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Rapid taxonomic revisions using Internet-integrated relational databases: an example using *Erythroneura* (*sensu lato*)

Dmitry A. DMITRIEV, Christopher H. DIETRICH
Illinois Natural History Survey, Champaign, Illinois, USA

Abstract

Taxonomic revisions of highly speciose groups are challenging because they require efficient management and synthesis of large amounts of nomenclatural, morphological, and distributional data. When undertaken using traditional methodologies, such projects often require many years to yield publishable results. Technological advances, including relational databases, digital imaging, and Internet dissemination, provide the means to overcome some of the logistical problems inherent to large revisions, and provide systematists with tools to increase both the quality and quantity of such studies. The paper describes the 3I software package, which is freely available from the following web site: http://ctap.inhs.uiuc.edu/dmitriev/ and intended to facilitate the efficient production of Internet-based virtual taxonomic revisions and published monographs. The package facilitates storage, retrieval and integration of taxonomic nomenclature, specimen-level data on distributions and ecological associations, morphological character data and associated illustrations, and bibliographic information. These data are stored in a customized MS Access database. Web interfaces for specialized querying of the database were developed using ASP (Active Server Pages).

Key words: 3I, interactive key, taxonomy, systematics, revision, software.

Introduction

Taxonomic revisions of highly speciose groups such as the cicadellid genus *Erythroneura* (s.l.) are challenging because they require efficient management and synthesis of large amounts of nomenclatural, morphological, and distributional data. When undertaken using traditional methodologies, such projects often require many years to yield publishable results. Technological advances, including relational databases, digital imaging, and Internet dissemination, provide the means to overcome some of the logistical problems inherent to large revisions, and provide systematists with tools to increase both the quality and quantity of such studies. We applied such tools to our revisionary study of the genus *Erythroneura*.

The genus *Erythroneura* was described by Fitch (1851) based on four species. Later, Oshanin (1912) designated *E. tricincta* Fitch as the type species. The genus was first revised by McAtee (1920), who described many additional species and varieties mainly based on their color pattern and proposed six species groups based on their wing venation. In a series of publications, Beamer (1930-1946) revised *Erythroneura* comprehensively, treating each of four species groups (Beamer, 1938) in turn (Beamer, 1930 - *obliqua* group; Beamer, 1931/1932 - *maculata* group; Beamer, 1938 - *comes* group; Beamer, 1946 - *vulnerata* group). Young (1952) established subgenera for each of Beamer's species groups: *Erythridula*, *Eratoneura*, *Erythroneura*, and *Erasmoneura* respectively, and included these in a new tribe, Erythroneurini, along with two other genera: *Zygina* Fieber and *Hymetta* McAtee. By the end of the twentieth century *Erythroneura* became the most speciose genus of Auchenorrhyncha and comprised more than 700 species. Dietrich and Dmitriev (2006), in a review of the New World genera, elevated Young's subgenera to the genus level and transferred three species of *Erasmoneura* into the new genus *Rossmoneura*. An Internet-integrated relational database is now being used to revise comprehensively the New World species of Erythroneurini.

Materials and methods

3I (Internet-accessible Interactive Identification), developed as part of our revisionary study (Dmitriev, 2006), is a set of software tools intended to facilitate the efficient production of Internet-based virtual taxonomic revisions and published monographs. The package facilitates storage, retrieval and integration of taxonomic nomenclature, specimen-level data on distributions and ecological associations, morphological character data and associated illustrations, and bibliographic information. These data are stored in a customized MS Access database. Web interfaces for specialized querying of the database were developed using ASP (Active Server Pages) programming technology. These interfaces include simple and advanced searches on any field in the database, interactive keys designed to include attributes similar to those of Delta IntKey and Lucid (two popular programs for development of interactive keys), and complete taxon treatments including synonymies, descriptions, images, lists of material examined, distribution maps, tables of host plants, and literature citations. The main features of 3I keys are the following: 1, 3I keys are multi-entrance polytomous keys, with unlimited number of characters, character states, and taxa; 2, after each step of identification the characters not relevant for further identification are removed from the list, not relevant states are marked; 3, 3I keys support numeric characters; 4, the characters in the key can be sorted by morphology, by rank (assigned by the author), or by separating power recalculated after each step of identification; 5, characters can have hyperlinks to explanatory images; 6, a key can handle taxa of different hierarchical levels, and the software can also generate

keys for higher hierarchical level taxa, based on a data matrix scored for taxa of lower hierarchical level; 7, uncertainties and user-specified error tolerance are allowed during identification; 8, phenetic trees are generated from the morphological data, or the data matrices can be exported in a format suitable for phylogenetic analysis; 9, 3I has a utility to convert interactive keys into conventional ones. For more detailed information about 3I software visit the web site http://ctap.inhs.uiuc.edu/dmitriev/.

To facilitate a revisionary synthesis of *Erythroneura* (s.l.), a 3I relational taxonomic database (Dmitriev and Dietrich, 2003 onwards) was developed. Label data for authoritatively identified specimens were georeferenced using online gazetteers and entered into the database. Morphological data for 90 characters were scored and entered into the database for all valid species and digital images (photos and line drawings) were linked to the appropriate character and taxon records in the database. Thus, the final database includes all the information normally compiled to produce a species-level revisionary study.

Results and discussion

The Erythroneurini database currently includes a total of 3387 available names (2111 valid) and 29308 individual records representing 108841 authoritatively identified specimens. These records are accessible online via web interfaces developed using 3I (http://ctap.inhs.uiuc.edu/dmitriev/). Once the remaining data are entered, the revision will be essentially finished because 3I's web interfaces organize the data into a near publication-ready format. A generic revision and the first of four monographs treating the species have been published (Dietrich and Dmitriev, 2006; Dmitriev and Dietrich, 2007).

A previous phylogenetic study of Erythroneurini (Dietrich and Dmitriev, 2006) provided evidence that the New World erythroneurine fauna arose through at least two independent invasions from the Old World and supported the recognition of 18 genera, including 3 taxa formerly treated as subgenera of *Erythroneura*. *Erythroneura* (*sensu stricto*) and related taxa previously included in this genus (*Eratoneura*, *Erasmoneura*, *Rossmoneura*, and *Erythridula*) are restricted in their distribution to temperate North America. Only two species appear to have been introduced to other continents (*Erythroneura elegantula* Osborn to Panama and *Erasmoneura vulnerata* Fitch to Italy). All species described and/or still placed in *Erythroneura* from the Old World should be treated as *incertae sedis* until they can be transferred into other genera.

Conclusion

The 3I software package has facilitated production of a nearly complete, virtual on-line revision of a group of leafhoppers comprising nearly 700 species in 4 years. This demonstrates the power of such tools for improving the efficiency of systematic revisionary studies. Such tools have become crucial to addressing the taxonomic impediment to biological research on hyperdiverse groups of organisms like Auchenorrhyncha and other insects, because the number of practicing systematists remains small and is unlikely to increase significantly in the near future. 3I enables systematists not only to increase their productivity, but to synthesize vast quantities of data that would be very difficult to manage using traditional methods.

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Corresponding author: Dmitry A. DMITRIEV (e-mail: dmitriev@inhs.uiuc.edu), Illinois Natural History Survey, 1816 S. Oak St., Champaign, IL 61820, USA.