolution to bird-plant ecology to environmental education, to mention a few.

In terms of biodiversity science, massive improvements in the situation have occurred in just the past three decades. Information is now far more complete, and this information is broadly available in Mexico so Mexican institutions and researchers can develop analyses specific to Mexican concerns and interests (López-Medellín et al. 2011). The protected natural areas system of the country is now much more viable, with biodiversity-based design and even a modicum of serious protection of key areas.

Finally, the research and policy community within Mexico is now much more vibrant, such that new ideas and new insights are conceived and explored regularly. Conservation science is among the most frequent subjects in the recent literature about the birds of Mexico, and a great percentage of these contributions are written by Mexican scientists dealing with conservation efforts on a more local or state level; another important portion represents the product of international collaborations between Mexican and North American institutions and

309 researchers. That is, bird conservation in Mexico is a task that goes beyond country borders
310 and is a major focus of collaborative efforts, not only for the bird species shared by Mexico, USA
311 and Canada, but also for birds endemic to each of the countries. Examples include scientific
312 research and conservation prioritization in shared biomes and ecoregions (Askins et al. 2007),
313 shared initiatives like the IBAs and AICAS, and science exchange programs (e.g., CONACyT-
314 Partnerships for International Research and Education, National Science Foundation;
315 http://www.conacyt.mx/index.php/comunicacion/comunicados-prensa/362-convocatoria-
316 conacyt-nsf-pire). Most important, however, they have benefited from the mutual experience
317 that international teams provide, leading to a transition from seeing Mexico as a source of field
318 assistants for US researchers to seeing Mexico as a source of high-level academic
319 collaborators, in a two-way beneficial sharing of expertise.
320 At the same time, other significant challenges remain. The taxonomic picture (i.e., what
321 are the important units for conservation?) remains incomplete. While many montane taxa have
322 been the subject of evolutionary differentiation analyses (Spellman et al. 2007, Bonaccorso et
323 al. 2011, Honey-Escandón et al. 2008), only very few studies have complemented this
324 phylogeographic picture by analyzing bird species of the lowlands (particularly the western
325 coastal lowlands) and the dryland and desert systems (Arbeláez-Cortés et al. 2014a, Arbeláez-
326 Cortés et al. 2014b, Cortés-Rodríguez et al. 2013, Miller et al. 2011).
327 Substantial gaps still exist also in distributional information about Mexican birds, even in
328 the face of such massive numbers of data records, and filling those gaps can be challenging,
329 particularly in view of security and safety concerns that now exist across much of the country.
330 Several steps can be taken to improve this situation. One is the growing mass of data served
331 through observational database portals like aVerAves and e-Bird, which allow diverse
332 ornithologists and aficionados to contribute accurate distributional and temporal data about
333 species important in conservation planning. The ongoing effort of surveying areas and
334 developing detailed new scientific collections provides a deeper and more information-rich

complement to this information, but will necessarily lag behind in numbers, owing to the time that specimen preparation requires.

Perhaps even more significant is the challenge of full implementation of optimal conservation measures. Supplying strong scientific information is crucial for the designation and later management plans of officially protected areas, but also a protected area is a powerful tool for developing scientific research (Maass et al. 2010). For birds, the data are in place, in large part, and the optimal areas can be and have been identified, yet implementation lags. Ceballos et al. (2002) offered early analyses of occurrences of birds in protected areas in Mexico through a complementarity approach, and detected that 98% of species are present in at least one protected area, as decreed at that time. However, several globally endangered species (e.g., *Hylorchilus navai*, *Dendrortyx barbatus, Amazona oratrix*) were not present in any such areas (Toribio and Peterson 2008). These results suggest that, even if the current protected area system is good, additional protected areas are needed to include those priority species. A rather unique analysis of Mexican mammal conservation progress (Fuller et al. 2007) illustrated a damning phenomenon: as conservation action is postponed, the cost of that action rises dramatically. Hence, time is a precious commodity in this challenge. Stated another way, the remaining priority areas from a bird-representation point of view need to be shepherded through the transition from priority areas to protected areas.

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Fig. 1. Digital accessible knowledge about Mexican birds based on four major sources: *Atlas of Mexican Bird Distributions* in blue triangles, VertNet in green diamonds, GBIF as red squares, and aVerAves as black crosses.

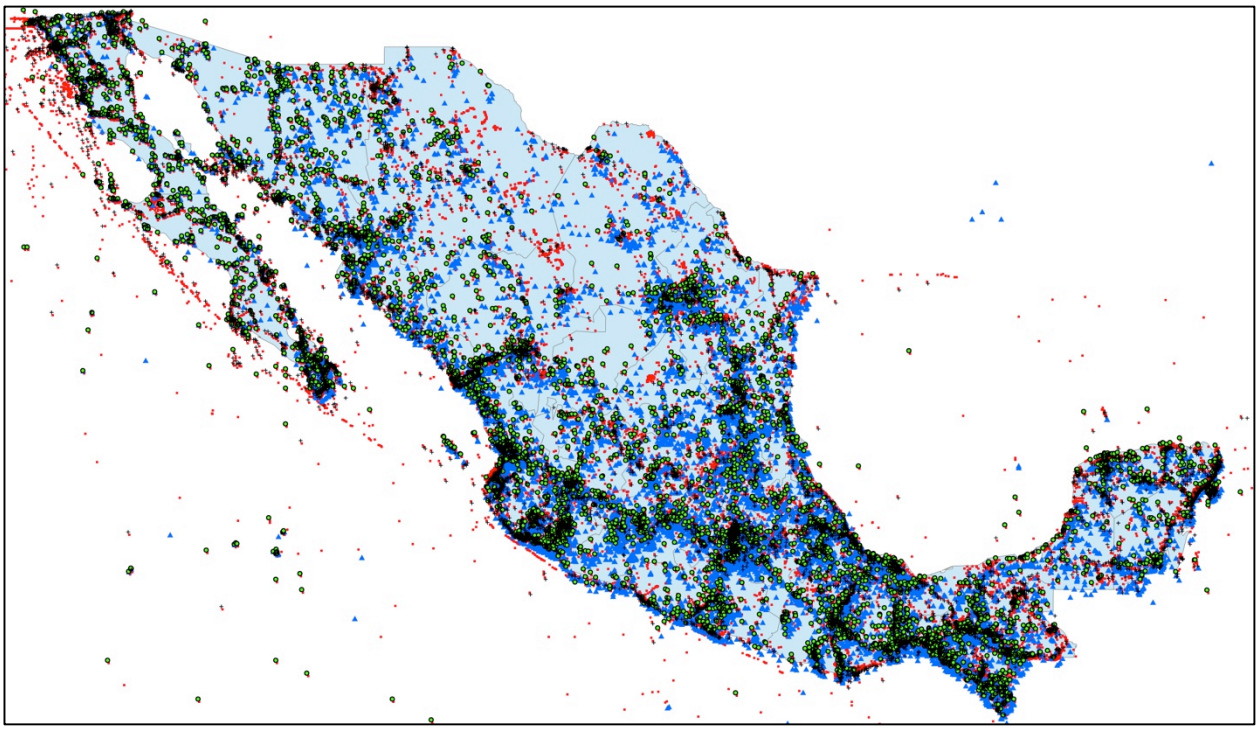

Fig. 2. Maps of summer species richness, richness of endemic species, and richness of endangered species developed from maps based on data from the *Atlas of Mexican Bird Distributions* (yellow indicates low values, and darkest blue indicates highest values).

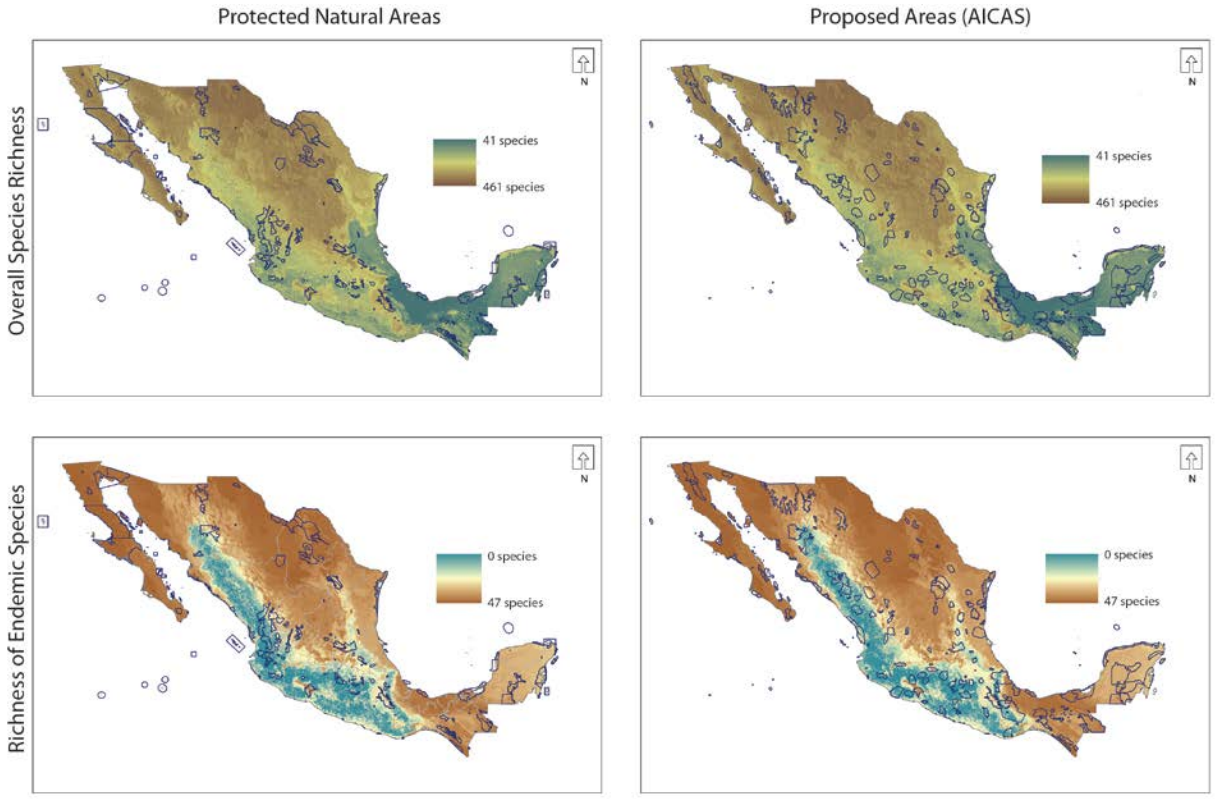

Fig. 3. Illustration of the need for and importance of detailed quality control in biodiversity occurrence databases. This example centers on the wren genus *Hylorchilus*, which comprises two species (shown in red and green) in southern Mexico. Data records that are corroborated by specimen vouchers are shown as stars, whereas observational reports are shown as circles. Note probable additional populations of this very-rare genus in between the two known distributional areas, but note considerable confusion as to which of the species is present (or even that both might be present!); note also the many wild distributional records that are quite unlikely to be correct.

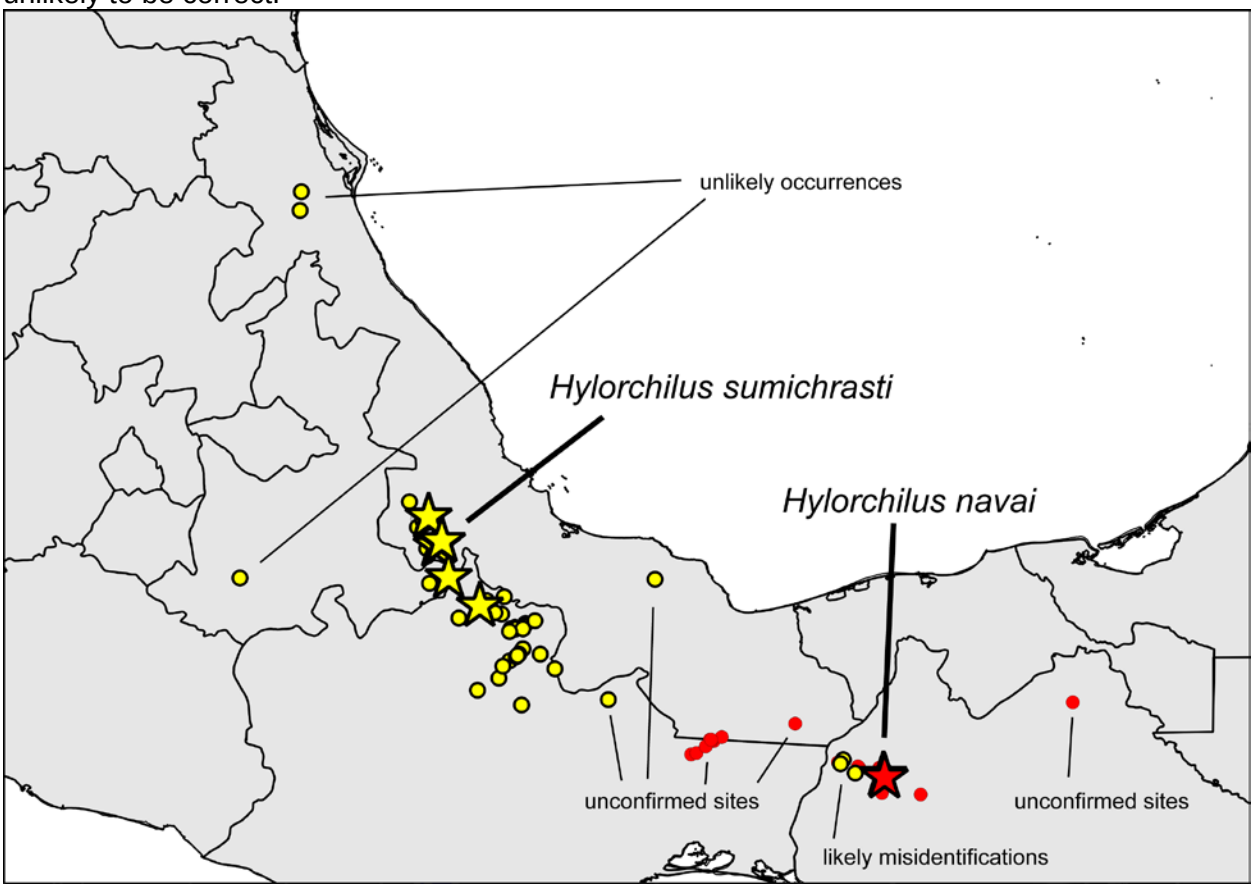

Fig. 4. Summary of priority areas for protecting bird diversity in Mexico (AICAS, gray shading), and their geographic relationship to currently protected natural areas (red stapling). Source of geospatial information: http://www.conabio.gob.mx/informacion/gis/.

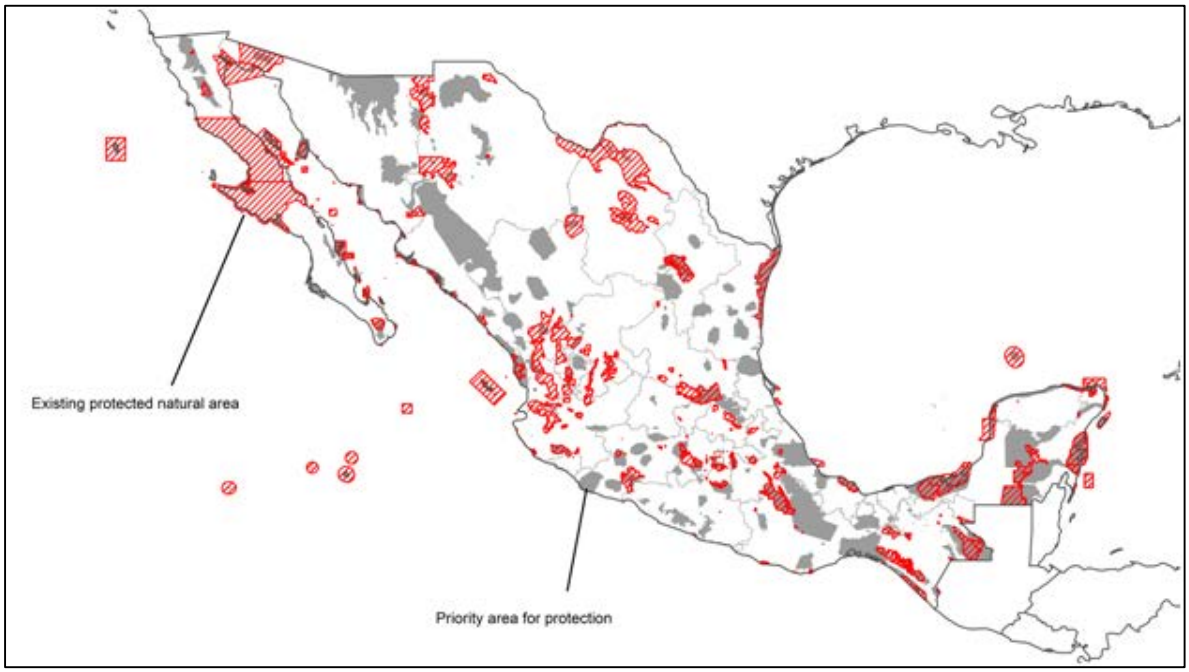

Fig. 5. Summary of spatial patterns of deforestation (as summarized by Colchero et al. 2005) in the Yucatan Peninsula (inset shows location of map within Mexico) in relation to existing protected natural areas (white outlines) and priority areas (i.e., areas proposed as priorities for addition to the protected natural areas system of the country (yellow outlines). Green areas have not been subjected to deforestation over recent decades, whereas black areas have.