Avian spirit collections: attitudes, importance and prospects

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SUMMARY

Spirit (fluid-preserved) specimens of birds play a special role in anatomical and systematic studies. A literature review and survey of natural history museums reveals that spirit collections of birds have undergone a modest, steady increase to compose roughly 2–3% of specimens worldwide. However, many problems of representation indicated by the *Global inventory* (Wood *et al.* 1982a) persist, and current users of spirit specimens often encounter additional problems over preservation, provenance and associated data. Consensus exists that spirit specimens are informative for phylogenetic investigations and are the key source of data regarding functional morphology, that the primary motivation for preserving specimens in spirit is to retain maximal information for future investigators, and that expertise deriving from the study of anatomical specimens is at greatest risk in specimen-based ornithology. Nevertheless, bias persists for the preparation of bird specimens as study skins, evidently in response to demand by visitors (including artists) to collections, to a high threshold of perceived sufficiency in skin series, and to a parochial perspective on the availability of taxa as study skins. Curatorial concerns over preparation, storage and study of spirit specimens are evident but generally exert little influence over allocational priorities. Recommendations and justifications regarding the preservation of bird specimens in spirit are given.

Introduction: spirit specimens in ornithological research

Systematic ornithologists work within a subdiscipline dominated increasingly by molecular methods (Avise 1996), despite the absence of an empirical justification for such a change in analytical priorities (Hillis 1987, Crowe 1988, Swofford 1991, Eernisse & Kluge 1993, Novacek 1994, Wiens & Hillis 1996, Lee 1997, Wheeler 1997). Nonetheless, preserved specimens of birds remain an important resource for many types of study, including those based on DNA (McKitrick 1981, Olson 1981, Finley 1987, Houde & Braun 1988; *contra* Ricklefs 1980, Ricklefs & Gill 1980). Given the enduring importance of morphological characters in modern systematics regardless of taxon (Sanderson *et al.* 1993), the relevance of museum collections of birds is not unexpected, and the view of natural history collections as invaluable archives has become increasingly appreciated (Cotterill 1997, Murariu 1997).

Spirit specimens of birds—also referred to as wet anatomical or fluid-preserved specimens—play a special role in a diversity of anatomical and systematic studies (Quay 1974, Raikow 1985). Essentially, any ornithological investigation that is based in part on aspects of the anatomy of birds exclusive of the integument or skeleton (i.e. soft internal tissues) requires samples of fluid-preserved specimens (these can involve whole birds, parts, stomachs and contents, tongues, chicks and even unhatched embryos, which are hard to preserve any other way), and moreover many osteological features are interpretable only through study of the overlying musculature and

ligaments or the internal organs, including the digestive apparatus and stomach contents (Baumel *et al.* 1993). Recent works incorporating information based on dissections of birds include descriptions of the musculature (e.g. Schreiweis 1982, Zusi & Bentz 1984, Homberger 1986, Raikow 1993, Weber 1996, Müller & Weber 1998), functional analyses (e.g. Zusi 1962, Livezey 1990, 1992a,b), studies related to pathology (e.g. Cooper *et al.* 1998), phylogenetic reconstructions based on morphological characters (e.g. Raikow 1978, 1987, Prum 1990, 1992, McKitrick 1991a,b, Livezey 1997, 1998), feeding ecology (e.g. Arizmendi & Ornelas 1990) and even shapes of birds (e.g. Hayman 1986).

However, despite the unique utility of spirit specimens for many aspects of ornithological research (for example moult, locomotion, feeding, display and systematics), such material remains comparatively rare in museum collections (Peters 1933, Wood *et al.* 1982a,b, Zusi *et al.* 1982, Wood & Schnell 1986, Raikow 1985). A number of surveys of ornithological collections have documented that spirit specimens are less abundant than skeletons and much less abundant than traditional skin specimens (Banks *et al.* 1973, Clench *et al.* 1976). Raikow (1985: 119) noted that the survey by Banks *et al.* (1973) revealed that museums in North America hold '...over 4 million avian study skins, but only 142,150 skeletons, and a bare 52,025 spirit specimens'. This observation indicates that the ratio of the three major classes of specimen in the survey by Banks *et al.* (1973) approximated 77 skins: 3 skeletons: 1 spirit specimen.

A fortuitous outcome of the rarity of anatomical specimens is the publication of inventories of spirit and (to a lesser degree) skeletal specimens in a number of museums (Ames & Stickney 1968, Blandamer & Burton 1979, Gillette & Bartle 1982), an exercise evidently prompted as much by the tractability of holdings as by the priority accorded the specimens themselves. The importance of the manageably small numbers of spirit specimens to the compilation of inventories is reflected by the fact that a global inventory of avian skin specimens remains years away (largely because many skin collections remain uncomputerised), whereas such inventories for skeletal and spirit specimens were completed roughly 15 years ago (Wood *et al.* 1982a,b, Wood & Schnell 1986). A review of such inventories or a personal visit to a natural history collection substantiates a commonly held perception among museum ornithologists: whereas skin specimens generally are available in substantial series in many collections, skeletons and (especially) spirit specimens are much rarer for a given taxon, if available at all (Raikow 1985).

Moreover, investigators often discover that those spirit specimens that are available are often damaged or derive from captive populations or are accompanied by limited or no associated data. Conventional wisdom holds that the disparate proportions and diverse quality of study skins, skeletons and spirit specimens result from a widespread curatorial tradition of allocating wild-taken specimens having detailed associated data to collections of study skins, whereas damaged specimens of captive origin and/or with poor documentation are allocated for preparation as skeletons or spirit specimens (Raikow 1985).

An unfortunate reality of curation is that collections of vertebrates are comparatively costly to acquire and maintain (Blackmore *et al.* 1997). Moreover, the relegation of spirit specimens to a lower priority than that accorded traditional skin specimens or prepared skeletons is to some degree understandable, given several curatorial and investigational characteristics of spirit specimens. First, spirit specimens typically entail the use of formalin for fixation and ethanol for storage; the former is a toxic, unpleasant substance with which to work, and the latter is often legally controlled, can be contaminated by trace amounts of toxic substances (e.g. methanol) and may be combustible under certain circumstances. Second, spirit (fluid-preserved) specimens are often comparatively massive, and their storage can pose special challenges for older museums not designed to meet the associated weight-bearing requirements. Third, fluid-preserved specimens are typically stored in glass containers subject to breakage and, regardless of the quality or nature of the containers used, ethanol is virtually certain to leak from the storage containers over time; such collections therefore require constant monitoring to prevent infection by mould or desiccation of specimens. Fourth, many anatomists consider fluid-preserved specimens to be aesthetically unattractive and difficult to study; moreover, those investigators who are willing to handle spirit specimens must overcome the curatorial hurdles that accompany (reasonably enough) the typically destructive impact of empirical methods usually employed with spirit specimens, a condition exacerbated by the rarity of many taxa in spirit collections. Other concerns about spirit collections include fire risks, sheer cost of glass jars, handling weights, availability of expertise with respect to the use of labels and inks and the sealing of jars, and sheer curation time (confirming, tracking and maintaining data on spirit specimens is, owing to problems with labelling, significantly more complex and time-consuming than equivalent work with skeletons, eggs, mounts or skins).

Consequently, ornithologists seeking spirit specimens for study are faced by considerable limitations in number, substandard quality in much of the scarce material available, and comparatively stringent conditions on access, which in combination often result in a given taxon not being represented, worldwide, by a single suitable fluid-preserved specimen. What is the severity of this problem for modern systematists—is the scarcity of spirit specimens at the outset of the twenty-first century as serious as indicated by the landmark surveys of Peters (1933), Banks *et al.* (1973), Wood *et al.* (1982a,b), Wood & Schnell (1986), and Rogers (1986)? Moreover, what are the priorities of curatorial professionals with respect to the method of preparation and preservation of birds specimens? Finally, what are the likely impacts of current curatorial attitudes on the quality and diversity of avian spirit specimens that will be available for future study?

The objectives of this study were several: (1) to review selected, prevalent opinions bearing on spirit (anatomical) specimens of birds; (2) to summarise historical trends in collections of spirit specimens based on published inventories and a new survey based on questionnaires; (3) to summarise curatorial attitudes regarding spirit specimens based on this same survey; and (4) to discuss the likely impacts of these

perspectives, trends and attitudes on avian spirit specimens and the investigations that require them.

Methods

Questionnaire

In the second quarter of 1999, I mailed questionnaires comprising 27 questions (see Appendix), with covering letters, to 50 North American and European institutions having significant ornithological collections. Addresses and curators of these collections were taken from the lists of institutions provided by Wood *et al.* (1982a,b) and Wood & Schnell (1986), as updated by the mailing list used in the unpublished survey conducted by Rogers (1986). By the deadline specified, responses were received from 29 institutions, to which I added my own completed questionnaire for the Carnegie Museum of Natural History. Most of the returned questionnaires were fully completed (all questions answered as instructed); a minority included one or more unanswered questions, but no more than four questions were returned without a response.

Acronyms used for major institutions were as follows: American Museum of Natural History, New York (AMNH), Carnegie Museum of Natural History, Pittsburgh, Pennsylvania (CMNH), U.S. National Museum of Natural History, Washington, D.C. (USNM), Museum of Vertebrate Zoology at the University of California (MVZ), and the Museum of Zoology at the University of Michigan, Ann Arbor (UMMZ).

Protocols for summarising responses

Most of the questions included in the survey consisted of multiple (3–10) alternative responses; typically, the respondents were asked to rank the responses from most appropriate (to be assigned a '1') to least appropriate (to be assigned the largest integer required), and indicating 'ties' by assigning the same integer rank to the responses deemed of equal relevance. As is conventional in such exercises, tied alternatives were all weighted by the median value of the ranks included in the ties. A minority of questions simply asked respondents to indicate without ranking which, if any, of the alternatives listed were applicable in their experience. Finally, a few questions asked for tallies of selected variables for each collection surveyed (e.g. current numbers of specimens by class of preparation).

In the oral presentation of this paper, most of the responses were displayed in summary pie-charts or histograms. Pie-charts were used to display overall preferences indicated for questions requiring ranking of alternative responses; in order to associate the responses receiving highest preference with the largest portion of the pie-chart, the total scores for each alternative were transformed into the inverse proportion of the grand total for the question. Simple counts (unranked) were presented as histograms or tables. In this written account, with considerations of space at a premium, I tabulate the mean scores for questions incorporating information on

ranks (highlighting the most favoured alternative in boldface). Simple tallies, as in the oral presentation, are compiled as such. This simplistic approach to summarising the data emphasises only the clearest findings suggested by the comparatively meagre sample of museums, and avoids the over-interpretation of minor differences which cannot be considered robust in what must be regarded as only a preliminary study.

Results

Growth of collections

A summary of tallies of skin, skeletal and spirit specimens of bird based on published surveys (Peters 1933, Banks *et al.* 1973, Wood *et al.* 1982a,b, Wood & Schnell 1986), an unpublished survey by Rogers (1986), and the present survey (questions 19–21) revealed that, despite an enduring, significant predominance of skin specimens in ornithological collections, the proportions of skeletal and spirit specimens have undergone a modest but steady increase (Table 1). Thus the approximate proportions of skin, skeletal and spirit specimens, respectively, changed from 192:2:1 in 1933 to 70:3:1 in 1973 to 34:2:1 in 1986 and to 36:2:1 in 1999. In other words, during 1933–1999, the proportions of the three types of specimen changed as follows: skins declined from > 99% to ~ 93%; skeletons increased from ~1% to ~5%; and spirit specimens increased modestly from <1% to ~ 2%.

These general patterns, however, obscure differences among major museums (Table 2). Although most major collections underwent a primary period of growth during 1933–1973, the proportions of the three major classes of specimen showed different trajectories (Table 2): AMNH showed virtually no growth in collections other than skins until the last decade or so, and this increase emphasised skeletal holdings; ornithological collections at UMMZ, MVZ and CMNH manifested an early plateau in numbers of study skins, with steady increases in skeletal and spirit specimens; and USNM showed essentially uniform increases in all three classes of specimens, although the rate of increase of skin specimens was distinctly, uniformly higher.

TABLE 1

Numbers (%) of avian specimens in major collections by class of specimen and year of survey, based on Peters (1933), Banks *et al.* (1975), Wood & Schnell (1986) plus Rogers (1986), and the present study

	Year of survey (number of institutions sampled)			
Class of specimen	1933 (16)	1973 (29)	1986 (32)	1999 (30)
Skin	1,757,625 (98.7%)	3,363,350 (94.9%)	3,411,786 (91.1%)	4,633,495 (91.7%)
Skeleton	14,654 (0.8%)	132,855 (3.7%)	232,786 (6.2%)	289,903 (5.7%)
Spirit	9,175 (0.5%)	47,785 (1.3%)	101,071 (2.7%)	128,732 (2.5%)
TOTAL	1,781,454	3,543,990	3,745,021	5,052,130

TABLE 2

Numbers of specimens of bird preserved as skins, skeletons and spirit specimens in five major North American collections in four different twentieth-century surveys, based on Peters (1933), Banks *et al.* (1975), Wood & Schnell (1986) plus Rogers (1986), and the present study

Collection	Class of specimen	Year of survey 1933	1973	1986	1999
American Museum of Natural History	Skin	685,000	900,000	900,000	900,000
	Skeleton	—	7,000	12,000	24,000
	Spirit	—	5,000	8,000	10,000
U. S. National Museum of Natural History	Skin	252,000	400,000	480,000	550,000
	Skeleton	12,654	25,000	30,000	51,248
	Spirit	8,875	18,000	20,000	26,784
Carnegie Museum of Natural History	Skin	100,000	150,000	160,000	155,379
	Skeleton	0	2,000	10,500	15,779
	Spirit	0	2,500	5,000	6,756
Univ. California, Museum of Vertebrate Zoology	Skin	59,200	150,000	169,500	160,000
	Skeleton	0	9,000	10,704	20,000
	Spirit	0	1,700	2,497	3,200
University of Michigan, Museum of Zoology	Skin	33,000	200,000	150,000	170,690
	Skeleton	—	11,100	20,000	23,200
	Spirit	—	300	1,300	3,393

Priorities of allocation

The majority of questions put to respondents concerned their perceptions of the use, potential informativeness and curatorial relevance of the various classes of preparations of avian specimens in museum collections. The primary objective of these questions was to gain insight into the motivation behind the critical decisions over the form of preparation or preservation to be allocated to new and important specimens. Limited redundancy of questions was intentional, as a means of confirming any patterns in attitudes that might emerge, and of limiting errors of interpretation stemming from single opportunities to reveal opinions.

Below, I summarise the responses to questions pertaining to the criteria and considerations that relate to allocation of new specimens to skin, skeletal or spirit preparations (Table 3). See the Appendix for full text of questions and alternative responses as provided to respondents.

Question 1.—New, valuable specimens made available for accession as scientific specimens were roughly twice as likely to be prepared as study skins as either skeletal or spirit specimens, the latter two options being approximately equal in preference.

Question 2.—Roughly half of the respondents consult both *Global inventories* (Wood *et al.* 1982a,b, Wood & Schnell 1986) when allocating specimens. Almost as many consult neither, and a small number refer only to the skeletal inventory on a regular basis for allocation of new specimens.

Question 3.—Of the alternative reasons for allocating a specimen for preparation as a study skin, the *popularity* of skin specimens with visitors was the most favoured response. Of the other seven justifications offered, none won a clear designation as second-most preferred.

Question 4.—Of the alternative reasons for allocating a specimen for preparation as a skeleton, the *condition* of the specimen was ranked the most important consideration. Comments by respondents and informal discussions with colleagues indicate that the criterion of 'condition' in this context typically implies that specimens in poor condition (freezer-damaged, spoiled before freezing, poor condition of plumage or incomplete associated data) were more likely to be relegated to the skeleton collection than were specimens in good condition. Of the other seven justifications offered, none won a clear designation as second-most preferred.

TABLE 3

Summary of scores of responses to questionnaire (Appendix); responses to questions in which alternatives were assigned ranks are summarised by the mean ranks reported (entries indicating strongest support are in boldface), whereas responses to questions asking that one or more alternatives be checked if appropriate (marked by *) are summarised as the total number of positive responses received (30 respondents, although some individuals declined to answer one or more questions); numbers of questions not amenable to numerical scores are enclosed by square brackets.

	Summary score by response									
Question	a	b	c	d	e	f	g	h	i	j
1.	**1.3**	2.1	2.6	—	—	—	—	—	—	—
2*.	13	0	4	2	12	—	—	—	—	—
3.	4.6	5.5	5.1	**2.0**	3.7	4.3	4.0	6.9	—	—
4.	3.9	5.1	5.1	3.7	**2.5**	4.9	3.7	7.1	—	—
5.	**1.5**	3.8	5.3	5.1	3.9	5.5	3.9	7.0	—	—
6.	6.1	3.6	**2.2**	4.2	4.7	5.1	**2.1**	—	—	—
7*.	9	5	14	1	1	—	—	—	—	—
8.	5.4	3.6	4.0	5.7	**2.4**	6.2	8.3	6.6	6.0	6.7
9*.	7	3	16	11	3	22	19	—	—	—
10.	2.5	2.9	**2.0**	3.1	3.8	—	—	—	—	—
11.	2.3	1.9	**1.2**	—	—	—	—	—	—	—
12.	**2.2**	2.4	3.0	2.4	—	—	—	—	—	—
13.	3.5	2.8	2.3	**1.3**	—	—	—	—	—	—
14.	2.9	1.9	**1.2**	—	—	—	—	—	—	—
15*	20	18	15	14	14	—	—	—	—	—
16*.	5	7	8	7	4	—	—	—	—	—
17*.	12	4	6	5	0	—	—	—	—	—
18.	**2.3**	2.7	4.3	4.3	**2.4**	5.0	—	—	—	—
[19–21].	—	—	—	—	—	—	—	—	—	—
22*.	1	17	12	—	—	—	—	—	—	—
23*.	9	18	2	—	—	—	—	—	—	—
[24–27].	—	—	—	—	—	—	—	—	—	—

Question 5.—Of the alternative reasons for allocating a specimen for preparation as a spirit specimen, the preservation of *maximal information* was ranked as the most important consideration. As in the corresponding questions for skin and skeletal specimens, none of the other seven justifications offered emerged as the second-most preferred.

Question 6.—Of the reasons perceived to account for the comparative rarity of spirit specimens in ornithological collections, *curatorial traditions* and *low demand* for study were ranked as the most plausible (Table 3).

Question 7.—Of the four cited classes of curatorial staff, or combinations thereof, the ranked responses indicated that the staff member most frequently responsible for allocation of new specimens is the *collection manager*. It should be noted in this context that budgetary limitations in some museums have shifted most or all curatorial duties from curators (if any) to support staff, notably collection managers, and that the importance of collection managers in this critical decision may reflect, in part, the dictates of logistics instead of genuine, administrative preference. Insights into such staffing issues largely derived from responses to questions 24–27 of the survey.

Question 8.—Of the ten alternative justifications for a hypothetical increase in holdings of spirit specimens in the coming years, respondents ranked the *preservation of the entire specimen for posterity* as the most persuasive. Ranks given other options were very close, forming a virtual continuum of scores, and precluded further designation of relative preferences.

Question 9.—Of possible preparations to be applied to an exceptionally rare and valuable specimen, respondents favoured the preservation of the specimens as a *study skin with partial skeleton*; conservation as a skull-less skin ('schmoo') and partial skeleton, or as an entire skin specimen, emerged as second and third preferences, respectively. However, 19 of 22 respondents also indicated an intention to retain, in addition to the various preparations of skins and skeletons, organs in spirit or frozen tissues. Allocations of the hypothetical 'voucher' specimen either as a full skeleton or complete spirit specimen were the least favoured of the alternatives presented.

Question 10.—The primary reason underlying current allocations of new specimens at the institutions of the respondents was the *availability of the taxon in their own collections* (i.e. 'local' representation). This preference was comparatively weakly indicated, however, as the other four alternatives listed received moderately strong support.

Question 22.—Increasingly, combination-preparations of specimens are being used to preserve more and diverse data from valuable specimens of birds. This question revealed that a majority of respondents oversee the preparation of study skins and partial skeletons at least infrequently, although most categorised these efforts as occurring 'rarely' as opposed to 'routinely.' Only a single respondent indicated that such dual preparations were never performed.

Question 23.—In parallel with the preceding question, respondents were polled as to the preparation of a second variation of dual preparation—study skin with

partial spirit specimen. In this case, the majority 'rarely' supervised such combinations, with almost one-third indicating that such preparations 'never' occurred; only two respondents characterised such preparations as 'routine'.

Importance of specimens

Several questions were intended to assess the perceptions of respondents concerning the relative importance of study skins, skeletons and spirit specimens for ornithological research. It was hoped that these questions would transcend current practices and patterns of use, and provide insights into underlying motivations, the potential informativeness of specimens and the impact of curatorial trends and current holdings on selected areas of expertise and future research.

Question 11.—Of three areas of anatomical expertise—those pertaining to the externum, skeleton or soft (internal) anatomy—*internal anatomy* was ranked most heavily as the subdiscipline undergoing a decline in recent decades (Table 3); the other two options received substantially less support. Although the majority of respondents implicitly agreed with the presumption that declines in expertise were evident across anatomical systems, the unintended bias reflected in the question may have distorted the responses. It is noted, however, that two respondents opposed this pessimistic assessment, and commented that they perceived *increases* in expertise in all three anatomical areas.

Question 12.—Respondents were asked to rank four sources of data—study skins, skeletons, spirit specimens and genetic material—based on their view of the role these have played in our *present* understanding of avian phylogeny. Responses indicated essentially a four-way tie in this assessment, with a slight preference indicated for the contribution of study skins (Table 3). The most valuable service of this ambiguous outcome is the provision of a benchmark against which responses to the following, predictive counterpart (question 13) could be viewed.

Question 13.—With respect to the four sources of information listed above, respondents considered *genetic material* to hold the greatest promise for *future* insights into avian phylogeny; the other three options divided the remaining support approximately equally (Table 3).

Question 14.—Respondents considered *spirit specimens* to be approximately twice as important as either study skins or skeletons for an understanding of the functional anatomy of birds (Table 3).

Curatorial concerns

Four questions concerned comparatively practical aspects of the curation and use of spirit specimens. These were included to assess the potential for such concerns to deter curatorial staff members from allocating new specimens to fluid-preserved collections.

Question 15.—Several frequently cited issues attending spirit specimens—including toxicity of formalin, combustibility of ethanol, breakage of glass containers,

excessive weight of collections—were accorded equal weight by respondents (Table 3). Under 'other', several respondents listed failure of seals on containers and the likelihood that ethanol would escape and permit desiccation of the specimens.

Question 16.—Of the various accidents that can occur in the preparation or study of spirit specimens, eight respondents listed lacerations with dissection or injection equipment, seven listed excessive exposure to ethanol or formalin (by inhalation and/or spillage), five reported cuts on broken glass, and four indicated other mishaps (Table 3).

Question 17.—Although the combustibility of ethanol in collections of spirit specimens has not been confirmed as a significant problem, there is a widespread perception that this risk exists. Accordingly, local fire codes in many regions impose special conditions for the storage of such specimens. This question indicated that roughly half of the respondents considered that their material was held in full compliance with fire codes, whereas the remaining respondents were approximately equally divided among the other three options (partial compliance, non-compliance or no information).

Question 18.—Access to specimens and the information these contain is of considerable scientific and ethical concern (Hoagland 1997). Given the destructive nature of most forms of study of spirit specimens (notably dissection), curators have increasingly been compelled to devise conditions or criteria for the approval of access or loans to investigators. Of the six alternatives provided, three choices (taxa involved, method of study, and experience of investigator) received slightly greater support than the other options (Table 3).

Discussion

Overview of responses

Data from several published surveys, an unpublished work by Rogers (1986), and the present survey indicate a steady but slow increase in the relative numbers of spirit specimens during the twentieth century (Table 1). Despite this trend, spirit specimens currently comprise only 2–3% of specimens held in ornithological collections surveyed. This situation appears unlikely to be reversed in the near future, as responses to the survey revealed that those responsible for allocation and preparation remain predisposed to prepare prime specimens as study skins. A substantial number of respondents prefer to preserve a critical specimen as a study skin and in various other forms (most frequently as a partial skeleton and frozen tissue).

The continuing preference for study skins stems primarily from the frequency with which the *current, varied* users of collections (including artists and other non-technical users) refer to these specimens. Also important to allocation decisions is a persistent, somewhat antiquated concern regarding the representation of the taxon in question as a skin specimen in the *local* collection, as opposed to basing decisions on *global* needs across all major types of specimen (e.g. as given by the *Global*

inventories). Other concerns pertaining to collections of bird specimens in spirit—excessive weight, dangers of desiccation, and risks related to fire, toxic substances, or 'sharps' (sharp-edged or -pointed instruments)—appear to be comparatively minor impediments to the growth of spirit collections.

Contradictory attitudes and practices

Perhaps most remarkable was the contrast in motivations for preparing a specimen as a study skin, skeleton or spirit specimen, and associated estimates of the potential value of the three classes of preparation. Study skins were favoured because this form of preparation was in the highest demand among current users. Skeletons were favoured where condition of the specimen was a concern. Spirit specimens were chosen most frequently when the intention was to conserve the maximal amount of information for future study.

All three major types of avian specimen were credited with approximately equal impact on our present understanding of avian phylogeny as genetic material, but the last was accorded a significantly greater role than all three traditional preparations in furnishing insights into avian phylogenetics in the coming years. Nonetheless, spirit specimens were valued at least as much as the more abundant skeletal collections held by museums, and spirit specimens were valued significantly more than all other sources of information for studies of functional anatomy.

When viewed as a form of 'avian archive', there appears to be a conflict between the perceived value of spirit specimens and the propensity of curators to allocate new specimens for preservation in fluid. Generally, spirit specimens are acknowledged to preserve the maximal amount of anatomical information, and collections of spirit specimens are considered critical resources for phylogenetics and unsurpassed sources of information on functional anatomy. Furthermore, there was a general consensus that the anatomical expertise at highest risk in ornithology is that most dependent on the availability and study of spirit specimens. However, when faced with the opportunity to add to this valuable resource, curatorial personnel persist in a long-standing tradition of filling deficiencies in local skin collections, and turning to skeletal or (least frequently) to spirit collections only when this primary concern is appeased or the condition of the specimen renders it undesirable for this purpose.

Recommendations for the twenty-first century

Availability and quality of specimens in ornithological collections to a substantial degree dictate the course of specimen-based research to be undertaken by future investigators. Extensive new collections to serve an individual investigator are becoming increasingly difficult to justify or accomplish, and most specimen-based studies are designed in part based on the current availability of requisite material in the museums of the world. Unfortunately, this global perspective on holdings often is not shared by those who determine the fates of new specimens in ornithological

collections, where parochial and seemingly insatiable preferences for skin specimens persist in a significant number of (especially smaller) museums. Spirit specimens are uniquely informative for a number of critical aspects of ornithology (e.g. phylogenetics, functional morphology and ontogeny), a need intensified by the fact that study of spirit specimens often entails various degrees of destruction (i.e. spirit specimens, like frozen tissues, are consumable).

Accordingly, I recommend that those who are empowered to allocate incoming specimens to various preparations do so as to:

(1) *minimise what is discarded* during the preparation of specimens by storing specimens material in multiple ways (see, e.g., Eames *et al.* 2002);
(2) serve *future* investigators *at least* as much as current users;
(3) preserve *maximal information*, perhaps best achieved through preservation of a spirit specimen, frozen tissue samples and digital photographs of the fresh specimen;
(4) complement g*lobal* as opposed to local deficiencies in holdings (cosmopolitan perspectives being appropriate for a future in which museums will be increasingly connected by electronic media); and
(5) *create uniquely valuable collections* not attainable by other means, e.g. ontogenetic series in spirit, and special preparations to facilitate the study of challenging organ systems or tissues.

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References:

Ames, P. L. & Stickney, E. H. 1968. Avian anatomical specimens in the Peabody Museum of Natural History, Yale University. *Postilla* 118.

Arizmendi, C. & Ornelas, J. F. 1990. Hummingbirds and their floral resources in a tropical dry forest in Mexico. *Biotropica* 22: 172-180.

Avise, J. C. 1996. Three fundamental contributions of molecular genetics to avian ecology and evolution. *Ibis* 138: 16–25.

Banks, R. C., Clench, M. H. & Barlow, J. C. 1973. Bird collections in the United States and Canada. *Auk* 90: 136–170.

Baumel, J. J, King, A. S., Breazile, J. E., Evans, H. E. & Vanden Berge, J. C. (eds.) 1993. *Handbook of avian anatomy: nomina anatomica avium*, 2nd edn. Nuttall Ornithol. Club, Cambridge.

Blackmore, S., Donlon, N. & Watson, E. 1997. Calculating the financial value of systematic biology collections. Pp.17–21 in Nudds, J. R. & Pettitt, C. W. (eds.) *The value and valuation of natural science collections*. Geol. Soc., London.

Blandamer, J. S. & Burton, P. J. K. 1979. Anatomical specimens of birds in the collections of the British Museum (Natural History). *Bull. Brit. Mus. (Nat. Hist.), Zool. Ser.* 34: 125–180.

Clench, M. H., Banks, R. C. & Barlow, J. C. 1976. Bird collections in the United States and Canada: addenda and corrigenda. *Auk* 93: 126–129.

Cooper, J. E., Dutton, C. J. & Allchurch, A. F. 1998. Reference collections: their importance and relevance to modern zoo management and conservation biology. *Dodo* 34: 159–166.

Cotterill, F. P. D. 1997. The second Alexandrian tragedy, and the fundamental relationship between biological collections and scientific knowledge. Pp.227–241 in Nudds, J. R. & Pettitt, C. W. (eds.) *The value and valuation of natural science collections*. Geol. Soc., London.

Crowe, T. M. 1988. Molecules vs morphology in phylogenetics: a non-controversy. *Trans. Royal Soc. S. Africa* 46: 317–334.

Eames, J. C., Steinheimer, F. D. & Ros Bansok. 2002. A collection of birds from the Cardamom Mountains, Cambodia, including a new subspecies of *Arborophila cambodiana*. *Forktail* 18: 67-86.

Eernisse, D. J. & Kluge, A. G. 1993. Taxonomic congruence versus total evidence, and amniote phylogeny inferred from fossils, molecules, and morphology. *Mol. Biol. Evol.* 10: 1170–1195.

Finley, R. B. 1987. The value of research collections. *Bioscience* 37: 92.

Gillette, J. & Bartle, J. A. 1982. Catalogue of anatomical specimens of living and recently extinct birds in the National Museum of New Zealand (NMNZ). *Natn. Mus. New Zealand Misc. Ser.* 5: 1–18.

Hayman, P. 1986. Notes on the plates. Pp.35-36 in Hayman, P., Marchant, J. & Prater, T. *Shorebirds: an identification guide to the waders of the world.* Croom Helm, London.

Hillis, D. M. 1987. Molecular versus morphological approaches to systematics. *Annu. Rev. Ecol. Syst.* 18: 23–42.

Hoagland, K. E. 1997. Access to specimens and genetic resources: an Association of Systematics Collections position paper. Pp.317–330 in Hoagland, K. E. & Rossman, A. Y. (eds.) *Global genetic resources: access, ownership, and intellectual property rights*. Assoc. Syst. Coll., Washington, D.C.

Homberger, D. G. 1986. The lingual apparatus of the African Grey Parrot, *Psittacus erithacus* Linné (Aves: Psittacidae): description and theoretical mechanical analysis. *Orn. Monogr.* 39: 1–233.

Houde, P. & Braun, M. J. 1988. Museum collections as sources of DNA for studies of avian phylogeny. *Auk* 105: 773–776.

Lee, M. S. 1997. Molecules, morphology, and phylogeny: a response to Hedges and Maxson. *Mol. Phyl. Evol.* 7: 394–395.

Livezey, B. C. 1990. Evolutionary morphology of flightlessness in the Auckland Islands Teal. *Condor* 92: 639–673.

Livezey, B. C. 1992a. Flightlessness in the Galápagos Cormorant (*Compsohalieus* [*Nannopterum*] *harrisi*): heterochrony, giantism, and specialization. *Zool. J. Linnean Soc.* 105: 155–224.

Livezey, B. C. 1992b. Morphological corollaries and ecological implications of flightlessness in the Kakapo (Psittaciformes: *Strigops habroptilus*). *J. Morphol.* 213: 105–145.

Livezey, B. C. 1997. A phylogenetic analysis of basal Anseriformes, the fossil *Presbyornis*, and the interordinal relationships of waterfowl. *Zool. J. Linnean Soc.* 121: 361–428.

Livezey, B. C. 1998. A phylogenetic analysis of the Gruiformes (Aves) based on morphological characters, with an emphasis on the rails (Rallidae). *Phil. Trans. Royal Soc. (Ser. B)* 353: 2077–2151.

McKitrick, M. C. 1981. Old specimens and new directions: a comment. *Auk* 98: 193–195.

McKitrick, M. C. 1991a. Forelimb myology of loons (Gaviiformes), with comments on the relationship of loons and tubenoses (Procellariiformes). *Zool. J. Linnean Soc.* 102: 115–152.

McKitrick, M. C. 1991b. Phylogenetic analysis of avian hindlimb musculature. *Univ. Michigan Mus. Zool. Misc. Publ.* 179: 1–85.

Müller, W. & Weber, E. 1998. Re-discovery of a supposedly lost muscle in palaeognathous birds and its phylogenetic implications. *Mitt. Mus. Nat. Berl. (Zool. Reihe)* 74: 11–18.

Murariu, D. 1997. Archives of nature in natural history collections. Pp.30–34 in Nudds, J. R. & Pettitt, C. W. (eds.) *The value and valuation of natural science collections*. Geol. Soc., London.

Novacek, M. J. 1994. Morphological and molecular inroads to phylogeny. Pp.85–131 in Grande, L. & Rieppel, O. (eds.) *Interpreting the hierarchy of nature*. Academic Press, New York.

Olson, S. L. 1981. The museum tradition in ornithology: a response to Ricklefs. *Auk* 98: 91–104.

Peters, J. L. 1933. Collections of birds in the United States and Canada: study collections. Pp.131–141 in Chapman, F. M. & Palmer, T. S. (eds.) *Fifty years' progress of American ornithology: 1883–1933*. American Ornithol. Union, Washington, D. C.

Prum, R. O. 1990. A test of the monophyly of the mankins (Pipridae) and of the cotingas (Cotingidae) based on morphology. *Univ. Mich. Mus. Zool. Occas. Pap.* 723: 1–44.

Prum, R. O. 1992. Syringeal morphology, phylogeny, and evolution of the Neotropical manakins (Aves: Pipridae). *Amer. Mus. Novit.* 3043.

Quay, W. B. 1974. Bird and mammal specimens in fluid—objectives and methods. *Curator* 17: 91–104.

Raikow, R. J. 1978. Appendicular myology and relationships of the New World nine-primaried oscines (Aves: Passeriformes). *Bull. Carnegie Mus. Natur. Hist.* 7: 1–43.

Raikow, R. J. 1985. Museum collections, comparative anatomy and the study of phylogeny. Pp.113–121 in Miller, E. H. (ed.) *Museum collections: their roles and future in biological research*. Brit. Columbia Prov. Mus. Occas. Pap. 25: 1–222.

Raikow, R. J. 1987. Hindlimb myology and evolution of the Old World suboscine passerine birds (Acanthisittidae, Pittidae, Philepittidae, Eurylaimidae). *Orn. Monogr.* 41: 1–81.

Raikow, R. J. 1993. Structure and variation in the hindlimb musculature of the woodcreepers (Aves: Passeriformes: Dendrocolaptinae). *Zool. J. Linnean Soc.* 107: 353–399.

Ricklefs, R. E. 1980. Old specimens and new directions: the museum tradition in contemporary ornithology. *Auk* 97: 206–207.

Ricklefs, R. E. & Gill, F. B. 1980. Fifty years of American ornithology. *Bull. Brit. Orn. Cl.* 100: 118–131.

Rogers, S. P. 1986. Summary of questionnaire concerning preparation of avian specimens. Unpublished typescript, Carnegie Museum of Natural History, Pittsburgh.

Sanderson, M. J., Baldwin, B. G., Bharathan, G., Campbell, C. S., von Dohlen, C., Ferguson, D., Porter, J. M., Wojciechowski, M. F. & Donoghue, M. J. 1993. The growth of phylogenetic information and the need for a phylogenetic data base. *Syst. Biol.* 42: 562–568.

Schreiweis, D. O. 1982. A comparative study of the appendicular musculature of penguins (Aves: Sphenisciformes). *Smithsonian Contr. Zool.* 341: 1–46.

Swofford, D. L. 1991. When are phylogeny estimates from molecular and morphological data incongruent? Pp.295–333 in Miyamoto, M. M. & Cracraft, J. (eds.) *Phylogenetic analysis of DNA sequence*. Oxford Univ. Press.

Weber, E. 1996. Das Skelet-Muskel-System des Kieferapparates von *Aepypodius arfakianus* (Salvadori, 1877) (Aves, Megapodiidae). *Courier Forsch.-Inst. Senckenberg* 189: 1–130.

Wheeler, Q. D. 1997. The role of taxonomy in genetic resource management. Pp.59–70 in Hoagland, K. E. & Rossman, A. Y. (eds.) *Global genetic resources: access, ownership, and intellectual property rights*. Assoc. Syst. Coll., Washington, D. C.

Wiens, J. J. & Hillis, D. M. 1996. Accuracy of parsimony analysis using morphological data: a reappraisal. *Syst. Bot.* 21: 237–243.

Wood, D. S. & Schnell, G. D. 1986. *Revised world inventory of avian skeletal specimens, 1982*. American Ornithologists' Union and Oklahoma Biol. Surv., Norman.

Wood, D. S., Zusi, R. L. & Jenkinson, M. A. 1982a. *Inventory of avian spirit specimens, 1982*. American Ornithologists' Union and Oklahoma Biol. Surv., Norman.

Wood, D. S., Zusi, R. L. & Jenkinson, M. A. 1982b. *Inventory of avian skeletal specimens, 1982*. American Ornithologists' Union and Oklahoma Biol. Surv., Norman.

Zusi, R. L. 1962. Structural adaptations of the head and neck in the Black Skimmer, *Rynchops nigra*, L. *Nuttall Orn. Club Publ.* 3: 1–101.

Zusi, R. L. & Bentz, G. D. 1984. Myology of the Purple-throated Carib (*Eulampis jugularis*) and other hummingbirds (Aves: Trochilidae). *Smithsonian Contr. Zool.* 385: 1–70.

Zusi, R. L., Wood, D. S. & Jenkinson, M. A. 1982. Remarks on a world-wide inventory of avian anatomical specimens. *Auk* 99: 740–757.

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Appendix

Questionnaire regarding avian spirit collections

Instructions regarding ranking.—If possible, use the integer ranking recommended parenthetically in each question in your responses. In the event that you feel that two or more options merit the same rank, then assign them the same integer value; e.g. for four alternatives in which two options are considered to have equal, intermediate ranks, then the integers assigned would be 1, 2, 2, 3. If you consider any option to be completely irrelevant to a particular issue, assign it a rank of zero.

1. Please indicate the normal priority assigned to the three classes of preparation in your institution for a single, newly acquired and valuable specimen of bird (e.g. new distributional record, representative of endangered species) (1 = highest; 2 = intermediate; 3 = lowest): (a) skin; (b) skeleton; (c) spirit.
2. Do you or your staff consult the *World inventory of avian spirit specimens* (Wood *et al.* 1982) or the *Revised world inventory of avian skeletal specimens* (Wood & Schnell 1986) in allocating specimens for preparation? (a) yes, I consult both inventories; (b) yes, but I only consult the spirit inventory; (c) yes, but I only consult the skeleton inventory; (d) no, I do not consult either inventory.
3. Please rank the following rationales *to the extent that you are in agreement with them* as justifications for allocation a critical specimen to be prepared as a **study skin**. (Please rank as '1' the rationale with which you are in strongest agreement, '2' for next-most important reason listed, etc., with '8' being used for the reason you find least compelling): (a) preparation preserves the maximal amount of anatomical information; (b) preparation is easiest to prepare; (c) preparation is easiest to curate; (d) preparation is sought most frequently by ornithologists using collection; (e) preparation is most appropriate given the condition of the specimen; (f) preparation conforms to the primary form curated at the facility; (g) preparation is of greatest interest or utility to the individual making the

allocation or to his/her colleague(s); (h) preparation is a condition of acceptance imposed by collector or donor.

4. Please rank the following rationales *to the extent that you are in agreement with them* as justifications for allocation a critical specimen to be prepared as a **skeletal specimen**. Same instructions and options as in Question 3.
5. Please rank the following rationales *to the extent that you are in agreement with them* as justifications for allocation a critical specimen to be prepared as a **spirit specimen**. Same instructions and options as in Question 3.
6. Please rank the following possible explanations for the relative rarity of spirit specimens in global ornithological collections (1 = most plausible, etc.): (a) spirit specimens retain the least amount of readily usable information; (b) spirit specimens are comparatively difficult, unpleasant or expensive to prepare and curate; (c) spirit specimens are only infrequently sought by ornithologists; (d) spirit specimens are messy to examine; (e) spirit specimens require very technical training to study properly; (f) spirit specimens suffer damage if dissected, and therefore curators are comparatively restrictive regarding access; (g) study skins were strongly favoured as specimens during much of the twentieth century in most museums.
7. In your facility, what is (are) the position(s) of the individual(s) who allocate incoming specimens as to form of preparation? (If this process varies, please indicate the most frequent option as "1" and the next most frequent as "2", etc.): (a) curator in charge; (b) curators as group; (c) collection manager; (d) preparator or technician; (e) other (specify).
8. Please rank the following motivations for an increase in spirit specimens of birds in your collection during the next decade (1 = most plausible, ..., 10 = least plausible): (a) receipt of numerous specimens for which there was low interest in alternative preparations; (b) arrival of new staff member or nearby colleague with interest in study of spirit specimens; (c) increase in importance of spirit specimens in your own research programme; (d) receipt of numerous specimens that were not considered suitable for alternative preparations; (e) professional concern for preservation of entire specimens for posterity; (f) increased familiarity with procedures for preparation and care of spirit specimens; (g) mandate from higher administration; (h) provenance of specimen (i.e. wild-taken or captive); (i) completeness of data associated with specimens; (j) indications of disease in the specimens.
9. If your collection was given a fresh specimen of a previously unknown species of bird that is of sufficient rarity that it could be assumed that no more specimens would be collected in the future (i.e., your specimen is assumed to represent the unique voucher for the species), which of the following preparations would you recommend (check [tick] more than one if a combination of preparations would be used): (a) study skin; (b) full skeleton; (c) study skin and partial skeleton; (d) study skin with skull removed ("schmoo") and partial skeleton; (e) entire spirit specimen; (f) frozen tissue specimen(s); (g) internal organs in spirit.
10. Please rank the following justifications for method of preparation for a newly acquired specimen to be added to your collection (1 = most important consideration, ..., 5 = least important): (a) availability/abundance of the taxon as a skin, skeleton or spirit specimen in the museums *of the world*; (b) availability/abundance of the taxon as a skin, skeleton or spirit specimen in the museums *of your country or continent*; (c) availability/abundance of the taxon as a skin, skeleton or spirit specimen in *your collection*; (d) utility of the preparation of the taxon to your own research; (e) preparatory skills of you or your staff.
11. Please rank the following skills by decline in expertise (regardless of reason) during the last 20 years in ornithological institutions worldwide (1 = greatest decline,..., 3 = least decline): (a) illustration/technical description of external appearance of birds; (b) identification/classification of skeletal elements; (c) description/illustration/comparative study of soft tissues (e.g., musculature, internal organs).

12. Please rank the following four classes of avian specimen by your perception of their importance to our *present* understanding of *avian phylogeny* (1 = probably most important, etc.): (a) skin specimens; (b) skeletons; (c) spirit specimens; (d) genetic material extracted from museum specimens.
13. Please rank the following four classes of avian specimen by your perception of their importance to our *future* understanding of *avian phylogeny* (1 = probably most important, etc.): (a) skin specimens; (b) skeletons; (c) spirit specimens; (d) genetic material extracted from museum specimens.
14. Please rank the following three classes of avian specimen by your perception of their importance to our understanding of *functional anatomy* (1 = probably most important, etc.): (a) skin specimens; (b) skeletons; (c) spirit specimens.
15. Please indicate which (if any) of the following concerns are held by you or your staff have regarding the preparation and storage of fluid-preserved specimens: (a) toxicity of formalin; (b) combustibility of ethanol; (c) risk of breakage of glass jars; (d) weight of collection with respect to structural limitations of facility; (e) other (specify).
16. Please indicate which of the following mishaps (if any) have happened in your facility during the preparation and storage of fluid-preserved specimens: (a) staff member or visitor suffered cut from broken glass; (b) staff member or visitor suffered from exposure to ethanol or formalin; (c) staff member or visitor suffered cut during dissection or injection; (d) staff member or visitor spilled significant quantities of ethanol or formalin on him-/herself or clothing; (e) other (specify).
17. Does your collection of spirit specimens meet local fire and safety codes? (a) yes, completely; (b) yes, with following exception(s); (c) no; (d) do not know; (e) there are no applicable codes.
18. Please rank the criteria considered by you in granting use of spirit specimens by visitors (1 = most important, ..., 6 = least important): (a) taxa involved; (b) nature of dissection intended; (c) outcome of prior study by visitor in question; (d) publication record of visitor; (e) reputation/experience of visitor with techniques intended; (f) personal familiarity with visitor.
19. Please provide the total number of **skin** specimens in your collection (if not sure, please give your best estimate and enclose the figure in parentheses).
20. Please provide the total number of **skeletal** specimens in your collection (if not sure, please give your best estimate and enclose the figure in parentheses).
21. Please provide the total number of **spirit** specimens in your collection (if not sure, please give your best estimate and enclose the figure in parentheses).
22. Do you or your staff prepare **skin/partial-skeletons**? Please check [tick] the most appropriate response: (a) no; (b) yes, but rarely; (c) yes, routinely.
23. Do you or your staff prepare **skin/partial-spirits**? Please check [tick] the most appropriate response: (a) no; (b) yes, but rarely; (c) yes, routinely.
24. Please indicate the number of staff members who work in the ornithological collection in your institution at present (tally in full-time equivalents).
25. Please indicate the number of years that you have been a professional, museum-based ornithologist.
26. Please indicate the number of graduate students using museum specimens in their research with whom you have been involved professionally during your career.
27. Please list the top five areas of personal research that involve to a significant extent specimens of birds (e.g., geographic variation, functional anatomy, paleontology, illustration).