

ISBN 0-9689321-2-6

**The Role of Voucher Specimens in Validating
Faunistic and Ecological Research**

A brief prepared by the
Biological Survey of Canada (Terrestrial Arthropods)

Biological Survey of Canada (Terrestrial Arthropods)

Document series no. 9 (2003)



Biological Survey of Canada

Commission biologique du Canada

Published by the
Biological Survey of Canada (Terrestrial Arthropods)
Ottawa
2003

Prepared on behalf of the Biological Survey by
Terry A. Wheeler
Department of Natural Resource Sciences,
McGill University, Macdonald Campus
Sainte-Anne-de-Bellevue (Québec) H9X 3V9

The Biological Survey of Canada (Terrestrial Arthropods) develops and coordinates national initiatives in systematic and faunistic entomology on behalf of the Canadian Museum of Nature and the Entomological Society of Canada.

The document series of the Biological Survey of Canada comprises invited bibliographies and other miscellaneous publications that are especially relevant to the fauna of Canada.

Additional copies of this document are available from the Biological Survey of Canada (Terrestrial Arthropods), Canadian Museum of Nature, P.O. Box 3443, Station D, Ottawa, ON K1P 6P4 or on the Survey's website: <http://www.biology.ualberta.ca/bsc/bschome.htm>

The role of voucher specimens in validating faunistic and ecological research

Abstract

Voucher specimens deposited in natural history collections are the only reliable means to verify the identity of species used in biological studies. However, despite their importance in confirming the results of research, deposition of vouchers is still the exception rather than the rule, especially in non-taxonomic studies. Furthermore, many journals do not require or even recommend deposition of vouchers. This brief reviews the nature of voucher specimens and sample policies on vouchers in systematic, faunistic and ecological research. The advantages of having vouchers available for subsequent study, and the pitfalls of not designating and depositing vouchers, are discussed using examples from the literature. Recommendations as to best practices in voucher policy are given for funding agencies, agencies that issue research permits, university departments, journal editors and natural history collections.

Le rôle des spécimens de référence pour valider les recherches faunistique et écologique

Résumé

Les spécimens de référence déposés dans les collections d'histoire naturelle sont la seule manière fiable de vérifier l'identité des espèces utilisées dans les études biologiques. Cependant, malgré leur importance dans la confirmation des résultats de recherche, le dépôt de spécimens de référence est très rare, surtout dans les études à caractère non-taxonomique. De plus, plusieurs revues scientifiques n'exigent pas ou ne recommandent pas le dépôt des spécimens de référence. Ce mémoire résume l'utilité des spécimens de référence et présente un aperçu des règles d'utilisation des spécimens en recherche systématique, faunistique et écologique. Les avantages d'avoir des spécimens de référence disponibles pour des projets futurs ainsi que les conséquences de ne pas désigner et déposer de spécimens de référence sont discutés en utilisant des exemples provenant de la littérature. Des recommandations sur l'utilisation adéquate de spécimens de référence sont données pour les organismes accordant des subventions, les organismes émettant les permis de recherche, les départements universitaires, les rédacteurs de revues scientifiques ainsi que pour les collections d'histoire naturelle

This brief was greatly improved by extensive comments and suggestions from members of the Scientific Committee, particularly H.V. Danks, K.D. Floate, D.J. Giberson, J.T. Huber, J.F. Landry, S.A. Marshall, R.E. Roughley, F.A.H. Sperling and N.N. Winchester.

Introduction

The Scientific Method is based on the principle that results of studies should be repeatable and verifiable. Research methods are made repeatable through description of the procedures used; results and interpretation are verifiable through peer review; cited references identify sources of previous data, interpretation or comparison. However, all these components of a paper may be rendered useless if there is no way to verify the identity of the study organisms themselves. The value of too many publications is reduced by the subsequent realization that the species actually studied may not have been the species named in the paper.

Errors in specimen identification can enter a study in several ways:

- Subsequent recognition of multiple species in a complex of closely related species, or changes in species limits.
- Subsequent recognition of variation in traits of populations that affect morphology, ecology, behaviour or physiology.
- Subsequent recognition of errors or omissions in keys or guides used for identification.
- Misidentification of an organism by a trained researcher inexperienced in the systematics of that taxon (an occasional problem).
- Misidentification of an organism by untrained or poorly trained “consultants” offering contract identifications (a frequent problem).

The above errors can be mitigated (or, at least, their impact reduced) by the deposition of properly prepared voucher specimens in recognized research collections, where they are maintained under long-term care and available for subsequent examination and verification.

Many previous authors (e.g., Sabrosky 1955, Francoeur 1976, Yoshimoto 1978, Lee et al. 1982, Knutson 1984, Danks et al. 1987, Kelleher 1988, Danks 1991, Wiggins et al. 1991, Huber 1998 and numerous other papers cited by those authors) have emphasized

the importance of voucher specimens and provided examples of studies with results that were either negated or called into question due to a failure to deposit and document voucher specimens. Unfortunately, the existence of this voluminous literature and of the lessons contained therein have not led to adequate deposition of vouchers, as a quick perusal of the entomological literature will attest.

On the assumption that repeated warnings may eventually prove effective, this document reviews the nature, preparation and deposition of voucher specimens, as well as the benefits of observing recommended practices with regard to vouchers and the potential costs of not doing so.

What Constitutes a Voucher Specimen?

Although specimens used in faunistic and ecological studies range in size from whales to viruses, and in abundance from houseflies to critically endangered species, this brief focuses primarily on terrestrial arthropods. Voucher specimens generally are entire preserved specimens, in accordance with the usual methods of collection and preservation of invertebrates. However, under certain situations (such as studies of rare or endangered species), acceptable vouchers may also be preserved tissue samples, photographs or even sound recordings.

Designation of voucher specimens is a long-established practice in systematic research, through the designation of type specimens of newly described species. The requirement for a one-to-one correspondence between a scientific name and a real organism is undoubtedly responsible for the convention in systematics of depositing authoritatively identified specimens from a study in a research collection, whether the specimens are types or not.

The advent of molecular systematics has led to the use of another type of taxonomic voucher specimen, in which DNA sequences are deposited in widely accessible electronic databases such as GenBank (but see Ruedas et al. (2000) for a discussion of the unsuitability of sequence data alone as voucher specimens and Harris (2003) for a sobering example of error rates in published GenBank sequences).

One of the differences between systematic studies and faunistic or ecological studies is that the latter may accumulate many more specimens (up to hundreds of thousands in some large scale biodiversity inventories) and many more species. However, correct identification of taxa is just as important and, thus, specimens should be available so that other workers can confirm the identity of the study organisms. Voucher specimens in faunistic and ecological research should be prepared in the same way and accompanied by the same data as specimens collected for systematic research. The number of specimens that should be deposited as vouchers from such studies is an additional consideration, discussed below.

Preparation and Deposition of Vouchers

Detailed guidelines and recommendations on the collection, preparation and labelling of specimens are available in a number of publications (e.g., Martin 1977, Huber 1998, Wheeler et al. 2001) so that information is not repeated here. It must be emphasized that the use of the term “voucher specimens” throughout this document should be taken to mean “*properly prepared, properly labelled voucher specimens*”. Poorly prepared specimens are of little or no use to other researchers, especially in the long term, and it is not the responsibility of museum staff to correct oversights and shortcuts of other workers.

In order to ensure long-term care and maintenance of voucher specimens, and to facilitate access by the research community, the specimens must be deposited in a recognized natural history collection. Indeed, one of the major roles of natural history collections is to ensure that such specimens are made available for study and for use in subsequent research projects, such as systematic revisions or studies of long term patterns of change in arthropod communities (Danks et al. 1987, Wiggins et al. 1991, Danks and Winchester 2000, Ponder et al. 2001, Favret and DeWalt 2002). Each collection has its own policies on voucher specimens. For example, some museums add distinguishing labels to vouchers in order to link the specimen to a particular study while others (usually smaller collections) may simply incorporate vouchers into the main research collection and rely on the specimens’ collection

label to associate them with the study. With the increase in specimen-level databases using barcodes or unique identifier codes associated with each specimen, vouchers can be identified as such in the museum's database, with additional data fields linking the specimen to the original study.

Current Requirements, Policies and Recommendations on Vouchers

Systematic vouchers – The International Code of Zoological Nomenclature requires that type specimens must be designated and clearly identified for any species described after 2000. Although deposition of type specimens in a recognized institution (as opposed to a private collection) is not expressly required by the Code, most responsible authors do so and make the type specimens available for study by other workers.

Genetic vouchers – Deposition of genetic sequence data in centralized electronic sites such as GenBank or EMBL is now a requirement of many refereed journals publishing the results of molecular studies. Unfortunately, those same journals do not usually require separate deposition of a voucher specimen to ensure that the specimens from which genetic material was extracted were correctly identified in the first place.

Ecological vouchers – In contrast to taxonomic work, there is no established history of depositing specimens collected in the course of an ecological study. However, correct and verifiable identifications are just as important in ecological studies and there is absolutely no reason that requirements for voucher deposition in taxonomic studies should not apply to faunistic and ecological studies, especially since identifications in such studies are probably made more frequently by non-specialists using published keys only.

Biochemical or physiological vouchers – These conclusions about ecological vouchers also apply to specimens collected in the course of physiological or biochemical studies. Just as specimens within a group of species, or even within a species, vary morphologically or ecologically, there can be major variations

at the species or population level in such characteristics as pheromone chemistry, responses to secondary plant compounds and other chemical substances, and physiological responses to environmental changes.

The Natural Sciences and Engineering Research Council of Canada has recognized the importance of natural history collections in research by publishing a *Framework for Researchers Working with University-Based Collections* (NSERC 2003) including a statement on the importance of both type specimens and voucher specimens in documenting the results of research. One of the pivotal collaborative roles that natural history collections can play in faunistic, ecological or physiological studies is in housing and maintaining the voucher specimens that permit verification of the identity of study organisms.

Despite the clear value of voucher specimens in validating research, and acknowledgment by major granting agencies of that value, many journals do not require, or even recommend, deposition of vouchers as a condition of publication. Table 1 summarizes the editorial policies concerning voucher specimens of a small sample of Canadian and international entomological journals (as well as some general journals with occasional entomological content). Primarily systematic journals, such as *Systematic Entomology*, require voucher specimens to be deposited in a collection. However, with a few exceptions (e.g., *Entomological News*), most journals, including the Canadian ones sampled, either fail to mention voucher specimens in their instructions to authors or only “recommend” that such specimens be deposited.

How Many Specimens? Guidelines on Depositing Vouchers

Since the advent of passive sampling methods and large scale, replicated studies of biodiversity and ecology, the number of specimens potentially generated in research projects has increased significantly. Few institutional collections are equipped to deal with the hundreds of thousands of specimens collected or observed in all ongoing studies, and the costs of mounting, labelling and curating that much material would be prohibitive. Consultation during the

Journal	Focus	Voucher deposition policy
Annals of the Entomological Society of America	General	Recommended
Aquatic Insects	General	No statement
The Canadian Entomologist	General	Recommended (English) Types required, no statement on vouchers (French)
Canadian Field-Naturalist	Ecology	Recommended
Canadian Journal of Zoology	General	Recommended
Ecological Entomology	Ecology	No statement
Entomological News	Systematics / Ecology	Required
Journal of Insect Behavior	Behaviour / Ecology	No statement
Journal of Insect Conservation	Ecology	Types required, no statement on vouchers
Journal of Insect Physiology	Physiology / genetics	No statement
Journal of the North American Benthological Society	Ecology	No statement
Molecular Phylogenetics and Evolution	Systematics / Genetics	Deposition of sequence data required; no statement on vouchers
Physiological Entomology	Physiology	No statement
Proceeding of the Entomological Society of Ontario	General	No statement
Proceedings of the Entomological Society of Washington	Systematics / Ecology	Types required, no statement on vouchers
Systematic Entomology	Systematics	Required

Table 1. Editorial policy on voucher specimens of selected journals. List shows the primary research focus of each journal and its stated policy on vouchers or type specimens (from posted or published author instructions, June 2003).

planning stages of a study with curatorial staff of the collection that will eventually receive the vouchers is the most reliable way to obtain an estimate of how many vouchers are recommended for a particular study.

The number of vouchers actually retained and deposited for long-term maintenance is largely dictated by the type of study. At the very least, one specimen of each species identified in a

study should be designated as a voucher. However, one specimen often is not sufficient for a reliable subsequent identification. Depositing two or more vouchers increases the probability that one of the specimens will be a member of the sex needed for species-level identification, or will be a clean, undamaged specimen with necessary morphological structures clearly visible. Multiple voucher specimens can also be useful in showing the range of variation in characters for later studies as well as indicating if more than one species was combined in the original identified series. Multiple voucher specimens are also advantageous in cases where destructive sampling is required for species confirmation, as in the case of molecular characters. At least five to ten specimens of each species are recommended to ensure subsequent identification and to determine if all specimens identified are in fact conspecific.

Systematic vouchers – In this case, the number of type specimens or vouchers is often dictated by the number of specimens available in museum collections or as a result of field work. In some cases species descriptions are based on only a single specimen. More specimens are preferable and will help to show the range of variation in characters of the species. In addition, larger numbers of specimens allow authoritatively identified specimens to be deposited in multiple collections, facilitating identification by other workers at those institutions.

Genetic vouchers – In molecular studies, the part of the specimen from which DNA for sequence data is extracted is frequently destroyed, but efforts should be made to ensure that the rest of the specimen remains intact, and preferably retains the morphological characters that allow species-level identification (e.g., genitalia, secondary sexual characters, sclerites with distinctive colour patterns). In the case of species in which individuals are small, the entire specimen must sometimes be destroyed for sequencing. If this is the case, conspecific specimens from the same collection event, identified by a specialist, may be suitable vouchers. If additional tissue samples are to be taken from voucher specimens for subsequent DNA analysis, appropriate protocols for storage of tissues for DNA extraction should be followed (e.g., storage of specimens in -70°C freezers, 95-100% ethanol). Here again,

consultation with museum curators prior to beginning the study will ensure that correct procedures are followed.

Ecological or physiological vouchers – Depending on the nature of the ecological study, thousands of specimens of a single common species may be collected; in this case, a subset of the series would obviously be sufficient to confirm the identity of the species. On the other hand, there are often differences in species characteristics or in the species assemblage of a community from habitat to habitat, or from season to season, within a larger-scale study. These differences increase the likelihood that multiple species may be collected and confused. To account for possible species or population differences, vouchers from ecological studies should include specimens of as many identified species as possible from across the range of habitats, seasons, treatments or other variables examined in the study.

The Benefits of Depositing Vouchers (and the costs of not doing so)

Many previous authors have outlined, often in general terms, the benefits of depositing vouchers (e.g., numerous papers cited in Huber 1998). That such benefits *are* often put in general terms may be responsible for the fact that many authors continue to disregard recommendations to deposit vouchers. In this section the benefits of good voucher practice, as well as some of the potential costs of not depositing vouchers, are reviewed using examples from the literature as well as some known but unpublished examples. Criticism of a particular paper for not following recommended voucher practices should not be interpreted as a criticism of the scientific validity or quality of the research; it is simply that, in the absence of voucher specimens, the research results cannot be independently verified or repeated with the certainty that the same taxon is being studied.

Deposition of vouchers permits long term studies

McCorquodale (2001) used old voucher specimens deposited in a variety of regional insect collections to re-assess the presence of several species of Cerambycidae (Coleoptera) in Ontario. Because

voucher specimens from studies by early authors were available for identification, McCorquodale was able to record several new species for Ontario.

In a similar, but larger scale study, Favret and DeWalt (2002) used newly assembled electronic databases of holdings of Ephemeroptera and Plecoptera in the Illinois Natural History Survey collection to assess faunal changes (range expansions, range reductions, changes in abundance) in those orders over the course of the 20th Century in Illinois.

Resh (1976) used old collection data to confirm (and correct) species identifications of caddisflies (Trichoptera) collected in Ohio and Illinois several years previously as well as documenting changes in the fauna resulting from habitat degradation over a 50-year period (see also Resh and Unzicker (1975)).

Leibherr and Song (2002) assessed carabid beetle (Coleoptera) diversity in bogs and marshes in New York, comparing their field data to specimens collected at least 75 years earlier in order to assess change in the community over time.

In addition to these specific examples other authors (e.g., Shaffer et al. 1998, Ponder et al. 2001) have recognized the general value of specimens housed in natural history collections in assessing changes in species distributions and abundance over time.

Unpublished data on selected groups of Canadian grassland arthropods provide the potential for assessing long-term change in those habitats. Manitoba entomologist Norman Criddle collected large numbers of ground beetles (Coleoptera: Carabidae) in grassland habitats in Aweme, Manitoba in the early part of the 20th Century. Criddle kept extensive and exhaustive field notes which survive largely intact, and he deposited specimens from his field studies in a number of insect collections, notably those at the University of Manitoba and the Canadian National Collection of Insects, although Criddle's Coleoptera are found almost worldwide in collections as a result of exchanges (R.E. Roughley, D. Pollock pers. comm.). Examination of those specimens in museums allows current workers to confirm the identity of Criddle's material against

current species limits and facilitates follow-up inventory studies of carabid diversity at the Aweme site almost 100 years later.

Criddle also collected large numbers of acalyptrate Diptera (especially Chloropidae and Agromyzidae) in southern Manitoba grasslands during the summers of 1915-1916 and sent the samples to the dipterist J.M. Aldrich in Washington DC, who identified the specimens and deposited them in the Smithsonian Institution collection. Because both Criddle and Aldrich made copious notes on these specimens, because later workers retained these notes (now housed in the University of Manitoba and the Lyman Entomological Museum), and because Aldrich deposited voucher specimens, cross-referenced to the field notes, it would be a relatively simple matter today to confirm Aldrich's species concepts, generate an updated species list and replicate Criddle's survey after a century of change in the habitat.

Deposition of vouchers permits correction of published errors

Sperling et al. (1994) published a molecular analysis of three forensically important species of Calliphoridae (Diptera) used in determining postmortem intervals. The authors noted the deposition of voucher specimens of adult flies, in addition to vouchered sequence data. Subsequently, Wells and Sperling (2000) re-examined the original voucher specimens and determined that specimens identified as *Phormia regina* in Sperling et al. (1994) were, in fact, *Protophormia terraenovae*. Based on the available vouchers, Wells and Sperling (2000) published a correction to the original publication.

Ruedas et al. (2000) cited a number of molecular studies in which the results were suspect, despite the deposition of DNA sequence data in electronic databases. Subsequent examination of documented voucher specimens from which DNA was extracted revealed misidentification of some species and incomplete identification of other species now known to constitute complexes of sibling species.

Baumann (1974) examined old museum specimens of *Alloperla imbecilla* (Say), a putatively widespread eastern North American species of Plecoptera, and found that the species regarded by most authors as *A. imbecilla* was in fact two species: *A. imbecilla*, largely restricted to the Ohio River drainage; and *A. atlantica* Baumann, widespread in eastern North America. Most voucher specimens of “*A. imbecilla*” deposited by previous authors were actually specimens of *A. atlantica*.

Ellison (1991) published an ecological study of case-bearing moths (Lepidoptera: Coleophoridae) in New England. Apparent inconsistencies in the reported phenology and host plant of one of the species prompted J.-F. Landry, a specialist in coleophorid systematics, to re-examine the vouchers deposited by Ellison. Because the specimens were available, Landry was able to correct the identification of the coleophorid and resolve the apparent ecological and behavioural differences in the larvae (J.-F. Landry, pers. comm.)

The above is only a small subset of the available examples. In the field of biological control alone, there is a large body of literature (Sabrosky 1955, Danks 1988, Huber 1998, and many papers cited in those publications) listing case studies of failed attempts, primarily resulting from misidentified pest species or misidentified natural enemies. Some such errors have been traced, confirmed and corrected in cases where vouchers were deposited.

Deposition of vouchers permits resolution of species limits

Franclemont (1980) addressed the taxonomic status of a widespread species of Noctuidae and and Munroe (1973) did the same for a “cosmopolitan” pest species of Pyralidae. In each case, the supposedly widespread species actually represented a complex of closely related, but previously unrecognised species. As a result, any previous publications on the ecology, behaviour, physiology, etc. of those species in North America would be suspect in the absence of documented voucher specimens that could be compared to the revised species limits and revised keys. These two examples from Lepidoptera are by no means unique; there are numerous examples

from other orders, including many medically and economically significant taxa, in which changing species limits rendered older work essentially useless in the absence of vouchers.

Harper and Harper (1981) used extensive voucher collections of mayflies (Ephemeroptera) collected by the Canadian Northern Insect Survey and the Service de l'Environnement de la Société de la Baie James to document significant range extensions and one new species in the arctic mayfly fauna. Similarly, Ricker (1966) used old museum specimens from arctic surveys to resolve distribution patterns of northern Canadian stoneflies (Plecoptera).

Lack of vouchers renders published results unverifiable

McCorquodale (2001) recorded several new Ontario records of Cerambycidae based on old vouchers (see previous section on long term studies) but also identified a number of questionable published records for which no museum specimens could be found. As a result, there was no way to confirm the past occurrence of these species in Ontario.

In contrast to McCorquodale's (2001) convincing illustration of the value of vouchers, another paper in the same issue of the same journal (Paquin and Dupérré 2001) recorded many new North American, Canadian and Quebec records in the course of a large biodiversity survey of boreal forest Coleoptera. Unfortunately, there was no indication as to where (or even if) voucher specimens were deposited and, as a result, there is no way for other workers to confirm the identity of those species in future.

In addition to documenting several misidentified species in studies that did match their sequence data to known voucher specimens (see above), Ruedas et al. (2000) found that 73% (41 of 56) of the papers they surveyed in *Molecular Phylogenetics and Evolution* did not link their sequence data to a voucher specimen at all; thus there is no way of knowing whether the species identifications were correct or not.

Although some errors in past biological control programs can be traced and corrected, as discussed above, many early biocontrol introductions were not usually accompanied by deposition of

voucher specimens (Sabrosky 1955, Danks 1988, Huber 1998) so there is no way to know what went wrong.

The Canadian Nature Federation's lady beetle survey in the 1990s (www.cnf.ca/beetle/index.html) was, unfortunately, a failure from a scientific perspective because the nationwide register of coccinellid species was based almost entirely on sight records submitted by non-specialists. Participants were not encouraged to collect specimens to serve as vouchers and the survey was rife with apparent misidentifications of species that cannot be corrected by subsequent examination of specimens (Marshall 2000). Thus, the data from the survey are useless for rigorous scientific analysis. In contrast, a more recent amateur initiative in eastern Canada, the Atlantic Dragonfly Inventory Project coordinated by P.M. Brunelle, has the potential to contribute to considerable scientific research because over 90% of the records in the species database are supported by voucher specimens.

"Recommendations" in the editorial policy of refereed journals on deposition of vouchers (Table 1) obviously have little impact on most authors. In three randomly selected issues of *The Canadian Entomologist* published in 2002, 30 papers involved species-level identification of insects, but only nine (six of which were taxonomic papers) mentioned deposition of voucher specimens. In two randomly selected issues of the *Annals of the Entomological Society of America* for 2002, 31 papers dealt with named species but only nine (eight of which were taxonomic) mentioned voucher deposition. The numbers are similarly discouraging for other journals.

Most identification work performed by freelance consultants or contractors is not documented by deposition of vouchers. This is particularly disturbing because many consultants are not trained specialists in arthropod identification and, in the absence of vouchers, their work cannot subsequently be verified by specialists. In many cases, such identifications subsequently checked by specialists have been found to have very high error rates (Danks and Winchester 2000, Marshall 2000). Given that the specimen identifications derived from contract work often are used in making

decisions on environmental impact assessment, land use planning and conservation priorities, the potential negative implications of not having vouchers available for verification are significant and far-reaching.

Recommendations

Despite numerous publications outlining the potential benefits of properly prepared and curated voucher specimens, many authors still do not bother with this crucial step in documenting research and not enough pressure is placed on those authors to change their practices. In view of the potential benefits (and costs), this document proposes six recommendations on best practices in voucher policy for studies in systematics, faunistics and ecology of terrestrial arthropods.

1. Agencies that fund systematic, faunistic and ecological research should acknowledge explicitly that voucher specimens constitute *necessary* documentation of research. Such a policy would be consistent with the growing recognition of the importance of natural history collections in biological research.
2. Field research in parks, reserves, field stations or other protected areas that require workers to obtain permits for conducting research should stipulate that deposition of vouchers is a necessary condition of initial permit approval and, especially, of renewal. Many research permits issued by National or Provincial Parks now require deposition of at least a synoptic collection of specimens in a recognized institution. Permits for entomological research at the Mont St. Hilaire UNESCO Biosphere Reserve in Quebec stipulate that vouchers must be deposited in the Lyman Entomological Museum. Adherence to this condition is monitored by Reserve staff and renewals of permits are contingent upon this condition being met.
3. The editorial policy of entomological journals should *require* (not simply recommend) that voucher specimens be deposited in recognized institutional collections and that the depository be clearly identified in the paper. Many journals already require documentation of type specimens and molecular sequences; it

would be a logical extension of editorial policy to make other research equally verifiable.

4. University departments should require that deposition of vouchers be a requirement of successful thesis completion. Many universities, and the agencies that fund the research, now require that all relevant animal care, research ethics, biohazard and environmental impact certificates be submitted as appendices to the final version of a thesis, to demonstrate that the research was conducted in accordance with good research practices. Similarly, confirmation that vouchers have been deposited in a named institutional collection should accompany final versions of theses submitted for deposition. In the author's experience, strong "recommendations" during a thesis defence to deposit vouchers generates enthusiastic support at the time (when much is at stake), but little concrete action after the fact.
5. Institutional natural history collections should be encouraged to accept and curate voucher specimens from faunistic and ecological studies, and should establish a policy on voucher specimens that is available to all potential researchers prior to starting a study. Some collection staff are hesitant to receive vouchers (especially in large numbers); reasons for this may include poor-quality specimens submitted as vouchers in the past, insufficient space to house vouchers, and a focus on other projects and taxa in the museum's current research. None of these objections should be an obstacle. Collections can provide appropriate guidance (through the preparation and distribution of instructions and recommendations) to untrained personnel on proper procedures for specimen preparation. Such instructions and guidelines are widely available to researchers initiating a new study. Furthermore, if researchers contact the appropriate collection early enough in the project planning stage, they can be encouraged to provide in their budget for the proper preparation, identification and curation of vouchers. Space in collections is almost always at a premium, but if a particular collection is too crowded or has a different taxonomic or ecological focus, an alternative depository could be suggested.

6. A database of Canadian entomological collections willing to accept vouchers should be established and maintained on the Biological Survey of Canada website. This would allow researchers to check quickly which collections are available, and would allow museums to change their information as the focus of the collection changes. The advantage of an electronic database is that it allows changes in personnel, institutional policies, website and email addresses and collection status to be updated, as well as providing a gateway to any available databases housed on the websites of those institutions.

Conclusion

Accessible voucher specimens are critical for accurate identification and subsequent verification of species. Species are the raw material of biodiversity research, whether the focus of that research is taxonomic, evolutionary, ecological, genetic, behavioural or physiological. Research projects in biodiversity require a significant investment of time, effort and money, but without adequate documentation in the form of vouchers there is great potential for that investment to be wasted. Indeed, a failure to protect the currency of science inevitably leads, just as in business, to bankruptcy.

References

- Baumann, R.W. 1974. What is *Alloperla imbecilla* (Say)? Designation of a neotype and a new *Alloperla* from eastern North America (Plecoptera: Chloroperlidae). *Proceedings of the Biological Society of Washington* 87: 257- 264.
- Danks, H.V. 1988. Systematics in support of entomology. *Annual Review of Entomology* 33: 271-296.
- Danks, H.V. 1991. Museum collections: fundamental values and modern problems. *Collection Forum* 7: 95-111.
- Danks, H.V., G.B. Wiggins and D.M. Rosenberg. 1987. Ecological collections and long-term monitoring. *Bulletin of the Entomological Society of Canada* 19: 16-18.
- Danks, H.V. and N.N. Winchester. 2000. Terrestrial arthropod biodiversity projects - building a factual foundation. Biological Survey of Canada (Terrestrial Arthropods) Document Series No. 7. 38 pp.

- Ellison, A.M. 1991. Ecology of case-bearing moths (Lepidoptera: Coleophoridae) in a New England salt marsh. *Environmental Entomology* 20: 857-864.
- Favret, C. and R.E. DeWalt. 2002. Comparing the Ephemeroptera and Plecoptera specimen databases at the Illinois Natural History Survey and using them to document changes in the Illinois fauna. *Annals of the Entomological Society of America* 95: 35-40.
- Franclemont, J.G. 1980. "Noctua c-nigrum" in eastern North America, the description of two new species of *Xestia* Hübner (Lepidoptera: Noctuidae: Noctuinae). *Proceedings of the Entomological Society of Washington* 82: 576-586.
- Francoeur, A. 1976. The need for voucher specimens in behavioral and ecological studies. *Bulletin of the Entomological Society of Canada* 8(2): 23.
- Harper, F. and P.P. Harper. 1981. Northern Canadian mayflies (Insecta; Ephemeroptera), records and descriptions. *Canadian Journal of Zoology* 59: 1784-1789.
- Harris, D.J. 2003. Can you bank on GenBank? *Trends in Ecology and Evolution* 18: 317-319.
- Huber, J.T. 1998. The importance of voucher specimens, with practical guidelines for preserving specimens of the major invertebrate phyla for identification. *Journal of Natural History* 32: 367-385.
- Kelleher, J. 1988. Suggestions for voucher specimens of imported species. *Biological Control News* 1: 26-27.
- Knutson, L. 1984. Voucher material in entomology: a status report. *Bulletin of the Entomological Society of America* 30(4): 8-11.
- Lee, W.L., Bell, B.M. and J.F. Sutton. 1982. Guidelines for acquisition and management of biological specimens. A report of the participants of a conference on voucher specimen management. Association of Systematics Collections, Snow Museum of Natural History, University of Kansas, Lawrence, KS. 42 pp.
- Liebherr, J.K. and H. Song. 2002. Distinct ground beetle (Coleoptera: Carabidae) assemblages within a New York state wetland complex. *Journal of the New York Entomological Society* 110: 127-141.
- Marshall, S.A. 2000. Comments on error rates in insect identifications. *Newsletter of the Biological Survey of Canada (Terrestrial Arthropods)* 19(2): 45-47.

- Martin, J.E.H. 1977. The Insects and Arachnids of Canada. Part 1. Collecting, preparing and preserving insects, mites and spiders. Agriculture Canada Publication 1643. 182 pp.
- McCorquodale, D.B. 2001. New records and notes on previously reported species of Cerambycidae (Coleoptera) for Ontario and Canada. *Proceedings of the Entomological Society of Ontario* 132: 3-13.
- Munroe, E.G. 1973. A supposedly cosmopolitan insect: the celery webworm and allies, genus *Nomophila* Hübner (Lepidoptera: Pyralidae: Pyraustinae). *The Canadian Entomologist* 105: 177-216.
- NSERC. 2003. Framework for researchers working with university-based collections. Natural Sciences and Engineering Research Council of Canada. Published electronically at www.nserc.ca/programs/framework_pub_e.htm.
- Paquin, P. and N. Dupérré. 2001. Beetles of the boreal forest: a faunistic survey carried out in western Québec. *Proceedings of the Entomological Society of Ontario* 132: 57-98.
- Ponder, W.F., G.A. Carter, P. Flemons and R.R. Chapman. 2001. Evaluation of museum collection data for use in biodiversity assessment. *Conservation Biology* 15: 648-657.
- Resh, V.H. 1976. Changes in the caddis-fly fauna of Lake Erie, Ohio, and of the Rock River, Illinois, over a fifty year period of environmental deterioration. Proceedings of the First International Symposium in Trichoptera, Lutz am See, Austria, 1974. Dr. W Junk, The Hague. Pp. 167-170.
- Resh, V.H. and J.D. Unzicker. 1975. Water quality monitoring and aquatic organisms: the importance of species identification. *Journal of the Water Pollution Control Federation* 47: 9-19.
- Ricker, W.E. 1966. Some Plecoptera from the far north. *The Canadian Entomologist* 76: 174-185.
- Ruedas, L.A., J. Salazar-Bravo, J.W. Drago and T.L. Yates. 2000. The importance of being earnest: what, if anything, constitutes a "specimen examined?". *Molecular Phylogenetics and Evolution* 17: 129-132.
- Sabrosky, C.W. 1955. The interrelations of biological control and taxonomy. *Journal of Economic Entomology* 48: 710-714.
- Shaffer, H.B., R.N. Fisher and C. Davidson. 1998. The role of natural history collections in documenting species declines. *Trends in Ecology and Evolution* 13: 27-30.
- Sperling, F.A.H., G.S. Anderson and D.A. Hickey. 1994. A DNA-based approach to the identification of insect species used for postmortem interval estimation. *Journal of Forensic Sciences* 39: 418-427.

- Wells, J.D. and Sperling, F.A.H. 2000. Commentary on: Sperling FAH, Anderson GS, Hickey, DA. A DNA-based approach to the identification of insect species used for postmortem interval estimation. *J Forensic Sci* 1994; 39: 418-427 and on Vincent S, Vian JM Carlotti MP. Partial sequencing of the cytochrome oxidase b subunit gene I: a tool for the identification of European species of blow flies for postmortem interval estimation. *J Forensic Sci* 2000; 45: 820-823. *Journal of Forensic Sciences* 45: 1358-1359.
- Wheeler, T.A., J.T. Huber and D.C. Currie. 2001. Label data standards for terrestrial arthropods. Biological Survey of Canada (Terrestrial Arthropods) Document Series No. 8. 20 pp.
- Wiggins, G.B., S.A. Marshall and J.A. Downes. 1981. The importance of research collections of terrestrial arthropods. A brief prepared by the Biological Survey of Canada (Terrestrial Arthropods). *Bulletin of the Entomological Society of Canada* 23 (2), Supplement. 16 pp.
- Wilkinson, C. 1981. Modern biosystematics. *Entomologist's Gazette* 32: 205-215.
- Yoshimoto, C.M. 1978. Voucher specimens for entomology in North America. *Bulletin of the Entomological Society of America* 24: 141-142.

