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Community perception of natural history collections – an online survey

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Abstract. Cultural, today mostly scientific, reflection on nature finds its physical manifestation in natural history collections (NHCs), which date back to the third century BCE at least. NHCs owe their existence to the formidable variation of life and other natural (e.g., geological) phenomena. Documenting, ordering, understanding this variation, communicating and showing it: these have been the classical functions of NHCs. What are the expectations for NHCs today, and how is their performance judged? The present survey captured a snapshot of values and opinions regarding NHCs from 525 poll participants from predominantly North America and Europe, mostly based in academia (41%) and at NHCs (32%), or students (10%). It was found that natural history collections are fascinating or highly interesting places for almost all respondents (challenging the idea that the 'dusty NHC' is really such a wide-spread cliché). Basic research, collection care, and educating the public were the three most often selected NHC core roles. The general importance of vouchering is acknowledged by the poll participants, and treatment of type material is regarded as near-adequate. Molecular vouchers, on the other hand, are considered to deserve more attention, reaching only medium levels of satisfaction, same as NHC data accessibility, sample documentation, and taxonomic expertise at NHCs. Insufficient funding was the strongest concern of most survey participants.

Keywords. NHC; museums; herbaria; research collections; online poll; community opinion.

INTRODUCTION

Worldwide, an estimated 3,000,000,000 (3 billion) objects (Soberón 1999, Wheeler et al. 2012) reside in about 8,000 natural history collections (NHCs): museums, herbaria, botanical gardens, etc. (Kemp 2015). They form the basis of an object-oriented approach to the natural world (Winker 2004) and offer the necessary baseline context for obtaining new biodiversity knowledge (Cotterill 1995, Lane 1996).

Together with their associated metadata, these unique preserved objects, the "physical archive of our world" (Pekarik 2003), inform taxonomy, systematics, evolution, ecology, conservation, public and environmental health, forestry, agriculture, and many other disciplines.

Classification of nature is a quintessentially human activity (Foucault 1966, in Ellis 2008), and over the last centuries, i.e., since the introduction of Linnaean classification (Linné 1758), a particularly strong focus of NHCs has rested with creating stability in naming and with the systematization of life, producing a reliable and steadily updated taxonomy (Tautz et al. 2003) within a pragmatic and more or less harmonized system. This is an ongoing process, and increasingly, molecular information is added to morphological evidence, be it derived from 'classical' collections (Bi et al. 2013, Buerki & Baker 2016 and references therein) or in the form of dedicated biobanks within NHCs (Corthals & DeSalle 2005, Astrin et al. 2013).

But apart from a traditional focus on taxonomy (Wheeler 2009), systematics (Wen et al. 2015) and phylogeography, over the last three decades, NHCs have consolidated and are still expanding their role as a fundamental infrastructural resource for ecological and environmental questions (Pyke & Ehrlich 2010) or conservation (Ponder et al. 2001, Lyman 2011), including topics like climate change, habitat conversion, pollutants and toxicants, biodiversity and ecosystem function loss, or introduction of exotics (Dunnum & Cook 2012).

Analogously, public and environmental health benefit are generated by NHCs, for example, by offering ways of characterizing, mitigating, and predicting emerging infectious diseases (DiEuliis et al. 2016), as exemplified, among others, by epidemiological investigations into Lyme disease (Persing et al. 1990), hantavirus (Sheldon & Dittmann 1997), or West Nile virus (Fonseca et al. 2001). Safety and food security issues (e.g., regarding agricultural bioterrorism, Suarez & Tsutsui 2004) equally depend on NHCs (SciColl International, in prep.).

The unifying feature in most of the manifold and increasingly interdisciplinary approaches relying on NHC specimens is their need for a retrospective view on nature. Each of the specimens in NHCs is unique spatiotemporally and opens a window on evolutionary processes (Holmes et al. 2016) and past environmental conditions, not uncommonly for species or populations already extinct at time of investigation (e.g., Albano et al. 2014). Ideal-

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ly, NHCs (individually or as a distributed network) offer time series of objects that allow seamlessly monitoring and investigating changing biodiversity and abiotic parameters at different spatial scales and over years, decades, or sometimes even centuries (Shaffer et al. 1998). Specimens in NHCs objectively document diversity and voucher our planet's historic conditions (Dunnum & Cook 2012).

A wealth of information results from these investigations and resides in the specimens themselves, and the transfer of such information is seen as one of the major responsibilities of NHCs (O'Connell et al. 2004), relevant both in the training of life and environmental science professionals (Cook et al. 2014, Wen et al. 2015) and in engaging the public to become society's biodiversity conscience (Krishtalka & Humphrey 2000).

To which extent are these published perceptions of NHCs reflected in the community? The survey presented here captured a snapshot of values and opinions regarding natural history collections, both from NHC users and NHC personnel. With its help we tried to roughly evaluate the current view on roles, functions, performance and appeal of NHCs.

MATERIALS & METHODS

The online poll was carried out over a period of two weeks in November (2nd to 17th) 2015 using SurveyMonkey (www.surveymonkey.com), a widely known platform for online polling. The survey was conducted anonymously, i.e., institutes' and respondents' names were not queried, and IP data not logged. However participants were given the opportunity to indicate their email address to receive feedback on survey results.

The poll took about ten minutes to complete and encompassed 28 questions, most of which expected answers in form of grades (1 to 5) or offered multiple-choice options (usually with comment function). Only one question, Q 28, was purely open-ended (free text). No question was defined as mandatory in order to complete the poll. Questions were grouped into two thematic blocks, the first one containing seven inquiries on respondent background: country, discipline, type of work place, frequency of contact with NHCs, own experience with sample depositions, type of samples, and type of characters / materials. The remaining 21 questions focused on NHC roles and functions (8 questions general in nature or weighing relevance of specific NHC functions, 13 questions evaluating current NHC performance, condition, or appeal): most important roles of NHCs, importance of voucher deposition, need for NHC growth, international legislation, current accessibility, importance of offering NHC data digitally, quality of maintenance, suitability for present-day science, attention given to molecular samples, relevance of molecular samples, attention given to type material, quality of sample documentation, need for libraries at NHCs, scientific relevance of NHC journals, importance of engaging the general public, adequacy of taxonomic expertise, overall satisfaction, appropriateness of funding, performance of NHCs in one's country, general appeal of NHCs, perceived deficits. The full questions alongside answer options are listed in Appendix I.

Requests to participate in the online poll were distributed via email lists, fora and social media, asking for opinions on natural history collections, their roles and services. We addressed the following mailing lists or fora: EvolDir, Taxacom, NHCOLL-L, ISBER, GfBS, CETAF, Bonn biology student listserv, and the following groups within social networks: LinkedIn: Biodiversity Professionals, Ecology & Evolutionary Biology, ESBB, GGBN, EDIT groups and Facebook: Natural History Collection group. We estimate that our announcement to participate in the survey may have reached 60,000 recipients altogether.

Survey results were exported from SurveyMonkey and processed with Microsoft Excel. We counted responses within categories and calculated arithmetic means (in the grading-mode questions, Q 9–Q 27) as well as proportions (other questions). A contingency table was generated to show average answer values dependent on respondent background.

RESULTS & DISCUSSION

We received 525 responses altogether (see Appendix III), more than 90% of these submitted within the first week of the poll. The calculated response rate lay at 0.9%, but can be assumed to be higher, as recipients are often subscribed to two or more of the lists/groups. Of all 525 participants, more than 90% gave an answer to all questions (without counting the purely free-text based question, Q 28).

Respondents' backgrounds (Q 1–7):

Respondents are scattered over 39 countries. 44% of them are based in North America, 43% in Europe, 7% in Oceania, 3% in South America, 1% in Africa and 1% in Asia. The individual country contributing by far most responses is the US (39% of all responses). Preponderance of responses from the United States is partly a consequence of distribution channels used in announcing the poll, but partly also reflects the dominance in the NHC scene, as ca. 1/4 of the registered collections and 1/3 of all NHC samples worldwide are located in the US (Ellwood et al. 2015, Kemp 2015).

All queried disciplines are well represented, with evolution, taxonomy, phylogeny and ecology most prominent, population biology least prominent. From those respon-

dents indicating their professional environment, 215 are based in academia, while 166 work at a NHC and 55 are university students. 328 participants indicated daily or ca. monthly contact with natural history collections, 160 a few times a year or more infrequently. Only 21 participants have never had contact with NHCs. 87% of interviewed taxonomists have frequent (daily or monthly) contact with NHCs, as have conservation professionals and phylogeneticists in almost 70% of the cases. Representatives of the other explicitly queried disciplines (ecology, evolution, population biology, molecular biology) had frequent NHC contact in 50–57% of the cases. 74% of the respondents have at least once deposited samples at a NHC (as have more than a third of the participating students). More than 2/3 of the interviewees (368) work with animal samples, followed by plants (128), then fossils (78). Respondents also marked geological (42), fungal (37), micro-organismal (35), and human (22) samples. 75% of the participants (answering this question) indicated that they work with morphology, 60% work with molecular samples (e.g., with DNA), 44% with images, 38% only with metadata, 8% with acoustic data. The contingency table in Appendix IV shows average answer values for questions 8–27 dependent on respondent background.

Ranking of NHC roles (Q 8):

Asked to identify the one to three most important role/s of natural history collections within society and science, 75% of the respondents (counting also abstentions) highlighted basic research, 61% collection care and loans, 58% educating the public, 30% collecting new samples, 27% training students, 22% performing applied research, 5% coordinating citizen science, and 5% shaping science policy (see Appendix IV). Most of the 5% free-text answers focused on the NHC role to safeguard collections and to document biodiversity, a function we missed to add more explicitly to the simple label ‘collection care’.

The most prominent role survey participants saw in NHCs was that of the active research institute, with a focus on mostly basic, but also on applied research. Although the poll does not offer a direct means to infer this, we hypothesize that a strong focus of this perceived necessity for research lies with the collections themselves (cf. Dosmann 2006). We base this assumption on the fact that almost 2/3 of the participants selecting basic research checked also the second most frequent answer, curation of collections. Furthermore, there exists a natural connection: with the physical collections, i.e., the “museum’s ‘soul’ and *raison d’être*” (Alberch 1993), NHC research has a unique resource directly at hand.

A look into respondent backgrounds revealed that opinion on most relevant NHC roles does not seem to differ strongly between North America and Europe, although some differences exist (e.g., participants from North America put somewhat more emphasis on applied research and training students, participants from Europe on educating the public and on citizen science). As other continents were less well represented, results for these must be taken with a (sometimes rather big) grain of salt, but average ranking hinted at higher valuation of science policy by respondents based in Oceania (37 participants), of academic training in South America (17 participants), or of educating the public in Africa and Asia (6 participants each). Other background traits had influence on responses as well, to eclectically name some examples (see Appendix IV for full data): on average, sample depositors and NHC staff give more importance to collection care, but less to educating the public. Students, ecologists and microbiologists see above-average relevance in teaching at NHCs (an activity that overall only about 1/4 of participants ranked among the 3 most relevant). Of all sample types, participants working with molecular samples see the highest necessity for gathering more samples, as do, in terms of discipline, phylogeneticists and taxonomists.

Perceived relevance of selected NHC activities and performance (Q 9–28):

Questions 9–27 were answered by using a grading scheme from 1 to 5, where consequently 3 would count as a neutral answer. A “5” denotes “high relevance”, “good”, or “much”. Table 1 lists the mean values for all responses. These are also presented in the text below, highlighting, as before, conspicuous correlations with respondents’ backgrounds. Not all correlations can be discussed here, and the selection is necessarily biased by our own (author) background. We therefore encourage readers to access the primary data in Appendix III, or for easier reference the contingency table in Appendix IV.

Q 9: Asked about the *scientific relevance of depositing vouchers*, the mean of all answers lay at 4.6. Of the interviewed persons, 77% graded with 5, and 1% with 1. There existed an obvious correlation between perceived relevance and frequency of contact with NHCs. The high importance assigned to the vouchering concept and also, as shown below, the overall positive evaluation of type deposition practice at NHCs can be seen as evidence for the long-established role of vouchers at NHCs as the material guarantors against which research is calibrated (Ellis 2008). Vouchers and associated databases form the nexus that links individual studies with past or future inferences (Astrin et al. 2013), and the costs for non-reproducibility in life science have been estimated to be very high (Freedman et al. 2015).

How much growth is still necessary for NHCs to comprehensively answer most biological / environmental questions? This question, *Q 10*, was answered with 4.2 on average. While NHCs are confronted with often serious budgetary bottlenecks (see below), the necessity for col-

Table 1. Mean responses on NHC functions and performance (Q 9–27), sorted by response value. There existed 5 answer options: 1, 2, 3, 4, and 5. A 5 usually denotes high relevance, good, much, etc. In Q 11 on current legislation, 1 indicates a major perceived problem, 5 none.

survey question	mean response
Q 27: Do you perceive NHCs as interesting places?	4.8
Q 9: Depositing vouchers – how relevant is this for science?	4.6
Q 17: How relevant are molecular samples in life sciences?	4.6
Q 13: How important is it for NHCs to offer their collection data digitally?	4.6
Q 22: How important is it for NHCs to engage the general public through, e.g., exhibitions, events, or social media?	4.5
Q 10: How much growth is still necessary for NHCs to comprehensively answer most biological/environmental questions?	4.2
Q 20: Are libraries necessary at NHCs?	4.1
Q 18: Is type material given the necessary importance at NHCs?	4.0
Q 24: Overall, how happy are you with the services offered by the community of NHCs?	3.7
Q 21: How relevant (scientifically) are journals edited at / issued by NHCs?	3.7
Q 14: Are the collections you know maintained properly?	3.7
Q 26: Overall, do your country's collections offer better or worse services than those in most other countries?	3.6
Q 15: Do you feel NHCs are up to present-day science?	3.5
Q 12: Are collections sufficiently accessible for science?	3.4
Q 19: On average, is sample documentation (sample metadata) in NHCs sufficient?	3.2
Q 16: Are NHCs paying enough attention to molecular samples (e.g., DNA used in publications)?	3.1
Q 23: Is there sufficient taxonomic expertise at NHCs?	3.0
Q 11: Is the current international legislation (esp. Nagoya Protocol) an obstacle for collection-based work?	2.7
Q 25: Are NHCs funded appropriately?	1.7

lections to continuously keep growing is recognized by the largest part of the community (as captured by this survey). It is obvious that NHCs cannot stop collecting activities if they are to inform seamlessly on changes in biodiversity and in environmental conditions (e.g., Brooke 2000, Winker et al. 2010, Habel et al. 2013, Rocha et al. 2014). However, it has been critically pointed out that haphazard growth often prevails (Alberch 1993, Ponder et al. 2001, Pyke & Ehrlich 2010). Targeted collecting strategies should consider, as Pyke & Ehrlich (2010) note, the increasing relevance of ecological and environmental issues in addition to taxonomic and geographic considerations. For instance, continuous time series for common species hold considerable long-term value (Winker 2004, Küster et al. 2015), as do bulk samples from ecological studies (Schilthuizen et al. 2015) and monitoring projects.

Q 11: Only 15 of all respondents have the opinion that *current international agreements (esp. Nagoya Protocol)* is no obstacle (= answer "5") for collection-based work. With 2.7 as the arithmetic mean (2.5 by NHC-based respondents), most answers revealed that current legislation was seen as a rather strong obstacle. Although obviously not the only regulatory framework governing NHC sample acquisition and/or transfer (e.g., Fowler et al. 2007, Vernooy et al. 2010), the Nagoya Protocol of the Convention on Biological Diversity (UNEP 2011) that came into effect in 2014 to cut back on biopiracy is placing a heavy bureaucratic burden (Comizzoli & Holt 2016) also on non-commercial research (Schindel et al. 2015) and necessitates major revision of workflows and capacity-building at NHCs (Davis et al. 2015).

Q 12: Current *access to collections* was evaluated with an average of 3.4, i.e., only somewhat better than neutral. Participants from South America (2.9) and especially Africa (2.3) chose lower values on average (but note the limited number of responses from these continents). However, when asked about the general *importance of digital access* to collections (*Q 13*), more than 90% responded with a 4 or 5 (mean: 4.6). Participants working with geological (4.2) or human (4.3) samples rated somewhat lower, whereas a raised answer value was apparent in responses from Africa (5.0), Asia (4.8) and South America (4.7) as well as from students (4.8). It seems obvious that those parts of the world farthest away from the bulk of NHC

specimens (in North America and Europe) and with often weaker economies are in especially acute need for digital access to collections.

Since earlier calls to better integrate biodiversity information sources (Soberón 1999, Krishtalka & Humphrey 2000), the situation has changed thanks to new biodiversity data architecture (e.g., Edwards 2004, Graham et al. 2004, Ratnasingham & Hebert 2007, Constable et al. 2010, Wheeler et al. 2012, Droege et al. 2014, Kelbert et al. 2015, Belbin & Williams 2016, Schindel et al. 2016). Also, efforts are under way to systematically digitize collections (e.g., Baird 2010, Nelson et al. 2012, Heerlien et al. 2015), some taking advantage of public participation (Ellwood et al. 2105), automation (Blagoderov et al. 2012, Hudson et al. 2015), or DNA barcoding campaigns (Hebert et al. 2003a,b). However, the poll mirrors the still considerable need for digitizing and linking NHC data. This becomes also apparent from answers to Q 28, where almost a third of respondents submitting free-text comments had explicit issues with current amount of data digitization or access to collections, and where some concern (5% of free-text answers) was expressed that NHCs were not networking sufficiently.

Adequacy of collection maintenance was the focus of *Q 14*. The overall average answer lay at 3.7. Respondents with zoological (3.7) and botanical or paleontological (3.6) background mostly defined this value. Micro-organismal or human background correlated with lower answer values (3.4). In terms of data type / material, responses from participants involved with acoustics were higher than others (4.0). Many free-text comments in Q 28 indicated that additional funds would be necessary to appropriately curate collections.

Do you feel NHCs are up to present-day science? The average opinion on *Q 15* condensed into a value of 3.5. Frequent NHC contact on average resulted in a slightly higher value (3.7). This difference may be explained with the notion that museums are sometimes perceived as dusty places stifling intellectual excitement (Brooke 2000). However, the feedback received in this survey on appeal of NHCs indicated that natural history collections are commonly seen as "fascinating" places (Q 27, see below). This finding challenges the idea that the 'dusty NHC' is really such a wide-spread cliché. Accordingly, NHC image cannot be used in explaining why collections are perceived to only moderately well meet the requirements of present-day science. The scope and focus of research carried out at NHCs is likely not the reason either, as no indication could be found among free-text answers (Q 28). On the other hand, insufficient funding is seen as a considerable obstacle (Q 25, 28), which supports the idea that missing or out-dated infrastructure as well as scarce or poorly trained staff pose problems for cutting-edge research at NHCs.

In answering this question, Q 15, molecular biology backgrounds were associated with somewhat lower values. This connects to the following question. The *importance that is currently being paid to molecular samples* (e.g., DNA used in publications) at NHCs (*Q 16*) was ranked with an average 3.1, one of the lowest marks in this survey. In contrast to this result stands the fact that 90% of the respondents consider the general *relevance of molecular samples* in life sciences (*Q 17*) to be high or very high. This is mirrored in the overall mean value for the answer: 4.6. Where explicitly expressed as free-text (Q 28), issues were usually that more (sub)samples should be preserved specifically for molecular analysis, and/or that a more liberal regime to sample also 'morphological' specimens should be applied. The high expectations towards molecular samples, taken together with the mediocre NHC performance perceived by the community in this context, suggest that NHCs are lagging behind and partially missing out on an important chance. As NHCs can curate specimen vouchers cross-referenced with molecular vouchers (DNA, tissue, etc.), they are an ideal place for establishing molecular collections or biobanks (Astrin et al. 2013) and can play a central role in the integrative study of biodiversity (Whitfield & Cameron 1994, Cristescu 2014). Efforts are under way to virtually unite as many molecular collections as possible under the single access point offered by the Global Genome Biodiversity Network, GGBN (Droege et al. 2014), and an increasing number of NHCs are joining this endeavor. However, the fact that NHC staff responded with a slightly lower value to this question (Q 17) indicates that NHCs have not yet fully understood the potential of molecular samples. Biodiversity biobanking is still in its infancy and needs to be ramped up, which becomes obvious when compared to human biobanking (Astrin & Betsou 2016).

The question (*Q 18*) whether *type material* was given the necessary importance at NHCs scored a mean answer of 4.0, the highest value among all those answers that evaluated NHC performance (see above), although considerable variation existed among countries.

For instance, the overall result was worse for *Q 19*, which found *satisfaction with sample documentation* (sample metadata) at NHCs to be rather low: 3.2. Participants based in Australia checked considerably higher values on average (3.8; possibly influenced by data presentation and accessibility in the *Atlas of Living Australia*, see Belbin & Williams 2016). 15 respondents explicitly wished to see more updates on specimen records (e.g., re-/identification of specimens) or added metadata in free-text question Q 28. As NHC samples are put to an ever-growing range of uses, one should keep in mind the high demand for detailed metadata, also by "new clients" in environmental, ecological, societal, and management-related areas (Winker 2004). Although sometimes an arduous task for both sides involved, it is an inevitable necessity

that collection managers and curators try to obtain from the depositors as much information on samples as anyhow possible. Data from subsequent analysis, like bibliographic information on resulting publications, database accession numbers, etc., should equally be fed back to the collection – a widespread but not always implemented prerequisite for loans. Adding high-resolution specimen images greatly enriches NHC datasets and can be performed semi-automatically (e.g., Balke et al. 2013). Metadata can be detected, mined, and semantically enhanced in automated fashion from already existing datasets (e.g., van den Bosch et al. 2009, Guralnick et al. 2016).

Q 20: The general *necessity for maintaining libraries* at NHCs was perceived as rather high with a mean answer of 4.1. Taxonomists (4.4) and conservation professionals (4.3) on average saw a higher need for these, as did NHC staff (4.4). Libraries are a fundamental research infrastructure, and represent yet another collection type at NHCs in addition to those focusing on natural history samples and metadata on these. Facilities are steadily evolving into hybrid libraries (Rusbridge 1998) that offer digital information alongside printed documents. The quasi-legal status of taxonomic literature (Minelli 2003) demands the archival of publications associated with nomenclatural acts, irrespective of age – an atypical situation in common libraries. Taxonomic literature and many other biodiversity documents are being digitized at NHCs libraries and other institutions (e.g., Pilsk et al. 2016), often in targeted projects and employing high throughput workflows (BHL 2017). The role of NHC libraries as information brokers will become even more relevant once library discovery systems and catalogs are deeply integrated with collection databases and with aggregator portals on sample data. There remains little doubt that such a fusion of physical evidence plus metadata (on particular instances of natural history) with the accumulated knowledge on various 'units' of nature (e.g., taxa, as in EOL: Wilson et al. 2003) will be the future of biodiversity informatics and NHC-based LIS (library and information science) approaches. Uniting and unifying these 'universes' allows powerful data mining if the necessary ontologies are in place (e.g., Tochtermann et al. 1997, Vogt 2009, Seltman et al. 2012, Walls et al. 2014, Thessen et al. 2015).

Q 21: The poll participants evaluate scientific *relevance of NHC-edited or NHC-issued journals* with 3.7. Elevated relevance was tied to background traits paleontology (4.0), taxonomy (3.9), NHC staff (3.9), decreased mean levels to bioacoustics (3.4), micro-organisms (3.4) or molecular and population biology (3.5).

Q 22: The *importance to engage the general public* through, e.g., exhibitions, events, or social media was regarded as very high (4.5), with little variation depending on background (but mark the average 4.8 in participants from UK or Africa). Exhibiting objects to the general public has a long-standing tradition at NHCs (Maerker 2005). Apart from exhibitions that illustrate life science or environmental topics, the research performed at NHCs is often put into focus. At some museums, the actual workflows of collection staff or researchers can be observed (like digitization, Heerlien et al. 2015). Based on the many free-text comments (in Q 28) on profile and education, NHCs should use all outreach means available to more convincingly explain and justify to general public and policy makers the outstanding importance of active and growing research collections for life and environmental sciences (e.g., Krishtalka & Humphrey 2000). Raising public awareness for the relevance of collections and collection-based research can foster participation in citizen science projects (e.g., Hill et al. 2012, Geiger et al. 2016) and vice versa.

Regarding *adequacy of taxonomic expertise* (*Q 23*) at NHCs, the survey revealed a heterogeneous notion within the community. The overall answer was neutral (3.0), and no individual answer reached more than 28% of the votes. Respondents from the Southern hemisphere responded with lower values than colleagues from Northern countries. Students (3.4) and respondents who had never deposited material (3.6) saw less of a taxonomic deficit at NHCs then NHC staff (2.8) or taxonomists (2.8). In this question on adequacy of taxonomic expertise as well as in the following one (Q 24), we see a logical correlation with funding issues (see Q 25).

Q 24: The *overall satisfaction with NHC services* reached 3.7, was elevated with conservation professionals and with students (both 3.9), and reduced in respondents working with human (3.3), fungal (3.4), or micro-organismal (3.4) samples.

Prompted on *funding* (*Q 25*), 54% of the interviewed persons indicated they considered funding of natural history collects as "insufficient" (lowest answer value "1"). Only 0.6% considered it "appropriate" and 3% near-appropriate. Overall, the arithmetic mean of all answers lay at 1.7, marking the lowest of all answer values in the survey. This finding coincides with the often raised argument that investments in NHCs are insufficient (e.g., Cotterill 1995, Lane 1996, Dalton 2003, Suarez & Tsutsui 2004, Dosmann 2006, Andreone et al. 2014, Kemp 2015, Stokstad 2015), endangering specimens and positions, and compromising research, infrastructure, outreach and NHC services (including loans, sample digitization, visitor programs, etc.). More than 130 free-text answers in Q 28 elucidate this problem (see Appendix V). Notwithstanding, the cost-efficiency and the economic benefit offered by NHCs are evident (Suarez & Tsutsui 2004, Overmann 2015) and will become even more pronounced thanks to the constantly growing number of disciplines and approaches using NHCs (Winker 2004, Pyke & Ehrlich 2010, Kemp 2015, McLean et al. 2016).

As *Q 26* sets *NHC performance in the participants' country* into relation with NHCs abroad, the overall mean (3.6) holds limited information value. We therefore extract-

Table 2. Mean values for Q 26 ("Overall, do your country's collections offer better or worse services than those in most other countries?"), grouped geographically. Left side of table: list of all countries represented with 10 or more answers. Right side: grouped by continent (Asia and Africa represented by only 6 answers each).

country	mean answer	number of answers	continent	mean answer	number of answers
USA	4.0	204	North America	4.0	224
UK	3.9	35	Oceania	3.7	36
Germany	3.9	47	Europe	3.3	216
Australia	3.7	26	Africa	2.5	6
New Zealand	3.7	10	South America	2.4	17
Austria	3.4	17	Asia	2.0	6
Canada	3.1	16			
Belgium	3.1	13			
France	3.0	27			
Brazil	2.5	12			
Portugal	1.8	13			

ed all countries with 10 or more responses and list the data for these along with information on continents in Table 2. Respondent happiness with NHC services varied greatly depending on geography, from an average "4" in North America to "2" in Asia. Although countries from especially Africa, Asia and South America are only marginally represented in this survey, geographical bias seems to be a fact: respondents from the mentioned continents have more issues on average with overall NHC services in their country. In the light of the current biodiversity crisis (Wilson 1985), one should keep in mind that it is on these continents where most of our planet's biological diversity is localized and where NHCs are especially challenged (e.g., Arbeláez-Cortés et al. 2015).

Q 27: Asked whether they *see NHCs as interesting places* (see also above), 82% of the survey participants indicated they found them "fascinating" by assigning a "5" (as opposed to "boring", answer "1", which did not receive any hits at all). The arithmetic mean for all answers is 4.8, the highest value reached in this survey.

The last question, *Q 28*, collected free-text opinions on the most fundamental critique points: "If anything, *what should improve most* at NHCs?" We received 240 responses, which we cannot discuss individually (although many provide food for thought, and we recommend browsing). Therefore we tagged responses according to categories. Appendix V shows our – often multiple – tag assignments and explains details on category tags. More than half of the answers (134) target the general lack of appropriate funding, apparent in staffing (and staff education), curation / collection care, infrastructure, etc. 72 respondents had explicit issues with current amount of databasing, data digitization, or digital/physical access to collections. 42 answers suggested sharpening or modifying NHC profiles, or commented on NHC strategies and on reception by policy-makers, while measures towards engaging the general public or training students and professionals were targeted in 34 comments. 22 respondents stressed the necessity to collect molecular samples more rigorously, or expressed their unhappiness about limited options to subsample morphological specimens for molecular studies. 16 answers pointed out the general need to add new samples to the collections. 15 participants explicitly wished to see more updates on specimen records (e.g., re-/identification of specimens) or added metadata. 12 comments suggested NHC need a stronger focus on networking efforts, either among themselves or with other institutions. Issues with either the way research is carried out at NHCs, with ABS and legal regulations, or with loans were represented in less than 10 responses each.

CONCLUSION

The survey results show a very positive connotation associated with natural history collections. 'Traditional' NHC roles and values are not questioned (emphasis on collections, research, engaging the public, etc.), and at the same time the importance of comparatively 'new' concepts in the NHC task spectrum becomes apparent (data digitization, molecular samples). Nevertheless, current performance of NHCs in various areas (Q 12,14–16,18,19,21,23,24) was graded with an average 3.5 points (out of 5), i.e., only somewhat better than neutral

(3.0). We interpret this mostly as a consequence of the relative scarcity in NHC funding, for which both this survey and the literature give evidence. Notwithstanding, independently from funding, there seem to be topics on which NHC staff need to pick up (see Appendix III). There are two sides to this coin, and the user community seems insufficiently informed on some efforts already undertaken at NHCs. Transferring this information is the task of NHCs, and we wonder if self-critical voices within the museum community have been sufficiently heard (Alberch 1993, Krishtalka & Humphrey 2000).

Our hope, bolstered by the survey results, is to see an unabated – or better even – a strengthened focus on *collections*, by performing and facilitating state-of-the-art biodiversity and environmental research on them, by actively and confidently advocating and communicating their immense and growing value, by using them for public and academic education, by safeguarding the legacy of existing collections and coordinating a targeted collection growth that meets the demands of the various traditional, emergent, and prospective NHC user communities – for the benefit of society and biodiversity. We further hope for this process to take place across the whole globe, with no geographic areas left behind.

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REFERENCES

Albano P, Bongiovanni B, D'Occhio P, Sabelli B (2014) Natural history museums as repositories of endangered diversity: the case of the United States Unionida in the Museo di Zoologia dell'Università di Bologna. Zoosystematics and Evolution 90: 105–111

Alberch P (1993) Museums, collections and biodiversity inventories. Trends in Ecology & Evolution 8: 372–375

Andreone F, Bartolozzi L, Boano G, Boero F, Bologna MA, Bon M, Bressi N, Capula M, Casale A, Casiraghi M, Chiozzi G, Delfino M, Doria G, Durante A, Ferrari M, Gippoliti S, Lanzinger M, Latella L, Maio N, Marangoni C, Mazzotti S, Minelli A, Muscio G, Nicolosi P, Pievani T, Razzetti E, Sabella G, Valle M, Vomero V, Zilli A (2014) Italian natural history museums on the verge of collapse? Zookeys 456: 139–146

Arbeláez-Cortés E, Torres MF, López-Alvarez D, Palacio-Mejía JD, Mendoza ÁM, Medina CA (2015) Colombian frozen biodiversity: 16 years of the tissue collection of the Humboldt Institute. Acta Biologica Colombiana 20: 163–173

Astrin JJ, Zhou X, Misof B (2013) The importance of biobanking in molecular taxonomy, with proposed definitions for vouchers in a molecular context. ZooKeys 365: 67–70

Astrin JJ, Betsou F (2016) Trends in Biobanking: A Bibliometric Overview. Biopreservation and Biobanking 14: 65–74

Baird RC (2010) Leveraging the fullest potential of scientific collections through digitisation. Biodiversity Informatics 7: 130–136

Balke M, Schmidt S, Hausmann A, Toussaint EFA, Bergsten J, Buffington M, Hauser CL, Kroupa A, Hagedorn G, Riedel A, Polaszek A, Ubaidillah R, Krogmann L, Zwick A, Fikacek M, Hajek J, Michat MC, Dietrich C, La Salle J, Mantle B, Ng PKL, Hobern D (2013) Biodiversity into your hands - A call for a virtual global natural history 'metacollection'. Frontiers in Zoology 10: 55

Belbin L, Williams KJ (2016) Towards a national bio-environmental data facility: experiences from the Atlas of Living Australia. International Journal of Geographical Information Science 30: 108–125

BHL (2017) The Biodiversity Heritage Library. Online at www.biodiversitylibrary.org last accessed on January 4, 2017

Bi K, Linderoth T, Vanderpool D, Good JM, Nielsen R, Moritz C (2013) Unlocking the vault: next-generation museum population genomics. Molecular Ecology 22: 6018–6032

Blagoderov V, Kitching IJ, Livermore L, Simonsen TJ, Smith VS (2012) No specimen left behind: industrial scale digitization of natural history collections. Zookeys 209: 133–146

Brooke MD (2000) Why museums matter. Trends in Ecology & Evolution 15: 136–137

Buerki S, Baker WJ (2016) Collections-based research in the genomic era. Biological Journal of the Linnean Society 117: 5–10

Comizzoli P, Holt WV (2016) Implications of the Nagoya Protocol for genome resource banks composed of biomaterials from rare and endangered species. Reproduction Fertility and Development 28: 1145–1151

Constable H, Guralnick R, Wieczorek J, Spencer C, Peterson AT, The VertNet Steering Committee (2010) VertNet: A New Model for Biodiversity Data Sharing. PLOS Biology 8: e1000309

Cook JA, Edwards SV, Lacey EA, Guralnick RP, Soltis PS, Soltis DE, Welch CK, Bell KC, Galbreath KE, Himes C, Allen JM, Heath TA, Carnaval AC, Cooper KL, Liu M, Hanken J, Ickert-Bond S (2014) Natural History Collections as Emerging Resources for Innovative Education. Bioscience 64: 725–734

Corthals A, DeSalle R (2005) An Application of Tissue and DNA Banking for Genomics and Conservation: The Ambrose Monell Cryo-Collection (AMCC). Systematic Biology 54: 819–823

Cotterill FPD (1995) Systematics, biological knowledge and environmental conservation. Biodiversity and Conservation 4: 183–205

Cristescu ME (2014) From barcoding single individuals to metabarcoding biological communities: towards an integrative approach to the study of global biodiversity. Trends in Ecology & Evolution 29: 566–571

Dalton R (2003) Natural history collections in crisis as funding is slashed. Nature 423: 575

Davis K, Smit MF, Kidd M, Sharrock S, Allenstein P (2015) An access and benefit-sharing awareness survey for botanic gardens: Are they prepared for the Nagoya Protocol? South African Journal of Botany 98: 148–156

DiEuliis D, Johnson KR, Morse SS, Schindel DE (2016) Opinion: Specimen collections should have a much bigger role in

infectious disease research and response. Proceedings of the National Academy of Sciences 113: 4–7
Dosmann MS (2006) Research in the garden: Averting the collections crisis. Botanical Review 72: 207–234
Droege G, Barker K, Astrin JJ, Bartels P, Butler C, Cantrill D, Coddington J, Forest F, Gemeinholzer B, Hobern D, Mackenzie-Dodds J, O Tuama E, Petersen G, Sanjur O, Schindel D, Seberg O (2014) The Global Genome Biodiversity Network (GGBN) Data Portal. Nucleic Acids Research 42: D607–D612
Dunnum JL, Cook JA (2012) Gerrit Smith Miller: his influence on the enduring legacy of natural history collections. Mammalia 76: 365–373
Edwards JL (2004) Research and Societal Benefits of the Global Biodiversity Information Facility. BioScience 54: 485–486
Ellis R (2008) Rethinking the value of biological specimens: laboratories, museums and the Barcoding of Life Initiative. Museum and Society 6: 172–191
Ellwood ER, Dunckel BA, Flemons P, Guralnick R, Nelson G, Newman G, Newman S, Paul D, Riccardi G, Rios N, Seltmann KC, Mast AR (2015) Accelerating the Digitization of Biodiversity Research Specimens through Online Public Participation. BioScience 65: 383–396
Fonseca DM, Campbell S, Crans WJ, Mogi M, Miyagi I, Toma T, Bullians M, Andreadis TG, Berry RL, Pagac B, Sardelis MR, Wilkerson RC (2001) Aedes (Finlaya) japonicus (Diptera: Culicidae), a Newly Recognized Mosquito in the United States: Analyses of Genetic Variation in the United States and Putative Source Populations. Journal of Medical Entomology 38: 135–146
Fowler AJ, Lodge DM, Hsia JF (2007) Failure of the Lacey Act to protect US ecosystems against animal invasions. Frontiers in Ecology and the Environment 5: 353–359
Freedman LP, Cockburn IM, Simcoe TS (2015) The Economics of Reproducibility in Preclinical Research. PLoS Biol 13(6): e1002165
Geiger MF, Astrin JJ, Borsch T, Burkhardt U, Grobe P, Hand R, Hausmann A, Hohberg K, Krogmann L, Lutz M, Monje C, Misof B, Morinière J, Müller K, Pietsch S, Quandt D, Rulik B, Scholler M, Traunspurger W, Haszprunar G, Wägele W (2016) How to tackle the molecular species inventory for an industrialized nation – lessons from the first phase of the German Barcode of Life initiative GBOL (2012-2015). Genome 59: 661–670
Graham CH, Ferrier S, Huettman F, Moritz C, Peterson AT (2004) New developments in museum-based informatics and applications in biodiversity analysis. Trends in Ecology & Evolution 19: 497–503
Guralnick RP, Zermoglio PF, Wieczorek J, LaFrance R, Bloom D, Russell L (2016) The importance of digitized biocollections as a source of trait data and a new VertNet resource. Database 2016: 1–13
Habel JC, Husemann M, Finger A, Danley PD, Zachos FE (2013) The relevance of time series in molecular ecology and conservation biology. Biological Reviews 89: 484–492
Hebert PD, Cywinska A, Ball SL, deWaard JR (2003a) Biological identifications through DNA barcodes. Proceedings of the Royal Society of London, Series B: Biological Sciences 270: 313–321
Hebert PD, Ratnasingham S, deWaard JR (2003b) Barcoding animal life: cytochrome c oxidase subunit 1 divergences among closely related species. Proceedings of the Royal Society of London, Series B: Biological Sciences 270 Suppl 1: S96–99
Heerlien M, Van Leusen J, Schnörr S, De Jong-Kole S, Raes N, Van Hulsen K (2015) The Natural History Production Line: An Industrial Approach to the Digitization of Scientific Collections. J. Comput. Cult. Herit. 8: 1–11
Hill A, Guralnick R, Smith A, Sallans A, Gillespie R, Denslow M, Gross J, Murrell Z, Conyers T, Oboyski P, Ball J, Thomer A, Prys-Jones R, de la Torre J, Kociolek P, Fortson L (2012) The notes from nature tool for unlocking biodiversity records from museum records through citizen science. ZooKeys 209: 219–233
Holmes MW, Hammond TT, Wogan GOU, Walsh RE, LaBarbera K, Wommack EA, Martins FM, Crawford JC, Mack KL, Bloch LM, Nachman MW (2016) Natural history collections as windows on evolutionary processes. Molecular Ecology 25: 864–881
Hudson LN, Blagoderov V, Heaton A, Holtzhausen P, Livermore L, Price BW, van der Walt S, Smith VS (2015) Inselect: Automating the Digitization of Natural History Collections. PLOS ONE 10: e0143402
Kelbert P, Droege G, Barker K, Braak K, Cawsey EM, Coddington J, Robertson T, Whitacre J, Güntsch A (2015) B-HIT - A Tool for Harvesting and Indexing Biodiversity Data. PLOS ONE 10: e0142240
Kemp C (2015) The endangered dead. Nature 518: 292–294
Krishtalka L, Humphrey PS (2000) Can Natural History Museums Capture the Future? BioScience 50: 611–617
Küster A, Becker PR, Kucklick JR, Pugh RS. Koschorreck J (2015) The international environmental specimen banks-let's get visible. Environmental Science and Pollution Research 22: 1559–1561
Lane, M.A. (1996) Roles of natural history collections. Annals of the Missouri Botanical Garden, 83, 536–545.
Linné C (1758) Systema naturae per regna tria naturae, secundum classses, ordines, genera, species, cum characteribus, differentiis, synonymis, locis. Salvius, Stockholm.
Lyman RL (2011) A warrant for applied palaeozoology. Biological Reviews 87: 513–525
Maerker A (2005) Scenes from the museum: the hermaphrodite monkey and stage management at La Specola. Endeavour 29: 104–108
McLean BS, Bell KC, Dunnum JL, Abrahamson B, Colella JP, Deardorff ER, Weber JA, Jones AK, Salazar-Miralles F, Cook JA (2016) Natural history collections-based research: progress, promise, and best practices. Journal of Mammalogy 97: 287–297
Minelli A (2003) The status of taxonomic literature. Trends in Ecology & Evolution 18: 75–76
Nelson G, Paul D, Riccardi G, Mast A (2012) Five task clusters that enable efficient and effective digitization of biological collections. ZooKeys 209: 19–45
O'Connell AF, Gilbert AT, Hatfield JS (2004) Contribution of Natural History Collection Data to Biodiversity Assessment in National Parks. Conservation Biology 18: 1254–1261
Overmann J (2015) Significance and future role of microbial resource centers. Systematic and Applied Microbiology 38: 258–265
Pekarik A (2003) Long-term thinking: what about the stuff? Curator 46: 367–370
Persing DH, Telford SR, Rys PN, Dodge DE, White TJ, Malawista SE, Spielman A (1990) Detection of *Borrelia burgdorferi* DNA in Museum Specimens of *Ixodes dammini* Ticks. Science 249: 1420–1423
Pilsk SC, Kalfatovic MR, Richard JM (2016) Unlocking Index Animalium: From paper slips to bytes and bits. ZooKeys 550: 153–171

Ponder WF, Carter GA, Flemons P, Chapman RR (2001) Evaluation of Museum Collection Data for Use in Biodiversity Assessment. Conservation Biology 15: 648–657

Pyke GH, Ehrlich PR (2010) Biological collections and ecological/environmental research: a review, some observations and a look to the future. Biological Reviews 85: 247–266

Ratnasingham S, Hebert PDN. (2007) BOLD: The Barcode of Life Data System (http://www.barcodinglife.org). Molecular Ecology Notes 7: 355–364

Rocha LA, Aleixo A, Allen G, Almeda F, Baldwin CC, Barclay MVL, Bates JM, Bauer AM, Benzoni F, Berns CM, Berumen ML, Blackburn DC, Blum S, Bolanos F, Bowie RCK, Britz R, Brown RM, Cadena CD, Carpenter K, Ceriaco LM, Chakrabarty P, Chaves G, Choat JH, Clements KD, Collette BB, Collins A, Coyne J, Cracraft J, Daniel T, de Carvalho MR, de Queiroz K, Di Dario F, Drewes R, Dumbacher JP, Engilis A, Erdmann MV, Eschmeyer W, Feldman CR, Fisher BL, Fjeldsa J, Fritsch PW, Fuchs J, Getahun A, Gill A, Gomon M, Gosliner T, Graves GR, Griswold CE, Guralnick R, Hartel K, Helgen KM, Ho H, Iskandar DT, Iwamoto T, Jaafar Z, James HF, Johnson D, Kavanaugh D, Knowlton N, Lacey E, Larson HK, Last P, Leis JM, Lessios H, Liebherr J, Lowman M, Mahler DL, Mamonekene V, Matsuura K, Mayer GC, Mays H, McCosker J, McDiarmid RW, McGuire J, Miller MJ, Mooi R, Mooi RD, Moritz C, Myers P, Nachman MW, Nussbaum RA, Foighil D, Parenti LR, Parham JF, Paul E, Paulay G, Perez-Eman J, Perez-Matus A, Poe S, Pogonoski J, Rabosky DL, Randall JE, Reimer JD, Robertson DR, Roedel M-O, Rodrigues MT, Roopnarine P, Rueber L, Ryan MJ, Sheldon F, Shinohara G, Short A, Simison WB, Smith-Vaniz WF, Springer VG, Stiassny M, Tello JG, Thompson CW, Trnski T, Tucker P, Valqui T, Vecchione M, Verheyen E, Wainwright PC, Wheeler TA, White WT, Will K, Williams JT, Williams G, Wilson EO, Winker K, Winterbottom R, Witt CC (2014) Specimen collection: An essential tool. Science 344: 814–815

Rusbridge C (1998) Towards the Hybrid Library. D-Lib Magazine

Schilthuizen M, Vairappan CS, Slade EM, Mann DJ, Miller JA (2015) Specimens as primary data: museums and 'open science'. Trends in Ecology & Evolution 30: 237–238

Schindel D, Bubela T, Rosenthal J, Castle D, du Plessis P, Bye R, PMCW. (2015) The New Age of the Nagoya Protocol. Nature Conservation 12: 43–56

Schindel D, Miller S, Trizna M, Graham E, Crane, A. (2016) The Global Registry of Biodiversity Repositories: A Call for Community Curation. Biodiversity Data Journal 4: e10293

Seltmann KC, Pénzes Z, Yoder MJ, Bertone MA, Deans AR (2013) Utilizing Descriptive Statements from the Biodiversity Heritage Library to Expand the Hymenoptera Anatomy Ontology. PLOS ONE 8: e55674

Shaffer HB, Fisher RN, Davidson C. (1998) The role of natural history collections in documenting species declines. Trends in Ecology & Evolution 13: 27–30

Sheldon FH, Dittmann DL (1997) The value of vertebrate tissue collections in applied and basic science. Global Genetic Resources: Access, Ownership, and Intellectual Property Rights 151–162

Soberón J (1999) Linking biodiversity information sources. Trends in Ecology & Evolution 14: 291–291

Stokstad E (2015) Research at Kew overhauled for leaner times. Science 347: 936–936

Suarez AV, Tsutsui ND (2004) The value of museum collections for research and society. Bioscience 54: 66–74

Tautz D, Arctander P, Minelli A, Thomas RH, Vogler AP (2003) A plea for DNA taxonomy. Trends in Ecology & Evolution 18: 70–74

Thessen AE, Bunker DE, Buttigieg PL, Cooper LD, Dahdul WM, Domisch S, Franz NM, Jaiswal P, Lawrence-Dill CJ, Midford PE, Mungall CJ, Ramírez MJ, Specht CD, Vogt L, Vos RA, Walls RL, White JW, Zhang G, Deans AR, Huala E, Lewis SE, Mabee PM (2015) Emerging semantics to link phenotype and environment. PeerJ 3: e1470

Tochtermann K, Riekert WF, Wiest G (1997) Using semantic, geographical, and temporal relationships to enhance search and retrieval in digital catalogs. In Research and Advanced Technology for Digital Libraries. Springer, Berlin Vol. 1324: 73–86

UNEP, United Nations Environmental Programme (2011) Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization to the Convention on Biological Diversity. Secretariat of the Convention on Biological Diversity, Montreal

Van den Bosch A, Lendvai P, Van Erp M, Hunt S, van der Meij M, Dekker R (2009) Weaving a New Fabric of Natural History. Interdisciplinary Science Reviews 34: 206–223

Vernooy R, Haribabu E, Muller MR, Vogel JH, Hebert PDN, Schindel DE, Shimura J, Singer GAC (2010) Barcoding Life to Conserve Biological Diversity: Beyond the Taxonomic Imperative. PloS Biology 8(7): e1000417

Vogt L (2009) The future role of bio-ontologies for developing a general data standard in biology: chance and challenge for zoo-morphology. Zoomorphology 128: 201–217

Walls RL, Deck J, Guralnick R, Baskauf S, Beaman R, Blum S, Bowers S, Buttigieg PL, Davies N, Endresen D, Gandolfo MA, Hanner R, Janning A, Krishtalka L, Matsunaga A, Midford P, Morrison N, Tuama ÉÓ, Schildhauer M, Smith B, Stucky BJ, Thomer A, Wieczorek J, Whitacre J, Wooley J (2014) Semantics in Support of Biodiversity Knowledge Discovery: An Introduction to the Biological Collections Ontology and Related Ontologies. PLOS ONE 9: e89606

Wen J, Ickert-Bond SM, Appelhans MS, Dorr LJ, Funk VA (2015) Collections-based systematics: Opportunities and outlook for 2050. Journal of Systematics and Evolution 53: 477–488

Wheeler QD (2009) Revolutionary thoughts on taxonomy: declarations of independence and interdependence. Zoologia 26: 1–4

Wheeler QD, Knapp S, Stevenson DW, Stevenson J, Blum SD, Boom BM, Borisy GG, Buizer JL, De Carvalho MR, Cibrian A, Donoghue MJ, Doyle V, Gerson EM, Graham CH, Graves P, Graves SJ, Guralnick RP, Hamilton AL, Hanken J, Law W, Lipscomb DL, Lovejoy TE, Miller H, Miller JS, Naeem S, Novacek MJ, Page LM, Platnick NI, Porter-Morgan H, Raven PH, Solis MA, Valdecasas AG, Van Der Leeuw S, Vasco A, Vermeulen N, Vogel J, Walls RL, Wilson EO, Woolley JB (2012) Mapping the biosphere: exploring species to understand the origin, organization and sustainability of biodiversity. Systematics and Biodiversity: 10, 1–20

Whitfield JB, Cameron SA (1994) Molecular Extracts from Museum Specimens Can and Should Be Saved - Reply. Molecular Phylogenetics and Evolution 3: 271–272

Wilson EO (1985) The Biological Diversity Crisis - a Challenge to Science. Issues in Science and Technology 2: 20–29

Wilson EO (2003) The encyclopedia of life. Trends in Ecology & Evolution 18: 77–80

Winker K (2004) Natural history museums in a postbiodiversity era. Bioscience 54: 455–459

Winker K, Reed JM, Escalante P, Askins RA, Cicero C, Hough GE, Bates J (2010) The Importance, Effects, and Ethics of Bird Collecting. Auk 127: 690–695

APPENDIX I

List of questions and possible answers from the online poll (NB: "..." indicates an open-ended answer, all other answers were predefined as 'multiple choice').

About yourself...:

1) Which country are you based in? (hint: use your keyboard for the first letters)
→ [dropdown menu with country list as supplied by SurveyMonkey]
2) Which discipline are you associated with (can choose various)
→ ecology / conservation biology / taxonomy / phylogenetics / evolution / population biology / molecular biology / other (please specify)…
3) Where do you work
→ academia / freelance biologist / education / natural history collection / non-academic research organization / science policy / zoological/botanic garden / I am a student / I earn my money elsewhere, but biology is my passion / other (please specify)…
4) How often do you have contact with natural history collections
→ daily / roughly monthly / once or a few times a year / seldom / never
5) Have you ever deposited material at a collection?
→ yes / no
6) Samples you routinely work with (can choose various)
→ fungal / animal / plant / micro-organismal / viral / human / fossil / geological / mixed environmental / other (please specify)…
7) Characters or materials you work with (can choose various)
→ morphology / molecules (e.g., DNA) / acoustics / images / pure metadata (e.g., from collection databases) / other (please specify)…

Questions concerning natural history collections (NHCs):

8) Which is the most important role of natural history collections (NHCs)? (check up to 3 – if 4 or more are checked, this question will not be evaluated)
→ educating the public / training students / collection care and loans / collecting new samples / performing basic research / performing applied research / shaping science policy / coordinating citizen science / other (please specify)…
9) Depositing vouchers – how relevant is this for science?
→ not relevant 1 2 3 4 5 relevant
10) How much growth is still necessary for NHCs to comprehensively answer most biological/environmental questions?
→ no growth needed 1 2 3 4 5 much growth needed
11) Is the current international legislation (esp. Nagoya Protocol) an obstacle for collection-based work?
→ major obstacle 1 2 3 4 5 no obstacle
12) Are collections sufficiently accessible for science?
→ not accessible 1 2 3 4 5 accessible
13) How important is it for NHCs to offer their collection data digitally?
→ not important 1 2 3 4 5 important
14) Are the collections you know maintained properly?
→ inadequately 1 2 3 4 5 well-maintained
15) Do you feel NHCs are up to present-day science?
→ antiquated 1 2 3 4 5 up to date
16) Are NHCs paying enough attention to molecular samples (e.g., DNA used in publications)?
→ not enough 1 2 3 4 5 sufficient
17) How relevant are molecular samples in life sciences?
→ not relevant 1 2 3 4 5 relevant
18) Is type material given the necessary importance at NHCs?
→ not enough 1 2 3 4 5 appropriate
19) On average, is sample documentation (sample metadata) in NHCs sufficient?
→ insufficient 1 2 3 4 5 sufficient
20) Are libraries necessary at NHCs?
→ not necessary 1 2 3 4 5 necessary
21) How relevant (scientifically) are journals edited at / issued by NHCs?
→ not relevant 1 2 3 4 5 relevant
22) How important is it for NHCs to engage the general public through, e.g., exhibitions, events, or social media?
→ not important 1 2 3 4 5 important
23) Is there sufficient taxonomic expertise at NHCs?
→ insufficient 1 2 3 4 5 sufficient
24) Overall, how happy are you with the services offered by the community of NHCs?
→ unsatisfied 1 2 3 4 5 happy
25) Are NHCs funded appropriately?
→ insufficiently 1 2 3 4 5 appropriately
26) Overall, do your country's collections offer better or worse services than those in most other countries?
→ below average 1 2 3 4 5 above average
27) Do you perceive NHCs as interesting places?
→ boring 1 2 3 4 5 fascinating
28) If anything, what should improve most at NHCs?
→ …
If you would like to be updated on results from this survey, type in your (plain) email address here:
→ …

APPENDIX II

List of networks and list-serves used to announce the online poll. Membership figures for the respective groups were obtained at time of the survey.

Mailing lists and fora

EvolDir mailing list (and platform) (http://life.mcmaster.ca/evoldir.html), ca. 10,000 recipients.
Taxacom list (http://mailman.nhm.ku.edu/cgi-bin/mailman/listinfo/taxacom): more than 2000 members.
Natural History Collections listserver, NHCOLL-L (http://mailman.yale.edu/mailman/listinfo/nhcoll-l), 1775 members.
International Society for Biological and Environmental Repositories, ISBER, forum (http://www.isber.org/): over 1000 members.
Mailing list of the German Society for Biological Systematics, GfBS (http://www.gfbs-home.de/?L=1): 285 subscriptions.
Consortium of European Taxonomic Facilities, CETAF (http://cetaf.org/) mailing list and website: 170 members (mailing list).
Listserv for biology students in Bonn, Germany (biostuff@listserv.uni-bonn.de): number of subscriptions could not be determined

Social Networks

LinkedIn (https://www.linkedin.com/) groups:
Biodiversity Professionals: 25,000 group members.
Ecology & Evolutionary Biology: 17,000 members.
European, Middle Eastern & African Society for Biopreservation& Biobanking, ESBB: 3000 members.
Global Genome Biodiversity Network, GGBN: 80 members.
European Distributed Institute of Taxonomy, EDIT: 220 members .
Facebook (https://www.facebook.com/) Natural History Collection group: almost 1000 members.

APPENDIX III

(electronic supplement, available at www.bonnzoologicalbulletin.de)

Table containing the full data collected in the survey (email addresses excluded).

APPENDIX IV

(electronic supplement, available at www.bonnzoologicalbulletin.de)

Mean values for questions 8–27 and overview of average answer values for the respective background traits.

APPENDIX V

(electronic supplement, available at www.bonnzoologicalbulletin.de)

Categorization of open-ended answers to question 28. The file consists of two spreadsheets: 1) the original answers along with category tags assigned by us, and 2) a summary as well as explanatory note on how we defined tags.

