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A GLOBAL SNAPSHOT OF AVIAN TISSUE COLLECTIONS: STATE OF THE ENTERPRISE

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In connection with the All Birds Barcoding Initiative (ABBI), one of us (M.S.) conducted a survey of the world's avian tissue collections at the species level (following Clements 2007). The information was compiled from online databases or summaries provided by collection managers and was accessed or obtained between March 2007 and January 2009. To harmonize taxonomic names among collections, a spreadsheet utility (Stoeckle 2008) was constructed that converts synonyms, alternate spellings, and subspecies into the names used by Clements (2007); incompletely identified (e.g., generic name only) and hybrid specimens were not included.

In all, 29 of 32 collections queried provided data on their holdings, which at the time of the survey represented at least 317,299 specimens of 7,228 species (Table 1). Tissue holdings among these collections spanned three orders of magnitude, from <99 to >40,000 samples; 12 collections—fewer than half—held >10,000 samples, and only 10 had >1,000 species represented (Table 1).

Genetic samples associated with vouchered specimen material, such as a skin that enables morphological identification, represent a desirable, high-quality standard for tissue collections, and vouchered collections were our focus. Benefits from vouchering include replicability and the availability of comparative phenotypic and other data (Winker et al. 1996, Ruedas et al. 2000, Bates et al. 2004, Peterson et al. 2007). Among collections reporting this information, the percentage of vouchered genetic holdings varied from 40% to 100% (Table 1).

To enable the most complete global snapshot possible, our compiled survey maintained anonymity for holdings of individual collections. This allows material obtained for short-term research interests to be counted as present in long-term archives. Together with many of the participants, we look forward to increased electronic access through institutional websites and community initiatives such as ORNIS (see Acknowledgments).

Taxonomic Coverage

Of the world's 9,933 avian species, fully 2,705 (27%) were undocumented in tissue collections in this survey (Table 2 and online Appendix; see Acknowledgments). Among orders, species-level coverage ranged from 56% in Pterocliformes and Strigiformes to 100% in seven small orders comprising 1–17 species (Table 2). For eight orders, there were no genetic samples for one-third or more of the species.

Some taxa that were seemingly missing from collections may instead be subspecies raised to species status in Clements (2007) that are not coded in existing databases as full species (and perhaps not even as the appropriate subspecies); other nomenclatural misconnections may have occurred as well. It is unclear what proportion of missing species are represented in this manner, but examination of the primary and compiled databases suggests that it is not likely more than a few percent. We recognize that taxonomic references such as Clements (2007) are incomplete summaries of avian diversity, because our knowledge of this diversity remains incomplete. Molecular data derived from genetic collections including those in this survey will be one key to continued work in this area.

Are the species not collected so far particularly those that are endangered or threatened? To investigate this, we matched the taxa that lack tissues to the IUCN Red List of species at risk (IUCN 2007), which lists 1,221 bird species as critically endangered (CR), endangered (EN), or vulnerable (VU). Of these, 675 (55%) lack tissues, which indicates that vulnerable, threatened, and endangered species make up a disproportionate fraction of the species unrepresented in tissue collections. Overall, 25% of species that lack tissues are listed by IUCN as at risk (CR, EN, or VU). Thus, although traditional methods of lethal sampling with vouchers can make considerable progress in documenting avian genetic diversity,

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Table 1. An initial survey of world avian tissue collections, showing number of tissue specimens, the number of species represented, and the percentage of the collection that is vouchered with a traditional museum specimen. Collections are ranked by number of tissue specimens. NA = no information available. Online databases are noted (*).

Collection	Number of specimens	Number of species	Percentage vouchered	Date accessed or obtained
Louisiana State University Museum of Natural Science, Baton Rouge, Louisiana*	44,821	3,825	98	January 2009
The Field Museum, Chicago, Illinois*	33,481	2,527	98	January 2009
Burke Museum, University of Washington, Seattle, Washington*	29,784	2,221	98	January 2009
Zoological Museum, University of Copenhagen, Copenhagen, Denmark*	27,872	2,903	40	January 2009
Royal Ontario Museum, Toronto	27,720	963	NA	September 2008
Smithsonian Institution, National Museum of Natural History, Washington, D.C.	20,000	1,910	98	January 2008
American Museum of Natural History, New York*	15,902	2,508	90	January 2009
University of Alaska Museum, Fairbanks	15,400	1,310	80	September 2008
University of Kansas Natural History Museum, Lawrence	14,462	2,596	97	April 2008
Barrick Museum, University of Nevada, Las Vegas	14,360	1,266	99	November 2007
Swedish Museum of Natural History, Stockholm, Sweden	12,315	941	80	April 2007
Museum of Vertebrate Zoology, University of California, Berkeley*	10,915	516	95	January 2009
Academy of Natural Sciences of Philadelphia, Pennsylvania	9,343	2,081	98	April 2007
Smithsonian Tropical Research Institute, Panama City, Panama	7,866	766	NA	April 2007
Museum of Southwestern Biology, Albuquerque, New Mexico	4,638	719	NA	January 2008
Coleccion Nacional de Aves, Instituto de Biología, Universidad Nacional Autónoma de México, Mexico, D.F.	4,550	496	95	March 2007
Museo Argentino de Ciencias Naturales, Buenos Aires, Argentina	3,317	552	100	December 2007
Los Angeles County Natural History Museum, Los Angeles, California	3,079	660	100	January 2008
Instituto Humboldt, Bogotá, Colombia	2,852	670	100	May 2007
Zoological Museum of Moscow University, Moscow, Russia	2,844	750	NA	May 2007
Cincinnati Museum of Natural History and Science, Cincinnati, Ohio	2,740	142	NA	February 2008
University of Alaska Anchorage, Alaska	1,655	206	99	September 2007
Museum of Comparative Zoology, Harvard University, Cambridge, Massachusetts	1,553	353	95	May 2007
California Academy of Sciences, San Francisco, California	1,523	393	99	May 2007
Australian Museum, Sydney, Australia	1,424	341	NA	May 2007
Istituto Nationale per la Fauna Selvatica, Ozzano Emilia, Italy	1,260	168	NA	April 2007
Indonesian Institute of Sciences, Cibinong, Indonesia	1,055	260	NA	September 2007
Natural History Museum, London, United Kingdom	485	326	NA	September 2007
Allan Wilson Centre, Massey University, Palmerston North, New Zealand	83	83	NA	April 2007
Totals	317,299	7,228		

comprehensive achievement of this goal will also require salvaging of specimens that die naturally, nonlethal sampling of living birds, and recovery of DNA from museum skins for those species that are too rare to warrant collection.

Geographic and Numeric Coverage

When considered by biogeographic region, species-level coverage varied from 96% in the Nearctic to 66–67% in the Afrotropical and Indomalayan regions, respectively, which means that the latter two regions lack representation of nearly a third of their species (Table 3). With only 73% of the world's presently recognized bird species archived in tissue collections, much work remains to be done. However, beyond filling taxonomic gaps, another important challenge is extending coverage within species. Exact numbers of specimens held for each species were not reported by all institutions (some used threshold values at the species level) and, thus, are not given here (though total collection sizes are considered accurate at the time of reporting; Table 1). Instead, we have used threshold values, reporting integers 1–9, 10+, and 100+ to obtain an order-of-magnitude understanding of the depth to which presently recognized species have been genetically documented. Thus far, only ~612 species (6% of the world's species) have been documented with >100 samples; for ~3,449 species (35%), >10 samples are archived; and 635 species (6%) appear to be documented with only a single sample (online Appendix; we do not know how many times single birds have had tissues archived in more than one collection, but, through examination of the Appendix for values <5, we reason that it is <10% of the totals).

The Louisiana State University Museum of Natural Science holds the world's largest bird tissue collection and, established in 1979, it was one of the first. Using this as the timeline basis for determining the growth of these resources, in the past 30 years ~10,000 tissue samples have been added to avian collections each year, on average. This is equivalent to approximately one tissue sample per species per year, an inadequate rate if our goal is to document avian genetic diversity and its distribution in a timely manner.

Institutional Representation

We recognize that some active institutions are not represented in this survey, and we encourage all institutions to summarize their holdings electronically. However, this survey probably includes

Table 2. A summary by avian order of the number of species existing, the number of those species represented in the world's avian tissue collections, and the number and percentage of species missing from these collections.

Order	Number of species	Number represented	Number missing	Percentage missing
Struthioniformes	1	1	0	0.0
Rheiformes	2	2	0	0.0
Casuariiformes	4	4	0	0.0
Dinornithiformes	5	5	0	0.0
Tinamiformes	46	40	6	13.0
Sphenisciformes	17	17	0	0.0
Gaviiformes	5	5	0	0.0
Podicipediformes	19	17	2	10.5
Procellariiformes	114	85	29	25.4
Pelecaniformes	67	41	26	38.8
Ciconiiformes	116	87	29	25
Phoenicopteriformes	6	5	1	16.7
Anseriformes	163	153	10	6.1
Falconiformes	314	199	115	36.3
Galliformes	284	187	97	34.2
Opisthocomiformes	1	1	0	0.0
Gruiformes	206	126	80	38.8
Charadriiformes	356	293	63	17.7
Pterocliformes	16	9	7	43.7
Columbiformes	308	184	124	40.3
Psittaciformes	367	271	96	26.2
Musophagiformes	23	19	4	17.4
Cuculiformes	141	97	44	31.2
Strigiformes	215	121	93	43.7
Caprimulgiformes	120	75	45	37.5
Apodiformes	443	334	109	24.6
Coliiformes	6	5	1	16.7
Trogoniformes	40	37	3	7.5
Coraciiformes	219	158	61	27.9
Piciformes	412	328	84	20.4
Passeriformes	5,897	4,322	1,575	26.7

all the world's larger vouchered tissue collections. Thus, the data in Table 1 are likely informative regarding the history of specimen-based ornithology over the past 30 years. We are witnessing a geographic and institutional redistribution in the growth of collections. This growth, not restricted to the world's largest bird collections, will help build scientific resources for countries that currently lack genetic collections and will increase representation and participation in this important global effort. Furthermore, in an era when genetic samples are being dependably shipped internationally and electronic communications are excellent, the value of regional collections to the global scientific community has never been greater.

Table 3. Species-level representation among biogeographic regions, with the number of species represented in collections, the number missing, and the percentage of species missing (some species occur more than once in this table).

Region	Target number of species	Number represented	Number missing	Percentage missing
Neotropical	4,075	3,544	531	13
Indomalayan	2,558	1,720	838	33
Afrotropical	2,363	1,553	810	34
Palearctic	1,566	1,229	337	22
Australasian	1,371	1,030	341	25
Nearctic	1,107	1,068	39	4
Oceanic	861	633	228	26

The top 10.—Of the 10 largest avian tissue collections, which together possess 77% of the world's holdings, two are national collections (Zoological Museum of Copenhagen and Smithsonian Institution) and one is a private natural-history museum (Field Museum). Five of the top 10 are university collections, which indicates that bird collections are still recognized as an important resource in higher education. Nonetheless, the number of universities with tissue collections seems small when contrasted with the scientific importance of genetic material in understanding avian diversity and the large number of such institutions possessing bird collections (Banks et al. 1973, Roselaar 2003). At least 3 of the top 10 collections are at institutions that currently have just one bird curator, and at least 2 have built their holdings in only the past decade or so (data not shown). These last points are both encouraging and sobering. Individuals can have a major effect on the archiving of avian genetic diversity, from guiding collection development to doing field work; indeed, several individual field biologists have added >1% of the total global resource (data not shown). If a modest number of additional institutions make genetic avian collections a priority, we will be in much better shape when it comes to establishing the baseline of avian genetic diversity.

Discussion

At present, although several collections have web portals for locating specimens, there is no electronic data-retrieval system that provides as extensive a survey of bird collections as presented here. The online Appendix presents detailed results in a sortable spreadsheet with which one can scroll through the world's birds and see the first summary of global specimen holdings. Our hope is that these results will promote more collecting (and salvaging or subsampling of taxa too rare to collect), both to fill the remaining gaps and to augment the small sample sizes that presently exist for so many of the world's bird species. We also look forward to the participation of collections presently not included, whether they are new or inadvertently overlooked. Individuals and institutions currently unable to establish or maintain vouchered tissue collections should seek partnerships and support that expand their capabilities in this regard.

If we take these data as a reflection of the bulk of bird collecting during the past three decades, it is apparent that collecting is an insignificant mortality factor for the world's bird populations. When spread around the world's land area (excluding Antarctica), these collections include just one tissue specimen per 600 km^2. For scale, this is equivalent to 6.7 specimens in an area the size of Rhode Island. To have such a low density of documentation among all avian species across geographic space from three decades of work indicates that there is much more to be done. To improve sampling densities at taxonomic and geographic scales, collectors can work with wildlife agencies and permitting officials to promote the many practical and scientific benefits of bird specimens and vouchered genetic samples.

We call for the avian collections community to establish comprehensive genetic representation of the world's birds. This will provide a detailed map of extant avian genetic diversity, help reveal cryptic species, and serve as a baseline for monitoring changes in bird populations resulting from anthropogenic and climatic changes. To achieve this goal, taxonomic and numeric representation must be greatly increased. Therefore, we advocate broadening and deepening the growth of the world's avian tissue collections: more countries and more institutions should make the vouchered archiving of avian diversity a priority. Our understanding of birds and our efforts to effectively manage avian populations will be much improved by doing so. The geographic and institutional diversification of bird collecting over the past 30 years demonstrates that smaller institutions and researchers in underrepresented countries can take an effective leadership role in building their own resources and making existing ones more apparent to the world community. Individuals and individual institutions can make a large difference in this important endeavor.

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