Comparing the Ephemeroptera and Plecoptera Specimen Databases at the Illinois Natural History Survey and Using Them to Document Changes in the Illinois Fauna

C. FAVRET[1] AND R. E. DEWALT

Illinois Natural History Survey, Center for Biodiversity, 607 E. Peabody Drive, Champaign, IL 61820–6970

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ABSTRACT Databasing of all Ephemeroptera and Plecoptera specimens in the Illinois Natural History Survey Insect Collection has recently been completed. Both databases are Internet-searchable in a simplified format (http://www.inhs.uiuc.edu/cbd/EPT/index.html). Analysis of the databases shows that the Plecoptera are at a much better level of determination than the Ephemeroptera, with 88% of the specimens determined to the species level. Only 22% of Ephemeroptera specimens have been determined to species. The Ephemeroptera collection is also much more narrow in geographic scope, with 74% of determined specimens from Illinois. In contrast, only 30% of determined Plecoptera specimens are from Illinois, with most of the remainder being from across the United States. Four new Illinois records were uncovered in the Ephemeroptera database: *Caenis diminuta* Walker, *C. punctata* McDunnough, *Pseudocloeon ephippiatum* (Traver), and *Serratella deficiens* (Morgan). Analyses of the data document range reductions in Illinois of the stonefly *Neoperla clymene* (Newman) and the mayfly *Pseudiron centralis* McDunnough, range expansion in the stonefly *Perlesta nelsoni* Stark, and a shift in the prevalence of perlid stonefly species assemblages from *Acroneuria* in the first half of the 20th century to *Perlesta* in the second half. We also discuss the change in Plecoptera diversity between historic and modern records from Illinois, and compare the relative stability of Plecoptera species assemblages from the major ecological regions of the state. We encourage entomologists to find other uses for these data and to contribute a growing pool of historic specimen-level data at their own institutions.

KEY WORDS Ephemeroptera, Plecoptera, databases, natural history, insect collection

"IF MAINTAINED PROPERLY, specimens in every (natural history) collection provide a permanent record of life on Earth" (Mehrhoff 1997). Every single specimen is a record of a particular species located in a particular place and time. Natural history collections are thus not only useful for such typical purposes as systematics research, identification, and teaching, but also to ascertain the geographic and/or temporal range of a taxon. By examining changes in geographic range over time, we can study the effects of environmental degradation, rehabilitation, or the invasion of exotic species. Morrison (2001) discussed museum data as a source of information for ecological restorationists.

Historically, the information associated with natural history collections has remained hidden behind museum doors, and even once there, data extraction proves extremely time-consuming. For instance, developing a list of all species collected from a particular locality meant a close examination of labels on almost every specimen in that collection. The use of information technology has allowed for easy access, extraction, and manipulation of the information associated with collection specimens. What once took several days, and thus usually not done at all, can now be done with a few clicks of a computer mouse. Of course the initial task of actually digitizing all that information is time-consuming and labor-intensive.

A long-term goal of the Illinois Natural History Survey (INHS) is to have the information associated with every specimen in its biological collections fully databased and available to all. The insect collection, with an estimated 7 million specimens, is the largest hurdle. The Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies) were chosen to be the first insect taxa to be databased because they contain important stream health indicators (Hilsenhoff 1987, Lenat 1993) and represent some of the INHS's particular taxonomic and historic strengths: all three of these aquatic orders have been the subject of major Illinois-based treatments (Burks 1953; Frison 1929,1935, 1942; Ross 1944, respectively). The Ephemeroptera and Plecoptera databases have been completed and are now available in a simplified, searchable format on the Internet (http://www.inhs.uiuc.edu/cbd/EPT/index.html).

[1] E-mail: c-favret@life.uiuc.edu.

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As an introduction to some uses of collection-based databases, we present here comparisons of the level of curation of these orders and findings of several analyses addressing whether changes have occurred in the Illinois Ephemeroptera and Plecoptera species assemblages over the past century.

Materials and Methods

Data entry officially began in the summer of 1999, although most of the Plecoptera information had been entered beforehand. It was conducted by hourly workers using a FileMaker Pro (FileMaker 2000) database on six Apple Macintosh computers. For ease of use, the data entry format of the databases was kept as a simple flat file. Database fields included those for a literal rendering of the specimen labels, as well as more specific fields to parse out label information. When data entry was completed, every record was back-checked by more knowledgeable workers (including the authors) to the original specimens to correct errors of a typographic or interpretive nature. Geographic and taxonomic fields were updated and standardized.

The taxonomy of nearctic Ephemeroptera followed W. P. McCafferty's website (http://www.entm.purdue.edu/entomology/research/mayfly/species.html) and nearctic Plecoptera, followed B. P. Stark's website (http://www.mc.edu/campus/users/stark/stonefly-.html). Non-nearctic taxonomy was checked using various Internet and paper-printed sources. Once data had been entered and standardized, the databases were streamlined by making related taxonomic and locality files. The specimen databases were also related to the collection loan file for easy tracking of loaned material.

To determine whether species assemblages have changed over time, each method of analysis, although dealing exclusively with the Ephemeroptera and Plecoptera of Illinois, employed a range of geographic and taxonomic levels. Data extraction was by simple searches of various fields in the databases and, where appropriate, exportation to spreadsheet software for analysis. Records were assigned to various time-spans, be they 20th century decade or spans based on historical and modern dates. GIS software was used to plot the distributions of collections of various species. We used Sørensen's (1948) index of beta-diversity as a means to compare which Illinois ecological regions, as defined by Iverson and Schwartz (1994), have remained relatively stable and which have seen the greatest change with regard to their species assemblages.

Results and Discussion

There are 123,442 and 100,480 specimens of Ephemeroptera and Plecoptera, respectively, in the INHS insect collection. The information in the databases is based mostly on specimen lots, or records, in ethanol vials and jars, but a few specimens are in envelopes or on insect pins. Currently, the Ephemeroptera collection consists of 16,649 records and the Plecoptera contribute 19,182.

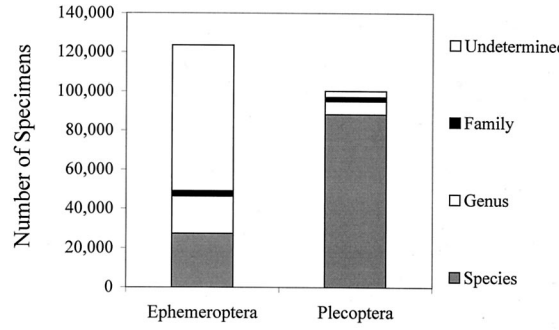

Fig. 1. Level of determination for Ephemeroptera and Plecoptera at the INHS. Determination levels in the bars are in the same sequence as in the legend.

Determined specimens were separated into different vials, so no single vial contains more than one determined species. In contrast, vials of undetermined material often contain many species. The Plecoptera are in a much better state of taxonomic determination. In fact, only 22% of the Ephemeroptera in the collection have been determined to the species level, in contrast with 88% for the Plecoptera (Fig. 1).

Age of Collections, Contributors, and Rates of Determination. The age of material in a natural history collection is one of its most important attributes because the older the material, the better it reflects species presence before human-induced ecological degradation. The oldest confirmed date in the collection is 1860 for *Allocapnia roberti* Surdick, collected by Illinois's first state entomologist, B. D. Walsh, in Rock Island, IL. Subsequent collecting efforts support the contention that this species is now extinct. The oldest mayfly record is of an 1879 collection of *Anthopotamus verticis* (Say) from Bloomington, IL (collector unknown).

The accession of Ephemeroptera and Plecoptera into the collection over the past century has not been steady. The 1930s saw a peak of collecting activity for both orders, followed by secondary peaks in the 1960s and 1970s for the Plecoptera and Ephemeroptera, respectively (Fig. 2). Collecting of both orders during the 1930s was performed largely by INHS scientists T. H. Frison and H. H. Ross, with B. D. Burks contributing Ephemeroptera and C. O. Mohr contributing Plecoptera. The peaks of collecting activity during the 1960s and 1970s were the result of efforts by around a dozen people, with J. D. Unzicker (INHS, at the time) contributing about half of the 60,000 Ephemeroptera specimens.

Curatorial status is not necessarily correlated with the level of collecting activity, however, and whereas the INHS has a relatively large amount of determined Plecoptera from across the 20th century, very few Ephemeroptera collected after 1950 have been determined to species (Fig. 3). The number of determined specimens increased in the 1990s because of the aquatic component of the Critical Trends Assessment

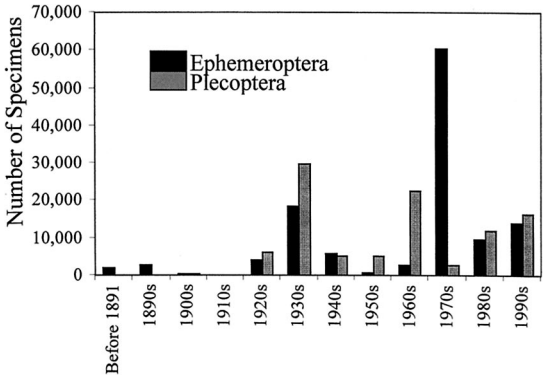

Fig. 2. Number of specimens, by decade, accessioned in the INHS Ephemeroptera and Plecoptera collections.

Program (a state-wide land use and ecosystem health monitoring program) that sampled Ephemeroptera, Plecoptera, and Trichoptera, and because of an Illinois River basin survey conducted by DeWalt et al. (1999).

Of course, the amount of determined material directly affects the number of species in the collection, and only 10 new species were added to the Ephemeroptera collection between 1941 and 1980, in contrast with 67 Plecoptera species during that time (Fig. 3). Currently, there are 270 Ephemeroptera and 496 Plecoptera species and subspecies in the INHS insect collection.

Geographic Distribution. These two collections are ≈80% North American in origin, but Illinois is the most well-represented and fully covered state. Whereas the Plecoptera collection includes 70% of its determined material from outside Illinois, the Ephemeroptera collection is more provincial in geographic scope with Illinois material constituting 74% of determined specimens (Fig. 4). Other geographic locations that are well represented in the Plecoptera collection are the Midwest in general, the Southwest, and the Southeast. The latter contributes 12.6% of all records, and >25% of these are from the biologically diverse Great Smoky Mountains National Park. Most of these 600 records

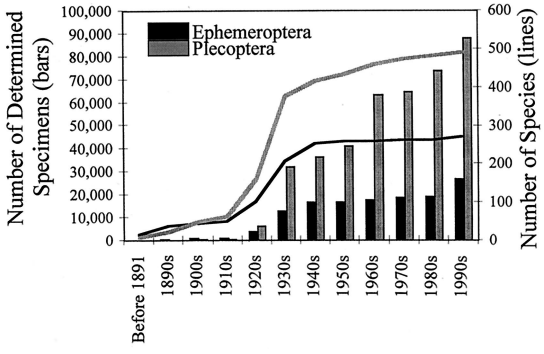

Fig. 3. Cumulative number of determined specimens (bars, left axis) and species (lines, right axis) of Ephemeroptera and Plecoptera across decades at the INHS

were collected in the 1930s and 1940s, shortly after the park's dedication.

The INHS has a large amount of determined Illinois Ephemeroptera and Plecoptera from the 1920s and 1930s, and especially from the 1990s. Despite the fact that many more Illinois specimens were collected in the 1990s (7,814 Ephemeroptera and 13,746 Plecoptera) than in the 1930s (4,304 Ephemeroptera and 3,619 Plecoptera), the 1930s collections were the more speciose: in the 1930s, there were 70 Ephemeroptera species and 56 Plecoptera species collected, whereas in the 1990s, there were 59 and 50, respectively (Fig. 5). This apparent temporal change in species richness supports the contention that species assemblages in Illinois have changed over the past century.

Illinois Species. There are now a total of 105 and 75 Illinois species and subspecies of Ephemeroptera and Plecoptera, respectively, in the INHS collection. Randolph and McCafferty (1998) produced the most recent checklist of Illinois Ephemeroptera. Not listed by them, Burks (1953) or DeWalt et al. (1999), are four Illinois species present in the INHS collection (Table 1).

Recorded from Illinois by Randolph and McCafferty (1998) but not present at the INHS are nine species: *Barbaetis cestus* (Provonsha & McCafferty), *Caenis youngi* Roemhild, *Camelobaetidius waltzi* McCafferty, *Ephemerella argo* Burks, *E. excrucians* Walsh, *Leptophlebia cupida* (Say), *L. nebulosa* (Walker), *Plauditus armillatus* (McCafferty & Waltz), and *Siphlonurus quebecensis* (Provancher). It is likely that most or all of these species are present in the large amount of undetermined material in the collection.

Likewise, Harris and Webb (1995) updated the nomenclature of Frison (1929 1935, 1942) treatments of Plecoptera. To Frison (1935) and the lists of Harris and Webb (1995), DeWalt et al. (1998, 2001, 2002) have added 14 more species. No new state Plecoptera records were uncovered by this databasing project. The only state Plecoptera record not present at the INHS is *Amphinemura nigritta* (Provancher) (Harris and Webb 1995), but which might still be found among Nemouridae collections as INHS researchers continue to update the stonefly fauna of the state.

Along with the new state records listed above are many new county records. A list of species by county is beyond the scope of the current article; however, interested parties may search the databases or contact the authors.

Range Reductions and Expansions. A rich Perlidae (Plecoptera) fauna occurred throughout Illinois and the Midwest region early in the 20th century (Frison 1935). The INHS database contains 1,268 Illinois records (vials and pinned specimens) in the genera *Acroneuria*, *Neoperla*, and *Perlesta* dating back to 1880 as documentation of their occurrence. During the 20th century, four of the seven *Neoperla* species known from Illinois were extirpated, whereas two of the remaining three, *N. clymene* (Newman) in particular, exhibited severe range reductions (DeWalt et al. 2002). *Perlesta*, however, maintained all seven of its historical species and added a recent immigrant, *P.*

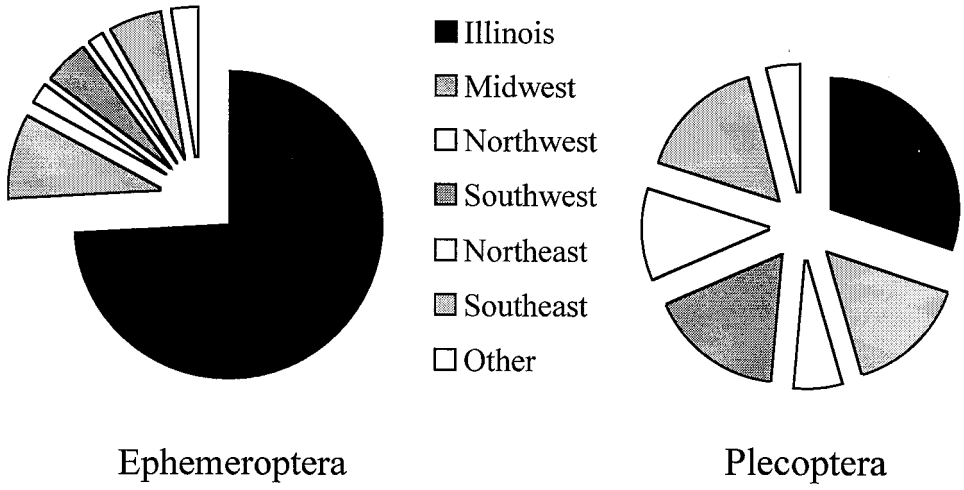

Fig. 4. Relative geographic scope of determined specimens of Ephemeroptera and Plecoptera at the INHS. Geographic regions in the pie chart appear clockwise in the same order as they are in the legend.

nelsoni Stark, in the far south of the state (DeWalt et al. 2001).

Acroneuria specimens have not been reevaluated; therefore, species level analysis is not possible at this time. However, collections data can give insight into changes occurring in a large proportion of the Illinois perlid fauna at the generic level. In the decades of the 1920s and 1930s, when most collection activity for perlids occurred, *Acroneuria* was the most frequently collected perlid genus, and *Perlesta* contributed <20% of all collections (Fig. 6). *Neoperla* species evidently were always a consistently small proportion of the perlid fauna collected in Illinois. The prevalence of *Acroneuria* and *Perlesta* changed dramatically in the last decades of the century: a Spearman rank correlation demonstrated a significant inverse relationship between *Acroneuria* and *Perlesta* percentage records ($R = -0.94$, $P = 0.001$).

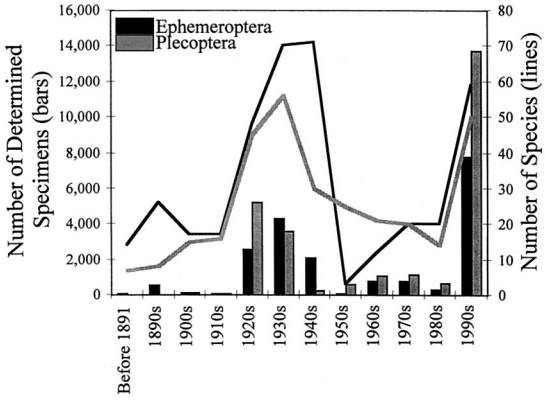

Fig. 5. Historical profile, by decade, of the accession of determined Illinois specimens (bars, left axis) and species (lines, right axis) of Ephemeroptera and Plecoptera at the INHS.

This documents a major change in perlid faunal composition, and is probably caused by changes in the Illinois landscape including channelization of streams, removal of natural riparian vegetation, and nutrient enrichment of waters from organic and inorganic sources. It is unknown why *Perlesta* species have fared better than other perlids, but it may be related to lengthy egg diapause and a short (6 mo) nymphal phase (as reported for *P. decipiens* Walsh in Snellen and Stewart 1979). This presumably allows *Perlesta* to be more competitive in degraded Illinois streams. The few *Acroneuria* species investigated lacked egg diapause and required 11 to 23 mo for nymphal growth (Stewart and Stark 1988), putting them at a distinct disadvantage in Illinois streams.

Because the Ephemeroptera are in such a poor state of determination, we have not yet performed similar analyses with them. We have noted certain trends, however, such as the absence of any recently collected *Pseudiron centralis* McDunnough. This species was collected in five counties up to 1949, one more in 1961, but has not been collected and deposited at the INHS since then. We surmise that the apparent decline of this species is because of the destruction, by siltation, of the naiad's preferred habitat, sandy river bottoms (Soluk and Clifford 1984). In fact, a total of 41 Ephemeroptera species that are in the collection have not been collected, determined, and deposited at the INHS since 1970. Whether these species are missing because they are truly absent in the wild will only be known when the great volume of Ephemeroptera is properly determined.

Plecoptera Diversity Across the 20th Century. Because the INHS Plecoptera are more fully determined, we can be more confident in assessing loss of species. Forty-three percent of U.S. Plecoptera species are extinct or at risk (Masters et al. 2000), and of the Illinois fauna alone, 24 of 75 (32%) species have not been collected, determined, and deposited at the

Table 1. Illinois Ephemeroptera records in the INHS collection not listed by Randolph and McCafferty (1998), Burks (1953), or DeWalt et al. (1999)

Species	No. of records	Years collected	Range in Illinois
Caenis diminuta Walker	11	1997–98	Wide
Caenis punctata McDunnough	14	1997–99	Wide
Pseudocloeon ephippiatum (Traver)	9	1997–98	Central to Northern
Serratella deficiens (Morgan)	1	1985	Northeast (Lake County)

INHS since 1970. This figure is considerably higher than nine of 214 butterfly species missing from the state of Oregon since 1970 (Fagan and Kareiva 1997).

A comparison of the historical changes in Plecoptera species complements of five ecological regions of Illinois (Iverson and Schwartz 1994) shows that the southern unglaciated region (the southernmost seven counties) has remained the most stable, with the northern region (12 northern counties) a distant second; Sørensen's (1948) beta-diversity between pre- and post-1970 collections is 0.763 and 0.625 for the southern and northern regions, respectively. These regions have been less-heavily impacted by the intensive agriculture common to the central parts of the state. Their streams would therefore be expected to have fewer of the plecopteran diversity challenges caused by siltation, channelization, and pesticide runoff. In contrast, the three large and agriculture-intense central regions of the state have seen the greatest change in collected Plecoptera species, with indices of 0.551, 0.458, and 0.523 for the Grand Prairie, western, and south Central regions, respectively.

General Remarks. The data, stored on specimen labels and recently made available in searchable databases, leave little doubt that Illinois has seen significant changes in its diversity of Ephemeroptera and Plecoptera. These data have allowed the exploration of changes in the distribution of several species, documented a shift in prevalence of species assemblages of Plecoptera, and shown a dramatic change in species diversity between historical and modern collections.

However, because of the ad hoc nature of most collecting, the number of specimens of various species in collections is not correlated with their abundance in nature, and so it is more appropriate to assess changes in the distribution of a species than to try to measure changes in population density. Furthermore, there are considerable trade-offs among sample size, the collecting effort expended, the scope (taxonomic and geographic) of the collecting, and even the amount of material that can be housed in collection facilities. As a consequence, collection data are typically most informative on broader geographic scales and with species assemblages, rather than point localities and individual species (Shaffer et al. 1998).

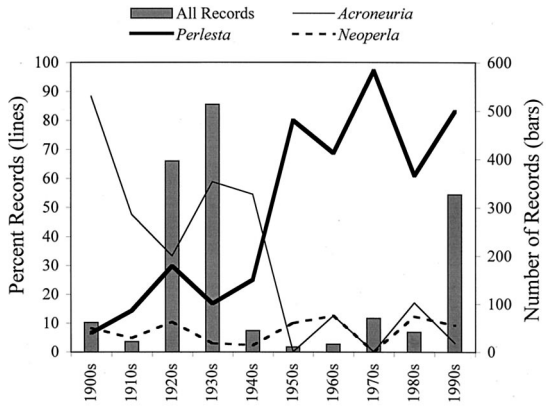

Fig. 6. Illinois collection rates for three perlid genera (lines, left axis) and number of collections (bars, right axis) taken in Illinois across 20th century decades.

Some weaknesses in museum data can be overcome: Ponder et al. (2001) proposed a method using "background records," records of species with similar ecologies, ranges, means of being collected, and so forth, as a control to identify systematic gaps in the collection data; McCarthy (1998) described statistical methods of measuring species declines using the kind of data we have made available on-line. Despite these new tools, they are no substitute for actual data. The paucity of digitized historic entomological specimens is a critical issue for entomologists, even though we as a community maintain some of the largest natural history collections available.

The INHS insect collection is but one among many, and filling gaps with data from other institutions is critical and should be a priority. Efforts to link specimen databases at museums across the globe are well under way (Soberon 1999) in other systematic domains, and we hope the entomological community will perceive the opportunities as well.

The INHS insect databases will become more useable and informative as we refine geographic information (e.g., streams and drainages), when all the material is geo-referenced (i.e., collection localities given latitude and longitude coordinates), and when collection localities become interactively mappable. The U.S. Ephemeroptera and Plecoptera have already been geo-referenced and Canadian records are currently being worked out for both orders.

Data entry of the Trichoptera collection (488,777 specimens in 68,414 records) has also recently been completed, although proofing for errors will continue for some time. Also completed are the Araneae, Opiliones, Scorpiones, Diplopoda, and Odonata databases, with the Diplopoda now available on the Internet and the Odonata soon to be. Of course, the long-term goal is to database the entire INHS insect collection. Now having completed >10% of it, the goal appears to be attainable.

We do not suggest that the use of museum data are without difficulties, and there will always be serious limitations that will punish those tempted to extrapolate beyond what is scientifically prudent. However, "it is important to use historic specimens when making inferences about historic populations" (Ristaino et al. 2001); if we truly wish to understand the current state of biological diversity, we have to understand its historic context, and doing so necessitates the use of collection data.

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