Just How Imperiled Are Aquatic Insects? A Case Study of Stoneflies (Plecoptera) in Illinois

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ABSTRACT Nearly 5,000 historical and contemporary specimen records of stoneflies (Plecoptera) from Illinois demonstrated that this fauna is highly imperiled, boding poorly for aquatic insect communities in North America and elsewhere. Losses include two extinctions of endemics and 20 extirpations of 77 total species, a rate of loss that is higher than for either mussels or fish in Illinois. Another 19 species (24.7%) were designated as critically imperiled, being known from five or fewer locations. Two families, Perlidae and Perlodidae, experienced the greatest number of losses. Species lost were mostly those with longer life cycles and direct egg hatch. Three historically hyperdiverse regions were identified and losses in all 14 natural divisions were documented. Large river habitats and historically prairie regions have experienced the greatest proportional losses of species. This scenario probably follows for Ephemeroptera, Trichoptera, and Odonata in the Midwest and in other areas with similar glacial and cultural histories.

KEY WORDS Plecoptera, Illinois, aquatic insect conservation

THE ANSWER TO THE QUESTION posed by the title is not answerable with great certainty. As with most insects, distributions are sketchy at best, especially with regard to historical distributions. For groups whose taxonomy has remained relatively stable (e.g., vertebrates and many plants), the use of literature and other records may be sufficient to document historical distributions. However, insect taxonomic concepts and nomenclature are constantly being revised. In this case, historical distributions of insects can only be reliably estimated from preserved specimens in natural history museums.

New (1994) discussed the need to improve conservation efforts for invertebrates. He pointed to a marked increase in invertebrate conservation activities, mostly in the Western world, including the publication of the Red Data Book for Invertebrates. The International Union for Nature and Natural Resources (IUCN) Red List (Red List 2004) of insects currently contains 181 U.S. species among 11 orders. These include species that are extinct and those at various levels of imperilment. Among them, terrestrial species dominate with 137. These data demonstrate that Lepidoptera are highly imperiled; indeed, they have experienced 34 extinctions among the 39 species listed (Fig. 1), and their listing in the Red Book was too late to help their conservation. Orthoptera and Hymenoptera are also well represented with "Vulnerable" being the most frequent listing (Red List 2004).

Only 46 aquatic species (25%) are on the list, the majority of which are Odonata (39 species). Chief among these are eight of the 23 species of *Megalagrion* damselflies (Coenagrionidae), the genus being endemic to the Hawaiian Islands (Polhemus 1993). Listed dragonflies are concentrated in the clubtails (Gomphidae: *Gomphus*, nine species, *Ophiogomphus*, five species) and emeralds (Corduliidae: *Somatochlora*, five species). Odonata are the butterflies of the aquatic world. They are conspicuous and subject to much amateur interest, so it is little wonder that they dominate the listed aquatic species. The Ephemeroptera (one species), Plecoptera (one species), and Trichoptera (three species) (collectively EPT taxa) were vastly underrepresented on the list, given their known intolerance to human-induced disturbance (Hilsenhoff 1987, Lenat 1993).

This disproportionately low recognition of the imperilment of aquatic insects is certainly not indicative of the true state of affairs. Master et al. (2000) have demonstrated that freshwater habitats are much more imperiled than terrestrial habitats, and Ricciardi and Rasmussen (1999) suggested that recent and predicted extinction rates of several aquatic groups are four to five times higher in freshwater systems than in terrestrial ones. Unfortunately, the latter's data do not include any insects, but their results suggest the potential for losses there as well.

Master et al. (2000) shed some light on the imperilment of aquatic species in the United States. They compiled states' natural heritage data through 1996 and found that among 14 groups of freshwater taxa, mussels, crayfish, and stoneflies were the top three most imperiled (cumulatively all the extinct, critically imperiled, imperiled, and vulnerable categories) taxa

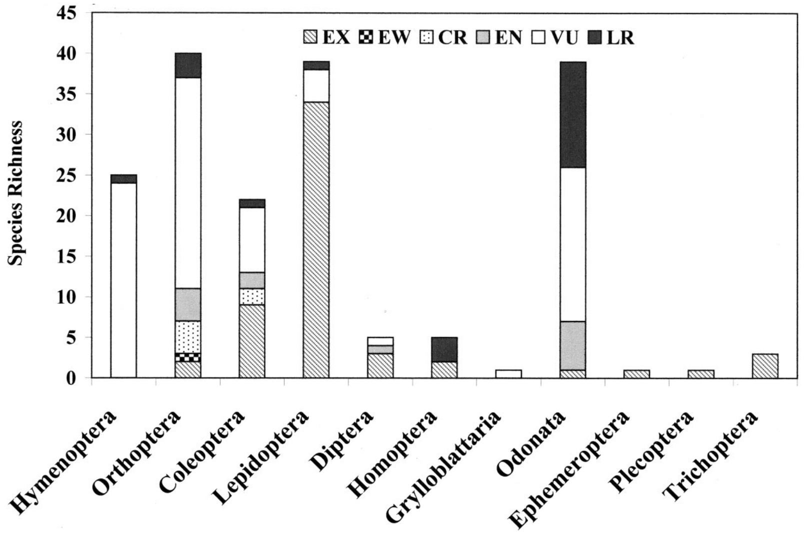

Fig. 1. Red List (2004) imperilment categories for U.S. insects by order. Categories are Extinct (EX), Extinct in the wild (EW), Critically Endangered (CR), Endangered (EN), Vulnerable (VU), and Lower Risk (LR). The rightmost orders are entirely aquatic.

at 69, 51, and 43% of species. Odonata were ranked as 13th most imperiled on their list. Still, Master and colleagues did not provide a comprehensive accounting of aquatic insect imperilment, although their effort is the best to date. Morse et al. (1993) provided an analysis of the general imperilment of 74 species of EPT in Appalachia, but they acknowledged the lack of a historical baseline and the comprehensive monitoring that would allow for more concrete determinations of imperilment.

Whether an insect species is recognized as imperiled is dependent upon many factors, including the availability and age of distribution data, the activity of systematists, the charismatic nature of the species, and the amount of public attention it receives. We are certain that these latter factors, fostered by amateur collecting, contributed greatly to the Odonata found on the Red List. There is a great amount of data about the distribution of aquatic insects, as they have long been recognized as indicators of stream condition (Barbour et al. 1999). However, many of these insects are unidentifiable as larvae, the most commonly collected life stage, because they have not been associated with adults. Additionally, a trend toward the use of lower taxonomic resolution (family and genus level) has taken place as a result of their being fewer well-trained taxonomists. The Entomological Society of America (2003) and the North American Benthological Society (Moulton 2004) have recognized the decline in number of qualified taxonomists in their membership and are trying to reverse it. The latter conducts day-long taxonomic workshops (focus on one order) and half-day "taxonomy fairs" (many systematists available to members) at annual meetings, and through a fledgling taxonomic certification for professionals (North American Benthological Society 2005).

Habitat degradation is the single largest factor leading to imperilment of species (Master et al. 2000), and few other landscapes in North America have been disrupted as much as that of Illinois. In the northern two-thirds of the state, grain production and cattle grazing occupy up to 95% of land use. The devastation that this has wrought on stream habitats and the insects occupying them is great. Because the Illinois landscape is naturally poorly drained, improvements in drainage (channelization and field drain-tiling) were instituted. Consequently, up to 25% of stream and river miles statewide have been channelized, leveed, and tiled, with the greatest modification taking place in the smallest streams (Mattingly et al. 1993). These hydrologic changes and removal of riparian trees has reduced groundwater flow in summer and increased variation in stream water temperatures (Wiley et al. 1990). It is surmised that a combination of hydraulic, hydrologic, and temperature effects is partly responsible for the extinctions, local extirpations, range reductions, and community turnover for mussels, fish, and aquatic insects throughout Illinois (Burr 1991, Cummings 1991, Cummings and Mayer 1992, DeWalt et al. 2002, Favret and DeWalt 2002). Although agricultural practices are the major culprit, ≈7 million people live in the six county metropolitan Chicago area, with the developed environment occupying 75–80% of the landscape.

Plecoptera have been the object of systematic and faunistic study in Illinois throughout the 20th century, in large credit to T. H. Frison, best known for his work on the winter stoneflies (Capniidae and Taeniopterygidae; Frison 1929) and his statewide monograph (Frison 1935). Illinois Natural History Survey policy states that scientists should donate their systematic specimens to the various formal collections that are maintained as a permanent record of the species inhabiting

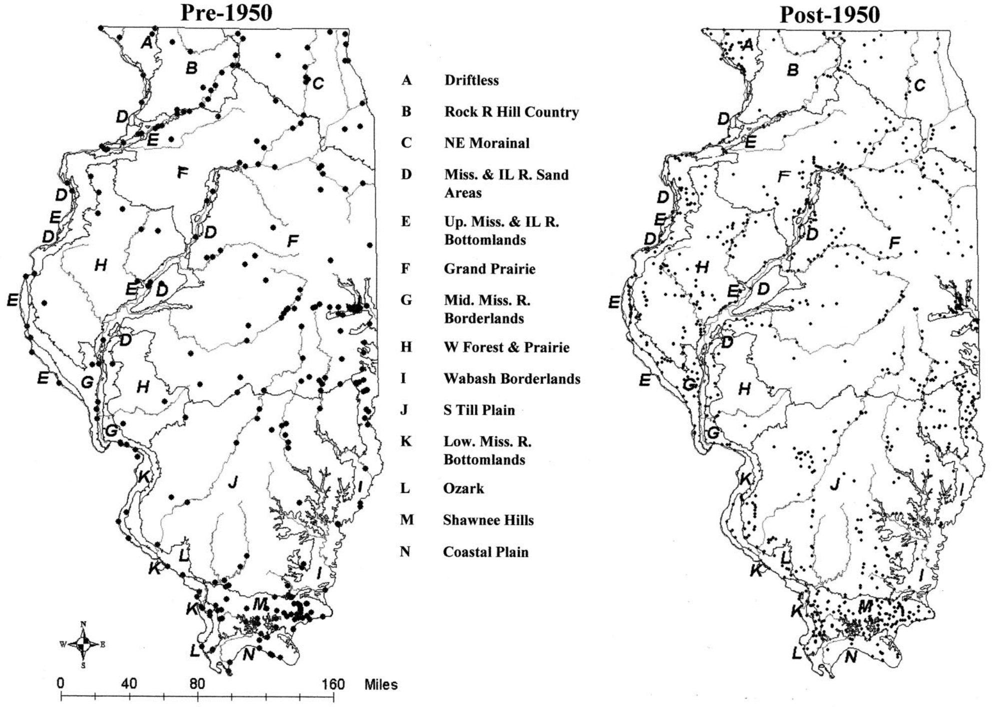

Fig. 2. Pre- and post-1950 unique collection localities for Illinois stoneflies and natural divisions of Illinois.

Illinois. Frison's work forms the basis of a historical record for stoneflies, but others such as Ross and Ricker (1971), Ricker and Ross (1968), Harris and Webb (1995), and Webb (2002) have added taxa, updated nomenclature, and provided revisions. Recent work by DeWalt (2002), DeWalt et al. (1998, 1999, 2001, 2002), and Favret and DeWalt (2002) described new species, allowed for reevaluation of specimens, and demonstrated some stonefly species losses and range reductions. Funding to RED by the National Science Foundation has been instrumental in creating a data management system that permits rapid retrieval of data and information. Therefore, the INHS Plecoptera collection is an extremely data-rich and valuable resource that is used to infer changes in the stonefly fauna of Illinois and ascertain the imperilment of stonefly species in the state. It will be a model for inferring changes in the aquatic insect fauna as a whole.

The use of collection data for ecological and conservation inference is best done using broad geographical and temporal scales, and with assemblages of species rather than individual indicator species (Shaffer et al. 1998, Favret and DeWalt 2002). The objectives of this study were to evaluate a rich historical and contemporary Illinois stonefly record to answer several questions, including 1) Has the number of species changed during the 20th century? 2) How does the change compare with other environmentally sensitive Illinois aquatic taxa? 3) Were changes taxon specific? 4) Do changes have a temporal component? 5) Were changes region specific? 6) Has there been a change in faunal affinity over time? 7) Have changes in the distribution of life history traits occurred?

As a result of amassing this large data set, it was possible to assign state imperilment status to all species based on NatureServe (2004) categories. Illinois stoneflies are not perfect surrogates for determining the extent to which aquatic insects are imperiled, but they are sufficient for interpreting the relative risk to other aquatic insects, especially mayflies and caddisflies, which are in many cases similarly intolerant to human disturbance (Hilsenhoff 1987, Lenat 1993). Our results should be most applicable to areas of similar glacial and cultural histories, but a more general warning is warranted as well.

Materials and Methods

A discussion of how the specimen data were captured and stored can be found in Favret and DeWalt (2002). All Illinois stonefly records were queried and split into pre-1950 and post-1950 time frames, a temporal break that was supported by previous work on the seven Perlidae genera known from Illinois (Favret and DeWalt 2002). The largest losses in these genera occurred with the decade beginning 1950. Unique locations were georeferenced to whatever level the specimen label data permitted and associated with 14 Illinois natural divisions (Fig. 2), geographic areas of relatively homogeneous plant communities and soil types (Schwegman et al. 1973). To compare imperilment with other Illinois aquatic fauna, we consulted the works of Cummings (1991) and Cummings and

Table 1. Illinois stoneflies, pre-1950 earliest or range of years (no entry post-1950), post-1950 last or range of years (no entry pre-1950), notes on rarity and affinity, and suggested imperilment categories

Species	Pre-1950	Post-1950	Notes	Status
Capniidae				
Allocapnia forbesi (Walsh)	1928	1995	Uncommon, restricted, Shawnee	S2
Allocapnia granulata (Claassen)	1891	2002	Occasional, N IL	S3
Allocapnia illinoensis Frison	1931	1965	Extirpated, Wabash	SH
Allocapnia mystica Frison	1928	1997	Common, Shawnee, Ozark, S Till	S5
Allocapnia nivicola (Fitch)	1938	2001	Rare, one location in Wabash	S1
Allocapnia recta (Claassen)	1926	2002	Abundant, Gr. Prairie and Wabash	S5
Allocapnia rickeri Frison	1928	1999	Scattered, abundant in Shawnee	S5
Allocapnia smithi Ross & Ricker		1958–1993	Rare, restricted to Shawnee	S1
Allocapnia vivipara (Claassen)	1926	2002	Abundant, displaced other *Allocapnia*?	S5
Nemocapnia carolina Banks	1928		Extirpated, Wabash	SX
Paracapnia angulata Hanson	1940		Extirpated, NE Morainal	SX
Leuctridae				
Leuctra alta James	1949		Restricted, Shawnee	SX
Leuctra rickeri James	1935	1993	Restricted, Shawnee, Ozark	S5
Leuctra sibleyi Claassen	1949	1996	Rare, restricted, Shawnee	S1
Leuctra tenuis (Pictet)	1939	2000	Rare, 1 Wabash seep	S1
Zealeuctra claasseni (Frison)	1928	1995	Restricted, Shawnee	S2
Zealeuctra fraxina Ricker & Ross	1928	1993	Rare, restricted, Shawnee	S1
Zealeuctra narfi Ricker & Ross	1933	1992	Rare, Shawnee and Wabash	S1
Taeniopterygidae				
Strophopteryx fasciata (Burmeister)	1907	1993	Rare, Shawnee, Gr. Prairie	S1
Taeniopteryx burksi Ricker & Ross	1910	2002	Weedy, displaces other taeniopterygids?	S5
Taeniopteryx lita Frison	1928	1995	Rare, S Till and Wabash	S1
Taeniopteryx metequi Ricker & Ross	1940	1993	Restricted, Shawnee, uncommon	S2
Taeniopteryx nivalis (Fitch)	1911	1994	Common, N 1/3 IL	S5
Taeniopteryx parvula Banks	1925–1928		Extirpated, N IL	SX
Nemouridae				
Amphinemura delosa (Ricker)	1935	2000	Scattered, locally abundant	S5
Amphinemura varshava (Ricker)	1909	1997	Scattered, locally abundant	S5
Amphinemura nigritta (Provancher)		1952	Extirpated, Shawnee	SH
Nemoura trispinosa Claassen	1939	1997	Restricted, NE Morainal, Driftless	S2
Prostoia completa (Walker)	1946	1993	Restricted, single drainage, Ozark	S1
Shipsa rotunda (Claassen)	1926	1993	Rare, Driftless, RR Hill Country	S1
Soyedina vallicularia (Wu)		2000	Rare, Wabash & S Till seeps	S1
Perlidae				
Acroneuria abnormis (Newman)	1888	2003	Restricted, peripheral larger rivers	S2
Acroneuria evoluta Klapalek	1913	2002	Rare, Mid. Miss. Border, Shawnee	S1
Acroneuria filicis Frison	1927	2003	Restricted, Shawnee, locally abundant	S3
Acroneuria frisoni Stark & Baumann	1886	2003	Rare, restricted to Shawnee	S2
Acroneuria internata (Walker)	1907	1960	Extirpated, Gr. Prairie, Wabash	SH
Acroneuria perplexa Frison	1927–1932		Extirpated, larger rivers, Coastal Plain	SX
Agnetina capitata (Pictet)	1906	1976?	Rare/extirpated, once common N 1/2	S1
Agnetina flavescens (Walsh)	1901–1939		Extirpated, N 1/2	SX
Attaneuria ruralis (Hagen)	1906–1945		Extirpated, once in all larger rivers	SX
Neoperla catharae Stark & Baumann	1892	1998	Restricted, Shawnee, once in Gr. Prairie.	S2
Neoperla clymene (Newman)	1890	2002	Restricted, large peripheral rivers	S2
Neoperla harpi Ernst & Stewart	1929	2001	Restricted, Ozark, Shawnee	S1
Neoperla mainensis Banks	1923		Extirpated, Wabash	SX
Neoperla occipitalis (Pictet)	1925		Extirpated, Wabash	SX
Neoperla robisoni Poulton & Stewart	1906		Extirpated, Wabash	SX
Neoperla stewarti Stark & Baumann	1892		Extirpated, Wabash	SX
Paragnetina kansensis (Banks)	1913–1944		Extirpated, Gr. Prairie, S Till, Mid. Miss. Border	SX
Paragnetina media (Walker)	1927–1932		Extirpated, Driftless	SX
Perlesta cinctipes (Banks)		1994	Rare, Mid. Miss. Border	S1
Perlesta decipiens (Walsh)	1892	2002	Abundant, statewide	S5
Perlesta golconda DeWalt & Stark	1927	1997	Locally common in larger rivers	S5
Perlesta lagoi Stark	1891	2003	Abundant, statewide	S5
Perlesta napacola DeWalt		2001	Rare, restricted to Wabash	S1
Perlesta shawnee Grubbs & Stark		1977–1998	Restricted, recent Shawnee immigrant?	S2
Perlesta shubuta Stark		2002	Rare, Wabash, RR Hill, Gr. Prairie	S2
Perlesta xube Stark & Rhodes	1929	1998	Uncommon, scattered	S4
Perlinella drymo (Newman)	1898	1998	Uncommon, scattered	S2
Perlinella ephyre (Newman)	1913	2002	Uncommon, larger rivers	S2
Chloroperlidae				
Alloperla caudata Frison	1938	1998	Restricted, Shawnee, Ozark	S4
Alloperla roberti Surdick	1860		Extinct, endemic, Up. Miss. Bot	SX
Haploperla brevis (Banks)	1938	2003	Uncommon, Shawnee, Wabash	S3
Perlodidae				
Clioperla clio (Newman)	1925	2003	Uncommon, scattered, springbrooks	S2
Diploperla robusta Stark & Gaufin		2003	Rare, one Wabash springbrook	S1
Hydroperla crosbyi (Needham & Claassen)	1927	2002	Uncommon, larger, sandy rivers	S2
Hydroperla fugitans (Needham & Claassen)	1914	1993	Rare, Coastal	S1
Isogenoides varians (Walsh)	1863–1939		Extirpated, Up. Miss. Bot.	SX

continued

Table 1. Continued

Species	Pre-1950	Post-1950	Notes	Status
Isoperla burksi Frison	1937	2002	Rare, restricted to Shawnee, Coastal	S1
Isoperla conspicua Frison	1931		Extinct, endemic, Up. Miss. Bot.	SX
Isoperla decepta Frison	1932	2002	Abundant, S Till, Shawnee, Ozark	S5
Isoperla bilineata (Say)	1879	2002	Abundant, large rivers	S5
Isoperla longiseta Banks	1943	1951	Extirpated, Shawnee, Gr. Prairie, Mid. Miss. Border	SH
Isoperla marlynia (Needham & Claassen)	1928–1932		Extirpated, RR Hill, Up. Miss. Bot.	SX
Isoperla mohri Frison	1932	2002	Restricted, Shawnee, S Till.	S2
Isoperla nana (Walsh)	1885	2003	Abundant, Gr. Prairie, adj. divisions	S5
Isoperla richardsoni Frison	1925–1941		Extirpated, large rivers, N IL	SX
Pteronarcyidae				
Pteronarcys pictetii Hagen	1892	2003	Uncommon, larger rivers	S3

S1, Critically Imperiled; S2, Imperiled; S3, Vulnerable; SH, Presumed Extirpated; and SX, Extinct. SH species persisted into 1960s then lost.

Mayer (1992) for mussels and Burr (1991) for fish. Life history traits were gathered from Stewart and Stark (2002), but some were surmised from field experience (R.E.D., unpublished data). Important traits were the presence or absence of egg or nymphal diapause, and voltinism.

We created a single presence or absence data matrix of species versus natural divisions and pre- and post-1950 time periods to address changes in faunal affinity. Our interests here were whether historic assemblages in natural divisions have changed in contemporary times. This would manifest itself in separation of pre- and post-1950 natural divisions into nonadjacent clusters in a cluster analysis. A distance matrix was constructed from the presence or absence data, representing a pairwise comparison of faunas for each natural division and time frame combination. This matrix was then subjected to a Bray and Curtis (1957) cluster analysis using flexible beta linkage ($\beta = -0.25$) (McCune and Mefford 1999) to yield relationships that were depicted in a dendrogram.

Imperilment status was set using criteria for the categories S1, Critically Imperiled; S2, Imperiled; S3, Vulnerable; S4, Apparently Secure; S5, Secure; SH, Apparently Extirpated; and SX, extirpated. Definitions for these categories (NatureServe 2004) depend mostly upon the number of recent unique locations for well sampled taxa. The pre- versus post-1950 division was abandoned for this purpose because six species that were present after 1950 seem to have been lost during the 1960s, with no losses since then. All data used in this study are available online (Illinois Natural History Survey 2004)

Results and Discussion

Seventy-seven species of stoneflies have been collected in Illinois since 1860 (see Table 1 for an updated list). The most recent state records, not included in any previous publication, are *Diploperla robusta* Stark & Gaufin, IL: Vermilion Co.; Unn. Trib. Vermilion River, 7.5 km SE Westville, Russell M. Duffin Nature Preserve, 40.0094 N, 87.5535 W, 15 March 2003, R. E. DeWalt; same location 7 May 1976, B. Baldwin; *Leuctra alta* James, IL: Bell Smith Springs, 29 April 1949, Sanderson & Stannard. Heimdal et al. (2004) provided the most recent comparison for Illinois's neighboring states. Our records constitute 1,120 unique positive collection localities and demonstrate that more locations have been investigated and have yielded stoneflies in the second half of the 20th century than in the first (Fig. 2).

Has the Number of Illinois Stonefly Species Changed during the 20th Century? Although some degradation had already occurred by the time of the greatest collection efforts of Frison between 1920 and 1935, much of the state was still rural and the large scale, energy intensive agriculture currently being used had not yet taken hold. A major exception to this was the heavily urbanized Chicago area. By 1900, the Sanitary and Ship Canal was constructed that linked Lake Michigan to the Illinois River, a large tributary of the Mississippi River, and conveyed large volumes of untreated and partially treated sewage away from Chicago, causing a massive ecological catastrophe in the watershed (Starrett 1971).

Initially, the Illinois stonefly community supported many relatively large, predaceous, long-lived species in the families Perlodidae (spring stones) and Perlidae (summer stones) (Fig. 3). The winter stonefly family Capniidae also was well represented. The presumed presettlement total is 77 species (one taxon may have immigrated during the 20th century, but it is included in this total) (Table 1); conversely, the post-1950 bar shows a dramatic decline in the number of species to 61, for an absolute loss of 15. These losses contain two extinctions of Illinois endemics, *Alloperla roberti* Surdick and *Isoperla conspicua* Frison. Additionally, 13 species are presumed extirpated because they have not been collected in the post-1950 period. This is certainly not the whole story as six additional species, present post-1950, have not been seen since the mid-1960s (Table 1). These, too, are considered extirpated from Illinois. Generally, large, long-lived species in the Perlidae and Perlodidae were impacted the most.

How Does the Change Compare with Other Illinois Aquatic Taxa? Burr (1991) reevaluated the Illinois fish fauna, documenting extinctions and extirpations and similar data were gathered by Cummings (1991) and Cummings and Mayer (1992) for freshwater mussels. Stoneflies and freshwater mussels have a similar species richness, whereas Illinois fish are more speciose (Fig. 4). Stoneflies have the highest proportion of extinct and extirpated species among the three at 22 of

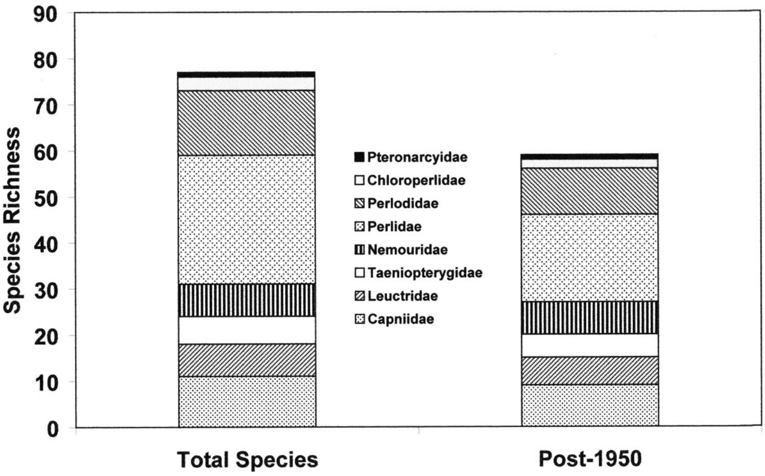

Fig. 3. Stonefly species richness by family for total species and for post-1950.

77 species, or 28.6%. Master et al. (2000), when assessing imperilment across the United States, placed stoneflies behind mussels and crayfish in the proportion of species imperiled (comparison for extinct, extirpated, and the lesser imperilment categories of S1, S2, and S3).

Are Changes Taxon Specific? Perlid stoneflies were most affected by changes in the Illinois landscape. Of 28 species among seven genera that have been recorded from the state, only 18 remain. One species, *Perlesta shawnee* Grubbs & Stark (a cryptic species related to *P. nelsoni* Stark), is probably a recent immigrant to Illinois (DeWalt et al. 2001). Five genera—*Acroneuria, Agnetina, Attaneuria, Neoperla,* and *Paragnetina*—have lost species, whereas *Perlesta* and *Perlinella* have not (Fig. 5). Several genera have been lost entirely (Fig. 5), and one, *Agnetina,* has not been seen since 1976, when two small nymphs, unidentifiable to species, were taken from the Pecatonica River near the Wisconsin border.

Do Changes Have a Temporal Component? Favret and DeWalt (2002) looked at the number of records of perlid genera in Illinois throughout the 20th century. The proportion of records of *Acroneuria* and *Perlesta,* two genera with vastly different tolerances to organic pollution and general watershed disturbance (Hilsenhoff 1987, Lenat 1993), differed dramatically throughout the century. *Acroneuria,* the more sensitive genus, averaged 56.5% (range 33.3–88.3) of perlid records over the decades 1900 through 1940, but only 6.5% (0.0–17.1%) from 1950 through 2000. Conversely, the most tolerant genus, *Perlesta,* averaged 18.5% (6.5–29.8%) and 78.1% (61.0–97.1%) over the same time frames. The decades of the 1940s and 1950s seem to be the breaking points, with cumulative impacts causing losses of many perlid species, and perhaps the release of tolerant species from competition.

Are Changes Region Specific? All natural divisions supported stoneflies and all 14 lost species (Fig. 6). Three natural divisions, the Shawnee Hills, a vaulted region in southern Illinois; the Wabash Borderlands, an area of clear, sand and gravel streams; and the Grand Prairie, historically a tallgrass prairie, were all hyperdiverse compared with other divisions. We were surprised to find that the Grand Prairie historically supported nearly as many species as these other divisions with faster flowing streams and forested watersheds. Species losses, as a percentage of their total

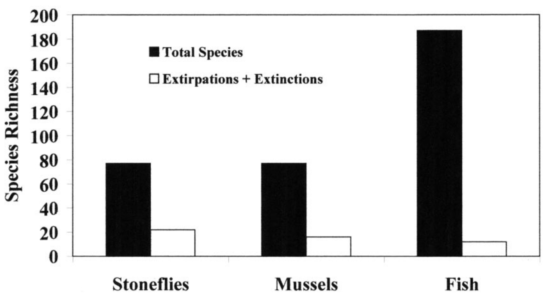

Fig. 4. Comparison of extirpations and extinctions with total species richness for stoneflies, mussels, and fish in Illinois.

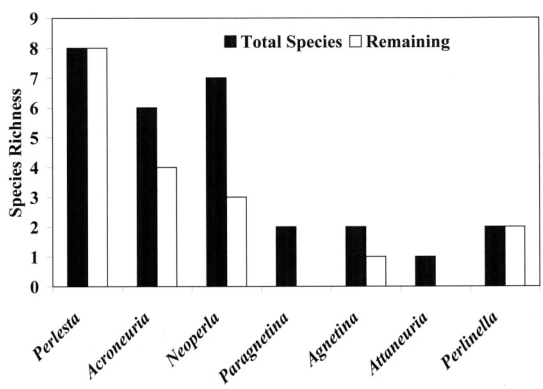

Fig. 5. Perlidae stonefly genera total species richness and those remaining contemporarily.

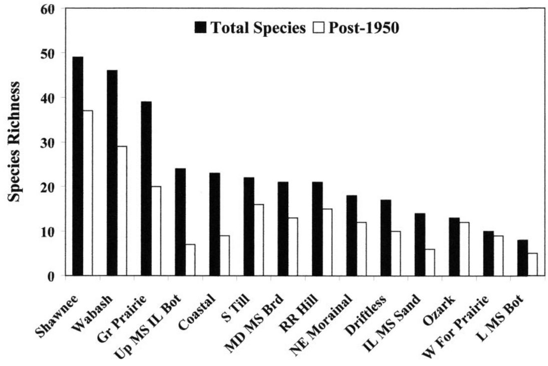

Fig. 6. Stonefly species richness by Illinois natural division. Total species richness versus post-1950.

species richness, were highest within the Grand Prairie and large river associated natural divisions (Upper Mississippi and Illinois River Bottomlands, Coastal Plain, Illinois, and Mississippi Sands). Streams were highly modified in the Grand Prairie to the point that in some counties almost all of the smallest streams have been channelized, with larger streams having >50% modification (Mattingly et al. 1993). These small streams are often tied to tile drainage networks that lower the water table and convey large volumes of water to channels that lack the hydraulic refugia capable of providing protective habitat during flooding. Large rivers have been heavily modified by construction of locks and dams for navigation and levees for flood control. The Rock River Hill Country, with the moderately large Rock River, was a highly diverse system that has been dramatically degraded by low dams, siltation, and organic waste.

Several clusters, signifying unique stonefly faunas, were found for pre-1950 communities, including the Shawnee Hills and the Coastal Plains; the Grand Prairie, Wabash Borderlands and Southern Till Plain; and several large river dominated divisions (Fig. 7). The Shawnee Hills and the Southern Till Plain have maintained faunal integrity to a higher degree than many divisions, as evidenced by clustering of faunas from the two time periods adjacent to each other. Conversely, the post-1950 Wabash Borderlands and Grand Prairie have diverged from the pre-1950 assemblages, but still maintain high similarity with each other, indicating that their faunas were degraded similarly. Most large river natural divisions have degraded in similar ways and cluster with other large river divisions of the same time frame.

Have Changes in Life History Traits Occurred? Historically, 45 (58.4%) of Illinois species had a univoltine-fast life cycle (Fig. 8)—1 yr cycle, egg or nymphal diapause, and a short (2–6-mo) nymphal growth phase. Another 24 (31.2%) had univoltine-slow cycles with direct egg hatch and nymphs exposed to stream conditions for ≈11 mo. Eight species (10.4%) had a semivoltine life cycle with direct egg hatch and 2 yr of nymphal growth. The preponderance

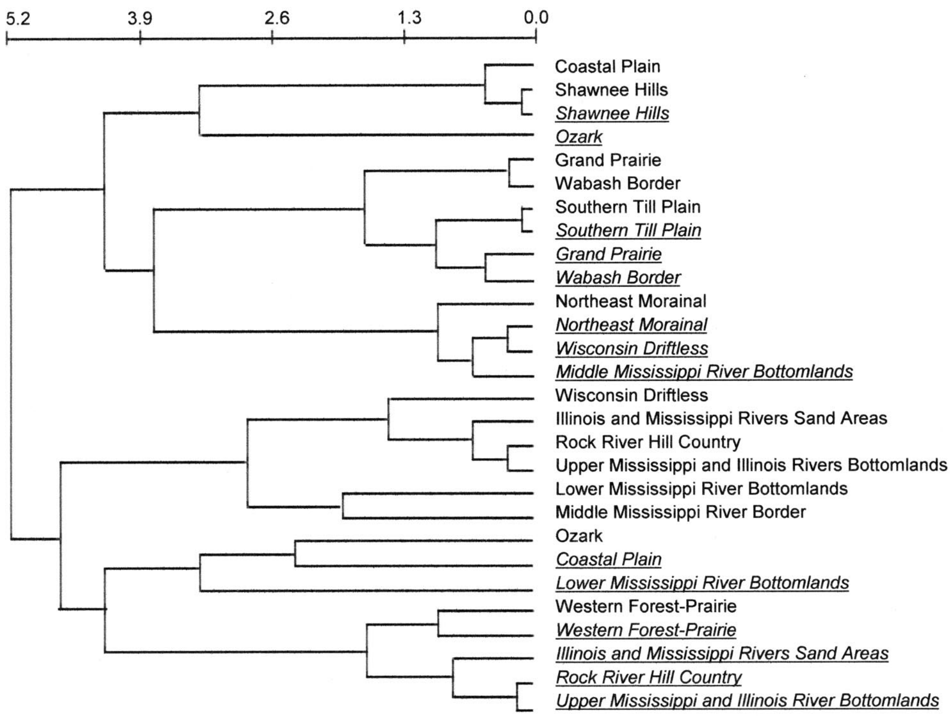

Fig. 7. Bray–Curtis cluster analysis of pre-1950 and post-1950 Illinois stonefly assemblages; post-1950 assemblages are underlined.

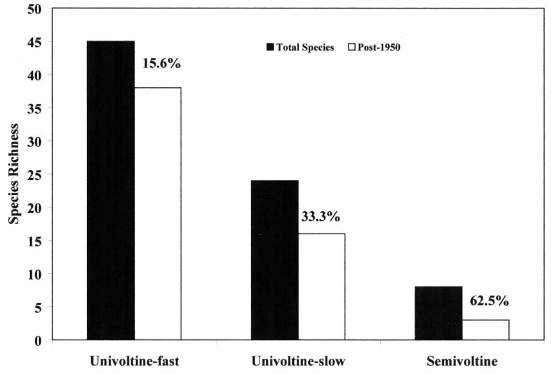

Fig. 8. Distribution of life history traits for all Illinois stonefly species and for those remaining.

of univoltine-fast cycles suggests that Illinois has experienced periodic drought for a long time. Chagnon (2003) demonstrated that drought was a major factor contributing to the original tall grass prairie in Illinois. The presence of slow life cycles suggests that at least parts of the state (Wabash, Rock River Hill Country, large rivers) historically have had permanent water and, in the case of several of the semivoltine species, had streams with significant groundwater inputs.

All life cycle strategies lost species during the post-1950 time frame. However, the most severe losses occurred among univoltine-slow (33.3% loss) and semivoltine life cycles (62.5%). These strategies expose nymphs to summer hypoxia, high water temperatures, and the increased intermittency that comes with the large scale agricultural and urban changes that took place in the 20th century. Therefore, the Illinois stonefly assemblage increasingly resembles a drought adapted fauna.

Imperilment Status of Illinois Plecoptera. We ascertained that nearly 28.6% of stonefly species have become extinct or have been extirpated from Illinois (Fig. 9). There is nothing that can be done for the extinct species, and reintroduction of the extirpated ones relies on improvements in and connection of existing habitat. What is most important is the number of remaining species that are highly imperiled. Another 19 species (24.7%) are known from five or fewer locations, corresponding to the S1 ranking of NatureServe (2004). Another 15 species (19.5%) meet criteria for S2 status (known from fewer than 20 locations). Most of these S2 species are known from between five and 10 locations. Added together, 72.7% of Illinois species have either been lost (SX and SH) or are in danger of being lost (S1 and S2), and only 27.2% can be considered secure (S3 through S5).

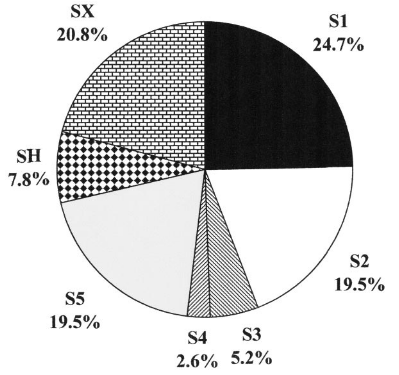

Fig. 9. NatureServe (2004) imperilment distribution for Illinois stoneflies. S1, Critically Imperiled; S2, Imperiled; S3, Vulnerable; SH, Presumed Extirpated; and SX, Extinct. SH species persisted into 1960s then lost.

General Remarks. The Illinois stonefly assemblage is highly imperiled. Their absolute losses are on a scale with other assemblages such as fish and freshwater mussels that garner more protection, funding, and attention. Losses have occurred in every region of the state, even in the Shawnee Hills where habitat and water quality have remained relatively high. Proportionally, losses have been greatest in several large river divisions and in the highly agricultural Grand Prairie. In most cases the losses can be attributed to hydrologic modifications such as levee, lock, and dam construction on the large rivers and channelization, coupled with tiling of fields, in agricultural areas. Further lock and dam construction on the Mississippi and Illinois rivers is being considered by the Army Corps of Engineers. Channelization of streams and tiling of fields has been most devastating to smaller streams, promoting more variable discharge, lower summer base flows, and intermittency where streams were once perennial. The clearing of native riparian vegetation and the changes in groundwater input (from tiling) also have increased the variability of stream temperatures (Wiley et al. 1990), with the probable result of eliminating many species having univoltine-slow and semivoltine life histories.

Several impediments to knowing the relative imperilment of aquatic insects exist. Many state, regional, and national agencies and consulting firms use insects as indicators of water quality. This should constitute one of our best resources for determining the conservation status of aquatic insects. However, specimens are rarely vouchered to accredited institutions and taxonomic resolution is often at the genus or family level, a resolution that often meets monitoring objectives, but negates other uses. Because insect systematics is a dynamic science with frequent revisions, the use of published species lists for conservation purposes becomes reduced over time. Consequently, we are often left to only natural history museums for determining imperilment status of insects. However, natural history museums and their taxonomic experts are not being well supported, despite their known value to society (Suarez and Tsutsui (2004).

Using stoneflies as a surrogate for other aquatic insects, it becomes apparent that tremendous losses have occurred in the past and will occur in the future. Although it is important to identify those species that are imperiled, we fear that the number of such species is very large. To protect the greatest number of species, we suggest that state and regional surveys be coupled with greater protection and enhancement of endangered aquatic habitats. Our data and experience suggest that large rivers, natural sand-bottomed streams, and cool and cold water habitats must be afforded greater protection. At smaller scales, the single-most important factor degrading Illinois streams is channelization and channel maintenance (R.E.D., unpublished data).

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