How taxonomic revisions affect the interpretation of specimen identification in biological field data

Katherine Huebner*

Department Of Biology, Stewart Biology Building, 1205, Dr. Penfield, Montreal, Quebec, H3A 1B1

Article submitted: November 13, 2008 - Article accepted February 9, 2009

Abstract

Cumulative revisions in taxonomy of organisms over time can create difficulties for researchers in numerous scientific fields, including conservation biology. This paper compares the taxonomic names of the *Collembola* species named in Ivan P. Vtorov's 1993 paper entitled *Feral Pig Removal: Effects on Soil Microarthropods in a Hawaiian Rain Forest*, with the more modern *Collembola* checklists. In comparing Vtorov's original graphs with recreated graphs, this study finds that out of the sixteen species Vtorov collected, three had changed generic names, two had changed species names, and one was absent from modern *Collembola* checklists. Five taxa were identified only up to genus, making it impossible to evaluate them in comparison with modern checklists. Only six species matched current moneclature of soil microarthropods. Not only were there taxonomic reclassifications, but also differences in the descriptions of species' ecological status indicating whether the species was endemic or adventive. None of the three species described as endemic in Vtorov's study were listed as such in current checklists. Additionally, Vtorov did not deposit voucher specimens, so morphological comparisons or re-identification of species named in his study are impossible. Inconsistencies due to changes in nomenclature and the species' ecological status or lack of physical documentation can, as shown here, be detrimental to researchers examining data from older studies.

Keywords:

Taxonomic revisions, Collembola, Microarthropods, Feral Pig, Sus scrofa.

Glossary

Dichotomous key: A tool used to classify organisms into respective taxa by following a series of choices; each choice presents alternative sets of descriptive morphological traits. The key eventually leads to the taxon name of the characterized organism.

Collembola: Minute, wingless insects that live in soil communities and primarily feed on detritus; common name is springtails.

Endemic species: A species with the ecological state of being unique to a particular geographic location, such as a specific island, habitat type, nation, or other defined zone.

Adventive species: These species have been introduced to a new habitat or environment that is outside of their native geographic range; they are neither native nor fully established in the new habitat or environment

Soil Microarthropods: A group denoting small invertebrates that are less than two mm in length; they are found in the phylum arthropoda; the most well known groups are the mites (*Acari*) and springtails (*Collembola*).

Cosmopolitan species: A plant or animal species that is found almost anywhere in the world.

Nearctic: Of, relating to, or denoting a zoogeographical region comprising North America as far south as northern Mexico, together with Greenland.

Holarctic: Of, relating to, or denoting a zoogeographical region comprising the Nearctic and Palearctic regions (Europe, parts of N. Africa and Asia) combined. The two continents have been linked intermittently by the Bering land bridge, and their fauna are closely related.

Voucher specimens: Any specimen that is retained as a reference for future morphological comparison. These should ideally be in a publicly accessible scientific reference collection. A type specimen is a particular voucher specimen that serves as a basis for the taxonomic description of a species through physical comparisons.

Biomass: The total mass of organisms in a given area or volume.

Introduction

Taxonomy is considered a science in its own respect, but it is also an essential tool for applied or experimental studies in many fields of biology, especially in microbiology and ecology. All biologists are involved in the identification of the particular organisms they are studying, but taxonomists produce or alter the classification of organisms as needed and provide tools by which fellow scientists can identify specimens. The number of described organisms has continually increased since the time of Linnaeus due to the discovery of new species. This growth requires methods for identification of organisms to be practical, easy, and flexible in order to efficiently adapt to changes in how organisms are classified. In addition, novel and efficient organization of data and infrastructure will have to be implemented in order for researchers to have the tools necessary to access this growing body of taxonomic data.

Brief Overview of Ivan P. Vtorov's Study

Vtorov's study was carried out in the Hawaii Volcanoes National Park (HAVO), Hawaii. The feral pig (*Sus scrofa*) is an invasive species that is problematic for Hawaiian ecosystems because it creates wallows and compacts the soil when foraging for food. The resulting higher soil density is known to negatively affect populations of endemic *Collembola*. The composition of Microarthropod communities can be used to indicate the quality of soil health (Straalen and Krivolutsky, 1996). Vtorov sampled and classified various soil microarthropod insects, but specifically focused on the presence of endemic *Collembolan* species as environmental indicators of forest succession following the removal of feral pigs. Results indicated that with ecological recovery of the sampling area, the total density of soil microarthropods nearly doubled, the biomass rose by 2.5 times and the number of species of *Collembola* doubled. The endemic population of *Collembola* increased with a restoration of populations within seven years while the number of adventive species of *Collembola* decreased: (Vtorov, 1993).

* Corresponding author. E-mail: katherine.huebner@mail.mcgill.ca

Taxonomic Comparisons Between 2008 and Vtorov's Collembola/Feral Pig Study 1993				
Family	**Vtorov's ID**	**Our ID**	**Vtorov's Status**	**Our Status**
Onychiuridae	*Tullbergia silvicola*	*Tullbergia silvicola*	Nearctic	Adventive
Onychiuridae	*Protaphorura cryptopya*	*Allaphorura cryptopyga (Arthropod sp. Checklist 4th ed. 2002)*	Nearctic	Adventive
Isotomidae	*Folsomina onychiurina*	*Folsomina onychiurina*	Cosmopolitan	Adventive
Isotomidae	*Cryptopigus caecus*	*Cryptopigus thermophilis?**	Pacific	Adventive
Isotomidae	*Isotomiella sp.*		Endemic	likely adventive
Entomobryidae	*Sinella caeca*	Sinella caeca	Cosmopolitan	Adventive
Entomobryidae	*Homidia sauteri*	*Entomobrya (subgenus homidia) sauteri*	Holarctic	Adventive
Entomobryidae	*Lepidocyrtus inornatus*	*Lepidocyrtus inornatus*	Endemic	Adventive
Entomobryidae	*Salina maculata*	*Salina celebensis*	Endemic	Adventive
Entomobryidae	*Harlomilsia occulata*	*Harlomilsia occulata*	Tropical	Adventive
Neelidae	*Neelides minutus*	*Neelides minutus*	Holarctic	Adventive
Hypogastruridae	*Xenylla sp.*			?
Hypogastruridae	*Neanura sp.*			?
Sminthuridae	*Sminthurides sp.*			?
Onychiuridae	*Mesaphorura sp.*	*Tullbergia (subgenus mesaphorura) sp.*		?
	Parisatoma dichaeta	*? Not in any of our keys*	Pacific	?

Table 1: Species lists and taxonomic comparisons from 2007 using current Hawaiian microarthropod references, Bellinger, Christiansen, 1992 & the Microarthropod Checklist 4th ed., 2002.[1]

Here, we examine the consequences of taxonomic revisions as they pertain to the interpretation of ecological data. We re-evaluate Vtorov's study by comparing his conclusions to those made interpreting his data with current taxonomic references.

Methods

In order to evaluate the effects taxonomic revisions have on present day research, we utilized a number of methods. Ideally, voucher specimens would have been obtained and compared to museum specimens and modern taxonomic checklists. Unfortunately, Vtorov did not leave any voucher specimens so morphological comparisons of species named by Vtorov were not possible. Since we were unable to employ this method, our analysis was restricted to using Vtorov's data and comparing this with modern checklists.

First, we compared Vtorov's listed specimen inventories to modern references. Then we further examined all discrepancies between them to determine if they were due to possible taxonomic reclassifications, changes in species ecological status, or misidentifications by Vtorov. We also calculated the total number of organisms of each *Collembola* species named in Vtorov's study, reanalyzed the data graphically, and compared the results of the recreated graphs to those of his original graphs. This was done in order to determine if there were differences in the ecological status or taxonomic classifications of organisms named in Vtorov's study and to see if these differences affected the interpretation of his results.

The most recent taxonomic references for Hawaiian *Collembola* species were used to evaluate the species lists and taxonomic classifications named in Vtorov's study. These included Bellinger and Christiansen's (1992) taxonomic dichotomous key and the Microarthropod Checklist 4th ed. (2002). Vtorov's references included Bellinger & Christiansen (1989), a reference which is no longer used in the field of taxonomy because it is outdated. Vtorov's original data from his Table 1 (not seen here) entitled "Numbers and biomass of microarthropods under ohi'a trees and tree ferns at fenced sites free of pigs for 0, 2-4, and 7 years" and Table 3 (not seen here) entitled, "Restoration of springtail poulations (in percent of numbers) under ohi'a trees and tree ferns at fenced sites free from pigs for 0, 2-4, and 7 years" were used to calculate the total number of each *Collembola* species examined in his study. These results were tabulated and graphs were reconstructed using Microsoft Excel.

In his data, Vtorov listed the number of individuals of each *Collembola* species per square meter, the percentage of each *Collembola* species in the total population and the average number of *Collembola* species per square meter. We used these values to graph Vtorov's original data and further analyse any reclassification and incompatibilities in the description of ecological species status in light of modern *Collembola* taxonomic references. Vtorov did not define which species he classified as cosmopolitan leading to some ambiguity in classification (Figure 1). To compensate for this, species from Vtorov's data were analyzed graphically in two groups of ecological species status. The classification of "Cosmopolitan" was either considered alone or it was considered to comprise all species listed as not endemic, i.e., all species listed as nearctic, cosmopolitan, pacific, holarctic, and tropical.

The discrepancies revealed by the reconstructed graphs showed how changes in taxonomic names for many of the *Collembola* species were significant enough to change Vtorov's original results. If we had access to a history of the revisions of the name of each *Collembola* species since 1993, it would have been possible to clarify the reasons for the differences between the recreated graphs and Vtorov's original graphs. Unfortunately, we did not have access to precise records of Hawaiian *Collembola* taxonomic historical literature because no databases or libraries contain clear, detailed, or accessible historic records of *Collembola* reclassifications to our knowledge. However, by analyzing graphs with various combinations of ecological species status, it was possible to determine if the discrepancies were a result of ambiguous groupings of ecological species status or because of recent taxonomic revisions. This comprehensive analysis and reconstruction of data allowed careful consideration of how taxonomic incompatibilities between Vtorov's data and present day checklists might affect research on *Collembola* using more modern resources.

Results

Many taxonomic differences were found between Vtorov's species lists and the current Hawaiian microarthropod references. Several of the sixteen *Collembola* species reported in 1993 have either disappeared from the checklist altogether, have had changes in their name or have seen changes in ecological status. The status of a species can be listed as endemic to Hawaii or adventive, having been introduced to Hawaii. *Lepidocyrtus inornatus, Salina maculata*, and *Isotomiella sp*. were described as endemic in Vtorov's species list while they are listed as adventive in the most recent literature. Here it should be noted that the standard procedure for naming specimens whose genus is known but the species identity cannot be determined is to name them "sp." following the genus name; for example, an unknown species of the genus *Salina* would be labelled *Salina sp.* Vtorov had a total of five specimens that were identified in this manner, making it difficult to analyze this data. *Isotomiella sp*. is likely an

1. According to Bellinger and Christiansen (1992), the family, Isotomidae, has only one species listed under the genera, Cryptopigus (Cryptopigus thermophilis). Thermophilis is the most common Collembola near vents in Hawaii Volcanoes National Park. It is found in litter soil and bird nests from sea level to 4000 ft.

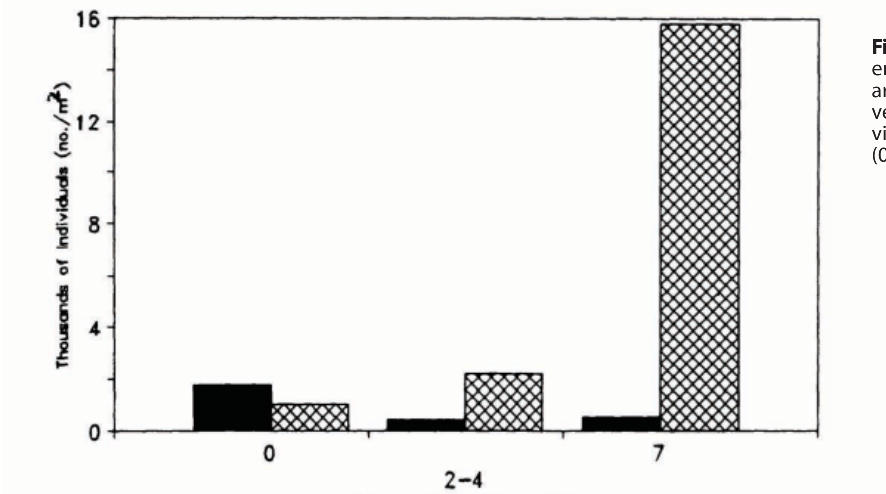

Figure 1: Changes in cosmopolitan and endemic Collembola species in fenced areas where feral pigs had been removed 7 years previously, 2-4 years previously, and where pigs are still present (0 years) (Vtorov, 1993).

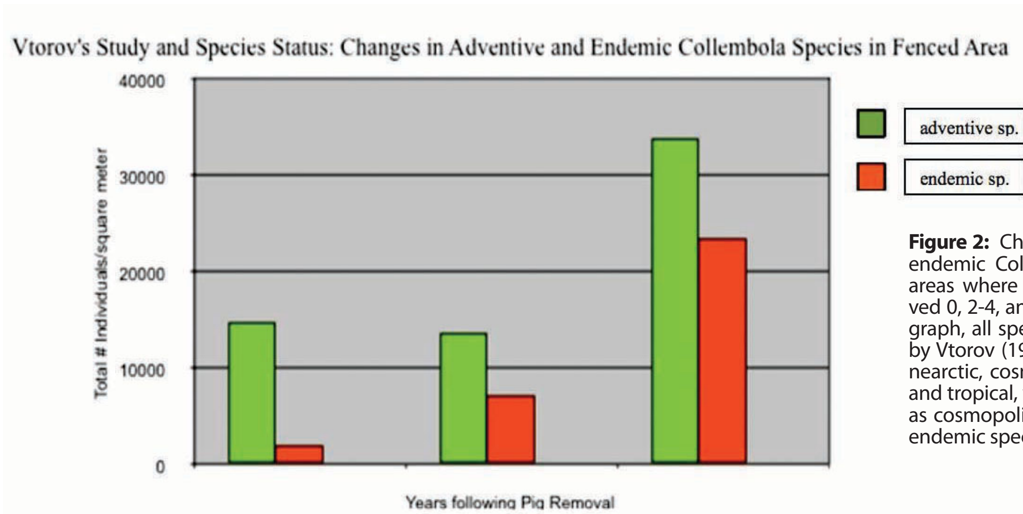

Figure 2: Changes in cosmopolitan and endemic Collembola species in fenced areas where feral pigs had been removed 0, 2-4, and 7 years previously. In this graph, all species listed as non-endemic by Vtorov (1993) i.e., all species listed as nearctic, cosmopolitan, pacific, holarctic and tropical, were combined, considered as cosmopolitan and were compared to endemic species.

adventive species because all species in this genus are listed as adventive according to Microarthropod Checklist 4th ed. (2002), although there is no way of being certain. There were additional changes in nomeclature and incompatibilities between Vtorov's taxonomic assignments and the presently accepted names of the organisms studied by Vtorov. Using a dichotomous key to identify the possible modern species names that were closest to Vtorov's names, *Protaphorura cryptopyga* was most likely identified as *Allaphorura cryptopyga* by Vtorov (Arthropod sp. Checklist 4th ed., 2002), *Cryptopigus caecus* was most likely identified as *Cryptopigus thermophilis, Homidia sauteri* was most likely identified as *Entomobrya* (subgenus *homidia*) *sauteri*, *Salina maculata* was most likely identified as *Salina celebensis, Mesaphorura sp*. was most likely identified as *Tullbergia* (subgenus *mesaphorura) sp*. and *Parisotoma dichaeta* was not present in the modern literature (Table 1). There was no way of knowing if these discrepancies were a result of reclassification or misidentifications by Vtorov as no voucher specimens were retained for comparison.

For faster and more accurate identification, Vtorov (1993) used a tiered approach to the taxonomic resolution of the species he named in his study. He identified his specimens of interest (*Collembola)* to the level of species while identifying less relevant specimens to a broader taxonomic grouping such as family or order. For example, he identified mite superfamilies (*Oribatida, Acaridida, Gamasida, and Prostimata*) and grouped several of the microarthropod specimens into even less specific classifications such as nematodes, enchytraenia worms, earthworms, butterfly larvae, molluscs, and protura, with *Collembola* being the only group classified to the level of genus and species.

Out of the sixteen *Collembola* species collected by Vtorov, six matched modern nomenclature according to the current Microarthropod Checklist 4th ed., (2002). Three species had changed genus names, two had changed species name, and one was absent from the Microarthropod Checklist 4th ed. (2002) altogether (Table 1).

In Figure 1, Vtorov examined changes in the number of cosmopolitan and endemic *Collembola* species in fenced areas, where feral pigs had been removed 7, 2-4 and 0 years prior to sampling. His results showed an overall decrease in cosmopolitan species and an overall increase in endemic species over time after the removal of feral pigs. In Figure 2, all species that were not endemic were considered to be cosmopolitan, i.e., all those species listed as nearctic, cosmopolitan, pacific, holarctic and tropical. Both adventive and endemic species populations increased with time after removal of feral pigs. Although this was similar to the original findings (Figure 1), we found a higher number of adventive species than Vtorov originally found. When we graphed the two species that Vtorov listed as cosmopolitan in comparison to endemic species, we observed an overall increase in both cosmopolitan species and endemic species (Figure 3), which was in accordance with his original findings (Figure 1). In order to clarify the trend seen in Figure 3, we created another graph with a scale of higher resolution showing only

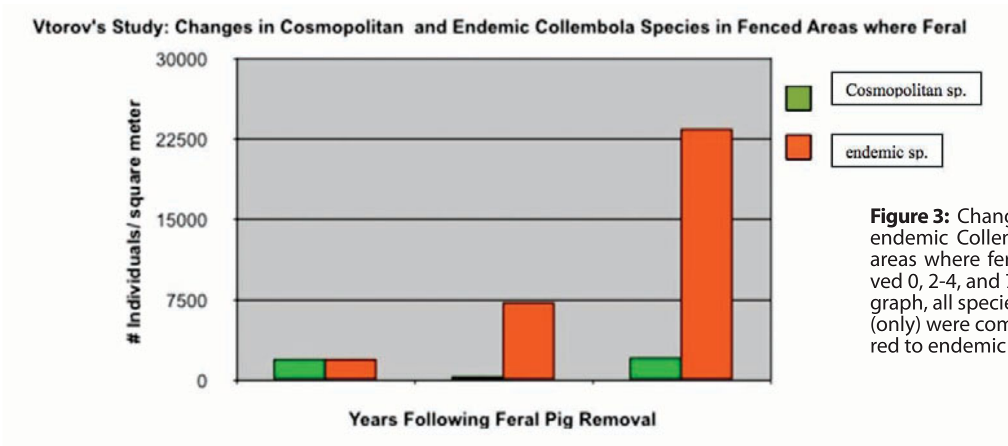

Figure 3: Changes in Cosmopolitan and endemic Collembola species in fenced areas where feral pigs had been removed 0, 2-4, and 7 years previously. In this graph, all species listed as cosmopolitan (only) were combined and were compared to endemic species.

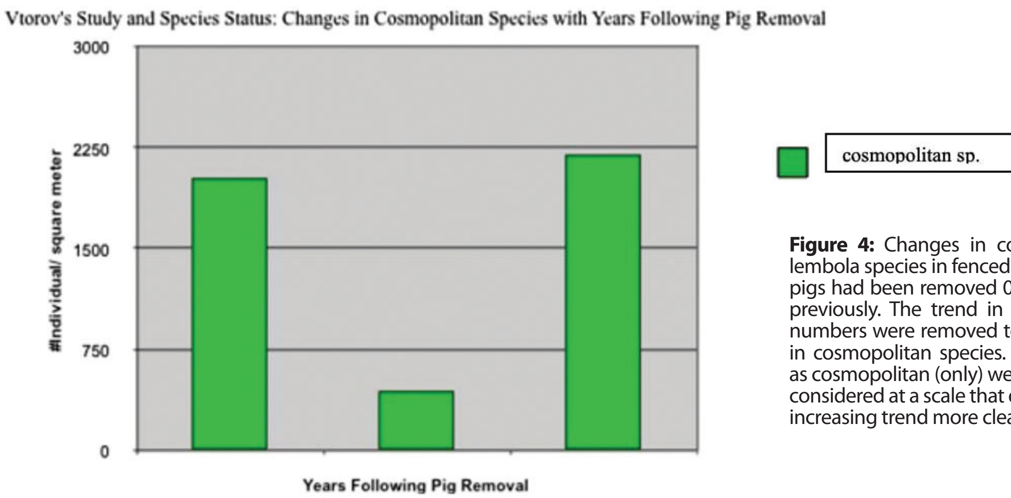

Figure 4: Changes in cosmopolitan Collembola species in fenced areas where feral pigs had been removed 0, 2-4, and 7 years previously. The trend in endemic species numbers were removed to show the trend in cosmopolitan species. All species listed as cosmopolitan (only) were combined and considered at a scale that demonstrates the increasing trend more clearly.

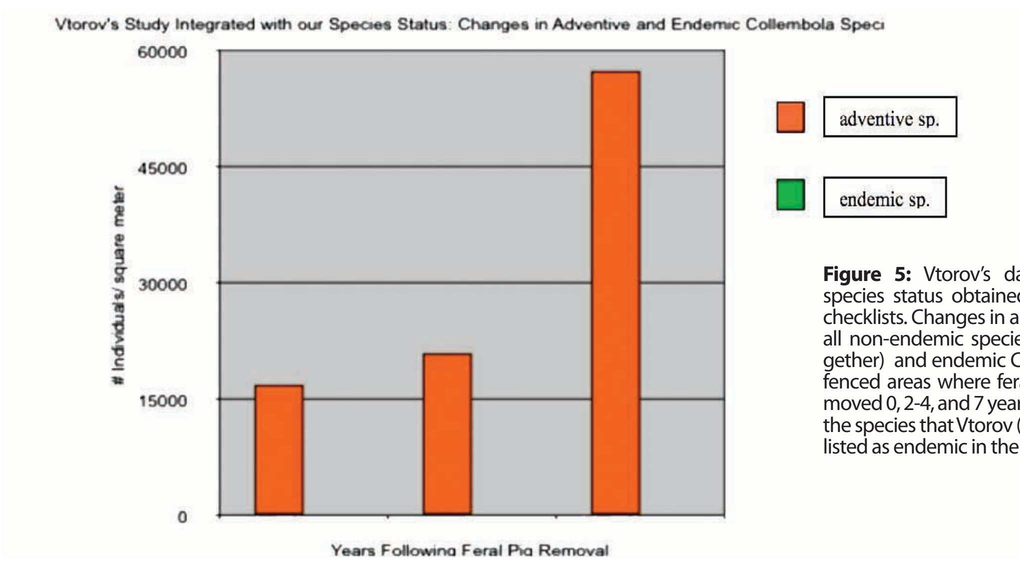

Figure 5: Vtorov's data integrated with species status obtained from modern day checklists. Changes in adventive (in this case all non-endemic species were grouped together) and endemic Collembola species in fenced areas where feral pigs had been removed 0, 2-4, and 7 years previously. None of the species that Vtorov (1993) recorded were listed as endemic in the current checklists

the effects on the cosmopolitan species. Here, it was clear that the number of cosmopolitan species increased overall with time after removal of feral pigs; data taken 0 years and 7 years after removal of feral pigs showed almost identical numbers of cosmopolitan species; there was a sharp decline in the 2-4 years after removal of feral pigs followed by another sharp increase from 2-4 years to 7 years (Figure 4).

A comparison of Vtorov's species lists with modern checklists showed no species listed as endemic in modern checklists, and the species that he listed as adventive showed a gradual increase in population over time after removal of pigs from the area (Figure 5).

Discussion

The discrepancies found in this case study include differences in *Collembola* taxonomic classification, ecological species status and the conflicting results between Vtorov's data and the revised graphs, all of which can be explained by a number of factors. Changes in taxonomic nomenclature and ecological status designations of the *Collembola* species since 1993 had the largest effect on the discrepancies found. In addition, Vtorov did not clearly specify which species were placed in the cosmopolitan group, which complicated the interpretation of his data. The degree to which Vtorov's graphs differ from the graphs recreated in this study can be explained by the modern techniques of graphing employed. For example, there could have been different scaling or rounding off to the nearest decimal point of numbers in the Microsoft Excel program, or perhaps errors introduced by manual drafting of figures in the original study compared to more accurate computerized drafting.

The largest discrepancies are primarily due to the adoption of new taxonomic nomenclature and reclassifications since 1993. This finding emphasizes the point that undocumented or inaccessible knowledge of revisions in taxonomic names accumulate over time, making interpretation of the original data a challenge for modern research.

Though we particularly focused upon changes in taxonomy of *Collembola,* the changes in ecological status of species are also apparent in Vtorov's study, as all the species Vtorov listed as endemic are considered adventive in modern checklists (Table 1). The status of a species as adventive or endemic is of particular interest to scientists in this area of the world as an island of Hawaii's size, isolation and fragile ecosystem renders it highly susceptible to ecological invasion by alien plants and animals (Canfield and Loope, 2000).

These findings also underline the importance of permanent physical documentation of specimens in taxonomic research. Voucher specimens are collections of organisms that are kept as confirmation of the identification of species; unfortunately, there are no supplementary data or voucher specimens available from Vtorov's study to enable further investigation of the discussed taxonomic discrepancies. There is no way of telling, for example, if *Cryptopigus caecus* (Vtorov, 1993) is similar or even identical to the reclassified *Cryptopigus thermophilus* (Nishida, 2002). As primary repositories for voucher specimens, museums are associated with many kinds of biological research and play an important role in documenting biological diversity through voucher specimen databases and catalogues (Wheeler, 2004). If Vtorov had retained voucher specimens, these could have been compared to museum specimens in conjunction with modern checklists to determine their correct classification. While descriptions, drawings and photographs can supplement identifications, the actual preserved specimens are essential to compare the original species with those identified using more modern techniques.

Here, we highlight one situation in which discrepancies between original identification and modern nomenclature may have been created by taxonomic revisions introduced since the original research. Difficulties, in differentiating between technical errors and actual revisions as the cause of these discrepancies, are compounded by the lack of voucher specimens to properly compare species originally identified by Vtorov. Our findings underscore the need for centralization of taxonomic revisions and nomenclature as well as the need for the retention of preserved voucher specimens for future comparison.

Fortunately, there are current and ongoing endeavours to reduce any discrepancies caused by taxonomic revision. The centralization of taxonomic information, including current and past knowledge of revisions in taxonomic names, will make the interpretation of original data less of a challenge for modern research.

Rapid and efficient access to large amounts of taxonomic data, including past and present name revisions, is now possible through online resources and databases. Not all taxonomic groups are available through extensive and complete online databases yet, but ongoing endeavours and collaboration by museums and specialized researchers are working towards improving existing databases and the creation of new ones. Such databases will hopefully enable researchers to easily and accurately refer to scientific literature containing recently revised taxonomy.

Acknowledgements

We are grateful to Hawaii Volcanoes National Park, and to D. Foote and M. Montgomery for their guidance at the USGS Pacific Island Ecosystems Research Center, Kilauea Field Station. We are also grateful to G. Fussmann of McGill University for his comments on the manuscript.

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