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# Natural history collections and the future legacy of ecological research

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## Abstract

Natural history collections are now being championed as key to broad ecological studies, especially those involving human impacts in the Anthropocene. However, collections are going through a crisis that threatens their present and future value, going beyond underfunding/understaffing to a more damaging practice: current researchers are no longer depositing material. This seems to be especially true for ecological studies that now benefit from historical collections, as those researchers are not trained to think about voucher specimens. We investigated indexed journals in Ecology and Zoology to assess if they have guidelines concerning voucher specimens. Only 4% of ecological journals presently encourage (but mostly do not require) voucher deposition, while 15% of zoological journals encourage it. In the first place, this goes contrary to scientific standards of reproducibility, since specimens are primary data. Secondly, this erodes the legacy we will leave for future researchers, because if this trend goes on unchecked, it will leave a massive gap in collections' coverage, undermining the quality that is presently acclaimed. The scientific community needs a wakeup call to avoid impoverishing the future value of natural history collections. Training and changing researchers' mindsets is essential, but that takes time. For the moment, we propose a stopgap measure: at the minimum, academic journals should encourage authors to deposit specimens in open collections, such as museums and universities.

**Keywords** Museums · Primary data · Reproducibility · Voucher specimens · Vouchering

## Introduction

After decades in relative obscurity, museums and natural history collections are now receiving renewed interest. More specifically, these collections are being championed as invaluable resources to broad and groundbreaking ecological studies, especially those pertaining to the Anthropocene and human impacts on the biosphere (Meineke et al. 2018; Schmitt et al. 2018). Macroevolution, climate change, and extinction are currently the hottest research topics involving

museum collections (e.g., Andrew et al. 2018; Kharouba et al. 2018; Lughadha et al. 2018; MacLean et al. 2018).

Utilizing natural history collections in this way is not new of course (e.g., Lane 1996; Green and Scharlemann 2003), but its potential has been historically underappreciated (Suarez and Tsutsui 2004; Webster 2017). Until very recently, collections were the purview of systematists and taxonomists; only in the past decade or so ecologists have start consistently to make use of them (Meineke et al. 2018). This new wave of researchers rightly argue that museum specimens have been underused and that there is profuse data locked in them, from morphology to DNA, to isotopes, and to compounds such as pigments (Meineke et al. 2018; Webster 2017).

Unrecognized, however, is the work of past collectors and curators, who assembled those collections over the past centuries; it is their legacy that we now have available. Even with the renewed interest, natural history collections have been going through a crisis that threatens their present and future value. This goes through the typical underfunding and understaffing (Dalton 2003; Hamer 2012; Schilthuizen et al. 2015) to a more insidious and

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largely unnoticed threat: current researchers (other than systematists and taxonomists) are not depositing new material in the collections (Bortolus 2008; Turney et al. 2015). These are the so-called voucher specimens and their importance is not fully appreciated, especially among ecologists (Bortolus 2008; Turney et al. 2015), which is ironic given the current praise they have been giving to the dormant potential of collections (e.g., Meineke et al. 2018 and references therein). If this trend of non-deposition goes on unchecked, in a few decades, collections will have a massive gap in their coverage, with scarcely any continuous series of specimens to study, undermining the very quality that is currently acclaimed.

To investigate this matter further, we scoured journals in the areas of ecology and zoology to assess if and how they address voucher specimens. Herein, we compare the two areas, and the subareas within each, pinpointing the main issues and offering both short- and long-term solutions.

## Material and methods

We accessed the Web of Science website (Clarivate Analytics) to compile a list of all indexed journals (with an impact factor) belonging to the following subjects within the biological sciences: ecology, entomology, marine and freshwater biology (henceforth “MFB”), ornithology, and zoology. Ecology and MFB were identified as the two subjects where ecological research is published. For zoology, we also had to include the subareas ornithology and entomology, which are large enough to merit their own subject in the Web of Science. Journals from other zoological subareas, such as malacology and herpetology, are listed within zoology.

We considered all the journals of those lists for our analysis, only removing those entirely focused on microbiology, data analysis (i.e., using available datasets, without data collection) and medicine. A few journals reported both ecology and zoology as their main areas ( $n=22$ ) and were also removed from further analyses. Refer to the Supplementary Material for a complete list and classification of the journals. During the month of March 2019, we accessed all the listed journals' websites, searching in their “Information for Authors” (or similar) section for the presence and content of any guidelines concerning voucher specimens.

Analyses were performed in R version 3.4.3 (R Core Team 2017). To define the minimal models, we used backwards model selection, dropping non-significant terms in each step. We used generalized linear models with binomial response and logit link function to test whether the probability of requiring a voucher was explained by the journal's impact factor, the journal's main area (zoology or ecology), and the interaction between impact factor and area.

## Results

In total, we examined 218 ecology journals (including 84 MFB journals), and 275 zoology journals (including 96 entomology and 25 ornithology journals). Neither impact factor nor the interaction between impact factor and area explained the probability of a journal to require a voucher (interaction between impact factor and area:  $\chi^2=0.14$ ;  $p$  value=0.71; main term impact factor:  $\chi^2=0.01$ ;  $p$  value=0.91). However, the area alone was significantly related ( $\chi^2=15.15$ ;  $p$  value<0.01), with zoology journals being more likely to request a voucher than ecology journals (estimates: zoology =  $-1.73 \pm 0.17$ ; ecology =  $-3.03 \pm 0.32$ ). The percentages of journals that refer to voucher specimens in their guidelines are as follows: ecology = 4.59% (MFB = 4.76%) and zoology = 15.6% (entomology = 20.0%; ornithology = 0.0%). These instances go from simple suggestions for vouchers to be deposited in a collection to (rarely) actually requiring it. While most refer to voucher specimens in general, there is a good number of journals (e.g., ca. 20% in zoology) that are just concerned with vouchers when there are molecular sequences involved.

## Discussion

Ecology and MFB journals are less than ideal with respect to vouchering guidelines, with only an insignificant fraction of each even mentioning the term “voucher”. The perceived importance or necessity of vouchers by the research community and their requirement (or lack thereof) by journals, editors and reviewers are possibly linked as a feedback loop. A survey of ecology papers by Bortolus (2008) found that only ca. 2.5% had voucher specimens, which is in line with our findings. Curiously, Turney et al. (2015) analyzed only arthropod-related biodiversity and ecology papers, reporting that less than one quarter of them included vouchers.

Zoology journals fare better, and entomology even better; ornithology, however, is completely inadequate and a surprise given the importance of historical data for ornithology (e.g., Remsem 1995; Mearns and Mearns 1998; Salvador et al. 2019). This difference was pointed out by Wheeler (2003), given that these journals have a stronger focus towards systematics/taxonomy and thus, are more likely to have guidelines about vouchers. Our finding is in line with the report of Turney et al. (2015) that the proportion of articles with vouchers was much higher (ca. 45%) in dedicated entomology journals.

## Specimens as primary data

Most ecological studies share their databases, typically in the form of Supplementary Material (a practice that is strongly recommended or even required by the journals). In fact, in many cases those datasets are not exactly raw data,

rather, the specimens per se are the primary data and only by preserving them can we secure re-examination and reproducibility (Ruedas et al. 2000; Schilthuizen et al. 2015; Wheeler 2003; Winker et al. 1996). It is thus paramount that some specimens are preserved for posterity as vouchers. This practice, however, is not currently followed (Turney et al. 2015), going contrary to the scientific standards of reproducibility (Popper 1935), which is even more alarmingly when species identification in two-thirds of non-taxonomic entomological research has been recently called into doubt (Packer et al. 2018). We will not explore this matter further here, as it has been recently and expertly addressed elsewhere (Wheeler 2003; Schilthuizen et al. 2015). Lack of reproducibility is a pressing matter (e.g., Bortolus 2008, on error cascades), but there are others needs and usages of vouchers that will be explored below.

### The conservation conundrum

From our results, not a single ornithology journal mentions voucher specimens in their guidelines; a problem long recognized in this particular field (Winker et al. 1996). Most mammalogy journals, despite not being a category on their own, present the same problem. The reluctance in suggesting the collection of charismatic fauna is understandable; just remember the kingfisher fiasco, when collecting a single bird sparked a hate movement on social media, death threats to the researcher and his eventual resignation from his job (Johnson 2018). While the public was acting on misinformation and double standards (Johnson 2018), even a few researchers have argued against collection, advocating for photographs and DNA samples instead of actual specimens. Fortunately, they have been quickly and thoroughly rebutted by the scientific community (e.g., Clemann et al. 2014; Rocha et al. 2014; Rogers et al. 2017), recovering the legitimate argument that objects retain a variety of information that no other media does (Knell 1999). Furthermore, conscientiously collected specimens can actually aid in conservation efforts. This might sound paradoxical at first, especially to the public, but the benefits of additional knowledge from specimen-based research can go a long way towards detecting pollution-related problems and for “red listing” (Remsem 1995; Green and Scharlemann 2003).

There has been an increased awareness of the insufficiency of the IUCN Red List for invertebrate taxa, which comprise only 21% of the listed species despite accounting for over 95% of animal species (Gerlach et al. 2014). The main reason for this is lack of information, which led Régnier et al. (2015) to propose a methodology for inferring the status of data deficient from the literature and natural history collections. Their methodology is an important step for conservation, but takes one fact for granted: that all researchers dutifully deposit voucher specimens, which we know is

not the case (e.g., Turney et al. 2015). Voucher specimens are extremely valuable for red listing invertebrate taxa, as they allow correcting published errors (usually in species identification) and analyzing changes in species distribution through time.

### Collections and future research

Natural history collections have been historically built, curated, increased upon and used for several reasons, coming a long way from the cabinets of curiosities to the modern archives of biodiversity (Findlen 1994; Alexander et al. 2017). As the so-called sixth mass extinction advances, the incorporation of vouchers in the collections gains yet another level of importance: it is a way of guaranteeing that the collection will be representative and useful for future studies. However, if only systematists and taxonomists (often collections' staff) are depositing vouchers, we run the risk of limiting study possibilities (and thus the importance) of natural history collections in the future. To put it simply, the lack of vouchers might leave collections with huge geographical, temporal or taxonomic gaps in their coverage and representativeness. These gaps thus erode the legacy we will leave for future researchers, undermining the quality of collections that is presently acclaimed (Meineke et al. 2018, and references therein).

As such, we need a wake up call to avoid impoverishing future natural history collections. This includes plans and actions for the long term and immediate measures for the short term, which we address below.

### Long-term vision

In the long term, the objectives are quite clear: (1) to raise awareness of the importance of voucher specimens as the scientific standard of reproducibility, as archives of biodiversity, as tools for conservation or long-term studies, etc. and (2) to change current culture of researchers so that voucher deposition becomes the norm. We believe that articles such as this one can only go so far and change must come from the training of future researchers. Presently, the majority of biologists are simply not trained to think about vouchers (Turney et al. 2015). The inclusion of this topic in university lectures is the best starting point to change this behavior, but senior researchers should also take the lead in making voucher deposition a main feature of their work, training students and staff. In the long run, science will benefit from these rather simple measures.

The number of vouchers to be collected and deposited greatly varies according to type of research and the taxon studied. Providing specific guidelines is far from the scope of the present article, but see Martin (1990) for a “quick start” (more thorough guides are Huber 1998; Westereng

1999), but there are some rules of thumb. For instance, one pair of taxidermized birds is enough, but this number will not suffice for invertebrates, for which several specimens (and life stages) can be easily collected and preserved. Not every specimen analyzed for a study must become a voucher; those that do not could also be documented through other means: mainly by digital photographs, but if possible, also by tissue samples.

One thing that is important to stress is that vouchers should not be kept only for specimens that have been sequenced (Astrin et al. 2013), as some journals' guidelines suggest (e.g., *Zoologica Scripta*, *Journal of Mammalian Evolution*). The field of molecular systematics has historically suffered from the lack of vouchering and reliability (Plejdel et al. 2008; Winker et al. 1996), so additional specimens beyond those sequenced should also be kept. Furthermore, it is imperative that even well-known common species have vouchers deposited: present collections are remarkably rich in rare species, but often abysmally poor in common "garden-variety" animals (Ruedas et al. 2000). Finally, active collection of some vertebrates and cephalopods, as well as extremely endangered species, is not only problematic in terms of public perception, but may also be subjected to ethical committee evaluations. If collecting a specimen is not appropriate, make sure that other types of records (e.g., photographs, tissue samples) are gathered in these cases and that any animal found dead is deposited in a collection (Green and Scharlemann 2003).

### Short-term action

Raising awareness of the importance of vouchers, changing researchers' mindsets, and training new generations of scientists in the practice of vouchering is a decadal project in the very least. We scarcely have time for this, so the scientific community needs a wakeup call and a drastic immediate measure to go along with that long-term vision.

We thus propose a stopgap measure: academic journals ought to require the authors to deposit specimens in publicly available collections such as museums and universities. Up to now, previous works have just pointed out that journals should encourage vouchering (e.g., Martin 1990; Astrin et al. 2013; Turney et al. 2015). We acknowledge that making voucher deposition a mandatory practice in all fields is impractical and may raise ethical issues depending on the study system. But we believe that journals should stimulate authors to deposit vouchers or to present a proper justification of why this is not possible. This is similar to what already happens to data deposition in open access databases, so this would not be a large step to take. If journals are clear in their guidelines, this culture would quickly start to change, as is currently happening with open datasets. After all, what are specimens if not the primary datasets?

Some journals already have this approach (e.g., *Malacologia*, *Salamandra*), but they are still very few and mostly concerned with type specimens. In one case (*Neotropical Ichthyology*), there is a remark that even well-known species must have vouchers deposited. As discussed above, each area will have its own guidelines and practices regarding vouchers and journals with broader scopes will have to rely on editors and reviewers to judge the adequacy of each contribution. Furthermore, waivers on voucher deposition can be made for particular taxa (see above).

Universities and grant agencies should likewise include voucher deposition in their policies, requirements, and judgement criteria for funding. For instance, if a faunal survey does not account for voucher deposition, it is thus an irreproducible project and that should weigh against it.

Museums and universities can be understaffed/ underfunded (Dalton 2003; Hamer 2012) and encouraging vouchering might stretch that even further (Danks 1991), given that processing and databasing specimens would have to be done quickly to allow the inclusion of registry numbers in publications (Schilthuizen et al. 2015). To date, the best solution to this was proposed by Schilthuizen et al. (2015): a fee for depositing specimens. Just as online depositories charge authors to keep their databases in their "virtual collection" so to speak, natural history collections could charge for the service of keeping the vouchers safe for future generations. The extra funding would allow the collections to acquire and maintain a high standard of archival materials to safekeep the specimens and to hire dedicated or temporary technicians or registrars. Naturally, a waiver of this fee should still be possible in certain circumstances to avoid excluding underfunded research scenarios, similar to the manner some journals have waivers on publication fees.

### Conclusion

Lack of vouchering is not a new problem; it has been lurking in academia for the past decades (Huber 1998; Martin 1990). Even though long recognized, the problem has only been disseminated within the restricted circles of museum researchers, taxonomists and systematists. Here, we provided a broad survey of the literature and publishing culture, while revisiting some previously raised points and bringing new perspectives to the fore. We offered short- and long-term measures to establish an effective culture of vouchering and we expect this message will reach a larger audience this time—one that can greatly collaborate to our future scientific legacy.

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**Author contribution statement** RBS conceived the idea and led the writing of the manuscript. RBS and CMC contributed equally to data gathering, analysis, and interpretation of results.

**Data availability** All data are available in the body of the article and in the Supplementary Material file.

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