Courtesy J.R. Bruschwein

Invertebrates

by
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Overview

Invertebrates are impressive in abundance and diversity, living on land and in water and air. Many species are borne to distant places on air and water currents, and via modern transportation.

Of the millions of species of animals worldwide, about 90% are invertebrates, that is, animals without backbones (Opler, Powell, this section). The arthropods, or jointed-leg invertebrates such as beetles, account for 75% of this total. More than 90,000 described insect species inhabit North America (Hodges, Powell, this section); the Lepidoptera (butterflies and moths) alone account for about 11,500 of these (Powell, this section).

Within an acre of land and water, hundreds of different invertebrates form an ecological web of builders, gatherers, collectors, predators, and grazers, all interacting with each other and each a necessary component of a healthy ecosystem. The large macroscopic invertebrates—like bees, beetles, butterflies, grasshoppers, snails, and earthworms—are well known, but other invertebrates are almost invisible because they are extremely tiny or camouflaged for protection. We have just begun to understand the ecology of some commercially important species, but we understand very little about the behavior, communication, and function of many other invertebrates within various ecosystems.

Each individual invertebrate is a highly complex, specialized animal. Some molt (change or metamorphose) into several distinct life stages. For example, some insects transform from egg to larva, then to pupa, and finally emerge as a terrestrial winged adult. Some aquatic invertebrates do not have pupal stages, and the larvae (nymphs or naiads) grow progressively larger by molts. Earthworms bear cocoons that each contain about six miniature juveniles; they also reproduce by fragmentation (architomy).

Changes to the environment can disrupt basic interactions of invertebrate species, thereby affecting other organisms in the food chain. Disruptions of natural food cycles may cause drastic changes in the community structure and ecological web of life. This is especially true of the fauna that dwell in fragile ecosystems like caves and springs (Webb, *see* box). Eventually even humans are affected by changes to food webs and destruction of beneficial habitat for wildlife.

Most invertebrates can survive extreme natural events like severe storms, blizzards, and flooding. When confronted by unnatural disturbances, however, such as excessive siltation from urban and highway developments, eutrophication (excessive nutrients) by runoff

from agricultural lands, and contamination of aquatic habitats by toxic substances and acids, invertebrate populations can be severely damaged. Airborne toxicants like acid rain are harmful to the long-term well-being of insects. If disturbances are sufficient, natural fauna may be extirpated (removed or lost) and replaced by more tolerant kinds. This "unbalanced" situation usually results in a population explosion of a few species (e.g., Tubificidae: Oligochaeta and red-blooded Chironomidae: Diptera). Such a biological reaction makes these aquatic invertebrates excellent bioindicators of overall environmental conditions (Bartsch and Ingram 1959). The use of aquatic invertebrates for bioassay (testing the toxicity of substances to "standard" test organisms) has greatly helped to minimize adverse effects of contaminants on aquatic life.

Butterflies and moths are particularly susceptible to environmental disturbances (Opler, this section), although their responses to mild disturbances and changes may be slow, lasting decades (Otte, Swengel, and Swengel and Swengel, this section). McCabe (this section) concludes that some of the flux in biodiversity is likely due to the "edge effect" at the interface from one habitat to another, and not necessarily to anthropogenic (human-caused) disturbances.

Courtesy V. Krantz

Leaf miner moth (*Acrocercops arbutella*).

In the aquatic realm, organic chemicals and other toxic substances, acids and alkalis, and mine drainage can quickly decimate populations of mussels, mayflies, and stoneflies, whereas reduced water flow and introduction of pollutants like silt and excessive nutrients (Mason et al., Webb, this section) cause a slow, relentless destruction of the indigenous fauna.

In the past 50 years, nearly 72% of the United States' 297 native mussel species have become endangered, threatened, or of special concern (Williams and Neves, this section). Their populations have been damaged because of siltation, point and nonpoint source pollution, and outright habitat destruction.

The zebra mussel (*Dreissena polymorpha*) and some other nonindigenous species represent "biological pollution" (Schloesser and Nalepa, this section), and should be considered much like toxic pollution for control and treatment. Non-native zebra mussels lack predators and have invaded nearly the full length of the Mississippi River and its major tributaries, threatening the native mussel fauna of the eastern United States (Williams and Neves, this section). The impact of the zebra mussel and other nonindigenous species is covered in greater detail in the "Non-native Species" section of this report.

Courtesy R.J. Gill

Citophilus mealybug (*Pseudococcus calceolariae*).

Historical data bases (e.g., Otte, this section) have traditionally focused on commercially important invertebrate species such as clams and oysters. In contrast, little information exists on the status and trends of nonconsumptive, indigenous invertebrate life, and existing data are often not in formats for use in modern decision-making tools (Messer et al. 1991).

An important, often-overlooked problem with providing scientifically credible data involves the taxonomy and systematics (identification and classification) of organisms. Today, our museum collections of invertebrates are often old and worn out, and there are few trained taxonomists to renew archival materials. In fact, many "type" specimens used for original species' descriptions in the early 1900's are unusable, making comparisons of recently collected specimens impossible.

Canada has been doing continuous biomonitoring for several decades, which has now resulted in status and trends analyses of subtle perturbations like acidification (Chmielewski and Hall 1993). It is clear that the success of future assessments in the United States will greatly depend on availability of and access to high-quality data; stop-gap measures are unlikely to prove successful because of inconsistencies caused by differing collection methods, taxonomy, and reporting units.

This section is organized by general articles on invertebrates and followed by terrestrial and aquatic case studies. The authors drew on original data, often unpublished, and therefore, although some of the studies may appear outdated, this does not detract from the usefulness of the examples.

Basic research on the taxonomy and ecology of species and communities is urgently needed as groundwork for future status and trend assessments. Complex ecological relationships are poorly understood. Only a few working ecosystem models (e.g., Chesapeake Bay) are sufficiently developed to allow semi-quantitative predictions about cause-effect relationships between some biologic components (e.g., plankton) and abiotic conditions. Other biological components need to be added to the modeling framework, especially as related to food web interactions. Future status and trends information gathering should be supportive of ecosystem model development wherever possible.

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Diversity and Abundance of Insects

by
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Insects are the most diverse group of organisms (Wheeler 1990); potentially they are highly indicative of environmental change through close adaptation to their environment; they represent the majority of links in the community foodchain; and they likely have the largest biomass of the terrestrial animals (Holden 1989). Thus, knowledge about them is fundamental to studying the environment.

The 34 orders of insects have 90,968 described species and an estimated 72,500+ undescribed species in 653 families and 12,578 genera (Arnett 1985; Kosztarab and Schaefer 1990) in America north of Mexico. Of the described species 71,931 are in the orders Coleoptera (beetles, 23,640), Diptera (flies, 19,562), Hymenoptera (ants, bees, wasps, and sawflies, 17,429), and Lepidoptera (moths and butterflies, 11,300). Undescribed species are distributed mainly among Homoptera (aphids, leafhoppers, scale insects, and allies, 4,334), Coleoptera (2,627), Diptera (41,622), Hymenoptera (18,571), and Lepidoptera (2,700; Kosztarab and Schaefer 1990).

Some aspects of the immature stages of 8,668 species are known (Kosztarab and Schaefer 1990); however, very few are fully known (i.e., documented with voucher specimens and publications with illustrations of eggs, each larval instar, and pupae). Detailed knowledge of the immature stages is important because insects often are present as adults for a short period during the year, but are present as eggs, larvae, or pupae during most of the year.

Taxonomic literature useful for identifying described species is available for less than 30% of them in the adult stage. No major order has been subjected to revisionary study at the specific level, and only two such projects are under way, Lepidoptera (Dominick 1971+) and Diptera (Griffiths 1980+). Some smaller orders, some families, and many genera have been revised for North America (e.g., bethylid wasps [Evans 1978], cerambycid beetles [Linsley and Chemsak 1961-84], chrysidid wasps [Bohart and Kimsey 1982], dragonflies [Odonata; Needham and Westfall 1955], grasshoppers [Orthoptera; Otte 1981, 1983], lady beetles [Gordon 1985], springtails [Collembola; Christiansen and Bellinger 1980-81], thrips of Illinois [Thysanoptera; Stannard 1968], and beetles of the Pacific Northwest [Hatch 1953-71]). Several family or ordinal groups have been revised for Canada and the northern United States. Diptera (Stone et al. 1965; Systematic Entomology Laboratory, U.S. Department of Agriculture, unpublished), Heteroptera (Henry and Froeschner 1988), and Hymenoptera (Krombein et al. 1979) have been cataloged. The Lepidoptera have a checklist (Hodges et al. 1983). A nomenclatorial data base (BIOTA, Biosystematic Information on Terrestrial Arthropods, available via Internet or on CD-ROM) for terrestrial arthropods (less Crustacea) is being developed and coordinated by the Systematic Entomology Laboratory, USDA (Hodges 1994).

For all major orders much revisionary work is needed to define and discriminate among species, genera, and higher taxa in a broad sense and with recognition of variation in nearly all characters. From these works field guides and identification manuals must be developed. Literature for lay workers and students should provide identification to the species level by state or region as this information is necessary for conducting surveys (*Keys to British Insects*—a continuing publication series of the Royal Entomological Society, London—is an excellent example).

Several states have programs to document their fauna with publications and voucher material: California Insect Survey, Florida State Collection of Arthropods, Illinois Natural History Survey, New York State Natural History Survey, and Insects of Virginia, Blacksburg. Few state faunal lists exist; the few that do are outdated or limited: all insects of New York (Leonard 1926) and North Carolina (Brimley 1938, 1942; Wray 1950, 1967); Lepidoptera of Florida (Kimble 1965), Maine (Brower 1974, 1983, 1984), New York (Forbes 1923, 1948, 1954, 1960), and Pennsylvania (Tietz 1952). Checklists or faunal lists of Odonata exist for 39 states and provinces (Westfall 1984). Surveys by county are under way for Kentucky (Lepidoptera, University of Louisville, unpublished data), Maryland (scattered orders and families, Maryland Entomological Society), Missouri (moths, J.R. Heitzman, unpublished data), Ohio (Lepidoptera, Ohio Lepidopterists; Metzler 1980; Iftner et al. 1992; Rings et al. 1992; unpublished data), and the western United States (butterflies; Stanford and Opler 1993). Extensive data have been collected on the distribution of Alaskan butterflies by the Alaska Lepidoptera Survey (Philip, University of Alaska, unpublished data).

No site in North America has been fully surveyed for all insects; however, the Mount Desert Island, Maine, survey (Procter 1946) was an early attempt to do so. Of an estimated 6,000 species, 3,400 have been reported from the H.J. Andrews Experimental Forest, Oregon (Parsons et al. 1991). Craters of the Moon National Monument, Idaho (Horning and Barr 1970); Deep Creek in San Bernardino County, California (S.I. Frommer, University of California, Riverside, unpublished data); and Pawnee Grasslands, Colorado (Kumar et al.

Courtesy G. Zolnerowich

Leaf-footed bug (*Thasus* sp.).

Courtesy J.R. Bruschwein

Mantidfly (*Mantispa interrupta*).

Courtesy C.E. Williams

Robber fly (*Diogmites symmachus*).

Courtesy J. Heraty

Spurge hawkmoth (*Hyles euphorbiae*).

1976) have been intensively surveyed for insects but none of the surveys approaches completion. A constant problem has been the inability to identify all the numerous taxa.

Sampling for taxa, except for aquatics, is based mainly on adults; results are highly variable, depending on the competency of the samplers, knowledge of habits of organisms, weather during sampling periods, and phases of the moon and wavelength of light (for those species attracted to light). With exceptions (aquatic insects; Merritt et al. 1984), sampling techniques to estimate species diversity within an area have not been developed or are preliminary for limited taxa.

Identification of adults within large orders depends on highly trained, experienced taxonomists who have access to good collections and libraries; very few taxonomists exist relative to the number of taxa. Identifications in collections must be held suspect unless the taxa have been revised in contemporary terms and the specimens studied and vouchered by the revisor (Hodges 1976) or other specialist.

Individuals capable and willing to provide authoritative identifications are becoming fewer each year. Many have retired or could retire. There has been a significant redirection of systematists from basic revisionary work to other research areas. Nearly 30% fewer persons are entering the field because the likelihood of obtaining a position upon completion of training is extremely poor (Lutz 1994). Technical and monetary support for systematists and curators always has been limited and is becoming more restricted.

Collections vary in size from small private collections to the 30+ million specimens in the National Insect Collection in the National Museum of Natural History. Many state universities, particularly in the Midwest and on the West Coast, have collections of 1+ million specimens, as do several private and public institutions. Despite this large number, many species are represented by few specimens and almost none with comprehensive representation by county and by state.

Surveys of many taxa are possible but require individuals to initiate them; sufficient taxonomic literature and research to enable recognition of taxa; curatorial support for preparing, sorting, and identifying specimens and potential supervision of the surveys; and adequate collection and library facilities for species recognition and permanent storage of voucher specimens.

These comments are meant to provide perspective on the status of systematic entomology and thus the role insects may have in the work of the National Biological Service.

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Courtesy N. Erwin

Tiger beetle (*Cicindela hirticollis*).

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Grasshoppers

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Grasshoppers (Orthoptera:Acrididae) are perhaps the most important grazing herbivores in the nation's grasslands, which from a human standpoint, are the most important food-producing areas. The damage that grasshoppers do to plants varies with the species. A few dozen species at most are highly injurious to crops, while those that feed on economically unimportant plants may have no measurable impact, and those that feed on detrimental plants are highly beneficial. Given such differences, it becomes important to distinguish properly between harmful and beneficial species. Grasshopper abundance in all kinds of grasslands means they are an important factor in the ecological equation. Their economic importance—positive and negative—means that they must be included in all studies of grassland and desert-grassland communities.

Taxonomic Status

More than 1,000 species of grasshoppers have been described from the United States (Otte 1976, 1994, unpublished data base). Taxonomic revisions at the Academy of Natural Sciences in Philadelphia (ANSP) reveal that approximately 20% of the U.S. species represented in the existing ANSP collection are undescribed (Otte 1981; unpublished data). Most new species belong to the very large genus *Melanoplus*, which contains some of the most injurious grasshopper species known. A considerable number of undescribed species are from the eastern states, from approximately central Texas to New England. New species are turning up even in extremely well-studied areas such as Michigan and Florida. It is expected that at least tens of species remain to be discovered in the coastal ranges of California, and many other mountain peaks in the western states should have species unique to them. Much of the academy's collecting efforts have been directed to investigating the grasshopper faunas of such mountain peaks ("sky islands").

Natural Range Increases

Great Lakes Region

Documenting natural range changes requires that comparable collections be made at several

points in time. The only such case involving grasshoppers that I am aware of involves the ranges of two grasshopper species along the Great Lakes shores. *Trimerotropis huroniana* and *T. maritima* displace one another on the dunes surrounding the Great Lakes, with *T. huroniana* occupying the northern shores and *T. maritima* the southern shores (Otte 1970). The boundary between these two species has shifted in the last seven decades. The two species may well be competitive on four different lakefronts, on the north-south shores of Lakes Michigan and Huron.

Prairie Peninsula

In southern Michigan the bandwing grasshopper (*Pardalophora haldemani*) was abundant in 1943 and the related species, *P. apiculata*, was rare (Cantrall 1943). By 1968 *P. haldemani* had been completely replaced by *P. apiculata*, probably because subtle habitat changes gave *P. apiculata* an advantage over the strictly prairie species *P. haldemani*.

Unnatural Range Increases

Precise documentation of range changes in grasshoppers could be achieved if historical collecting sites could be resurveyed today. We are reasonably certain, though, that the cutting of eastern forests (mainly during the last century) opened up habitats for numerous species adapted to grasslands and forest edges. Numerous prairie margin species now occur widely in the eastern United States in areas that were almost completely covered by forests. By colonizing roadsides, other species have become extremely widely distributed. The Carolina locust (*Dissosteira carolina*), for example, is a ubiquitous roadside species that is now found in previously heavily forested regions. Whether the overall range (outer limits of the range) has changed is debatable because the species inhabits river margins and small natural eroded areas within the eastern forest region.

In the western United States, certain species do well in eroded habitats that often result from overgrazing. Thus, the ranges of species specializing on eroded ground probably increased along with increases in grazing. The clear-winged grasshopper (*Camnula pellucida*), a pest species from the northern Great Plains that greatly damages crops in the northern United States and western Canada, is now extremely abundant in overgrazed mountain meadows in the western states and is a good indicator of meadow degradation there.

Many pest species specialize on agricultural fields; their ranges have increased because of irrigation and the planting of crops in normally desert habitats (e.g., migratory grasshopper [*Melanoplus sanguinipes*], two-striped grasshopper [*M. bivittatus*], and differential grasshopper [*M. differentialis*]). Ball et al. (1942) documented numerous cases of grasshoppers moving into areas altered by agricultural practices.

Range Reductions and Extinctions: Case Studies

The Rocky Mountain Locust

Although it was the most abundant species during much of the last century in western North America, the Rocky Mountain locust (*M. spretus*) is now extinct; no specimens have been collected in this century. This species spread its destruction over many western states and was the source of great difficulty for early farmers east of the Rocky Mountains. The complete disappearance of the species has puzzled biologists for decades. The most reasonable hypothesis is that this species reproduced mainly along river valleys in Montana and Idaho and that with the heavy grazing of these habitats, beginning in the last part of the 1800's, these breeding areas were so heavily disturbed that breeding was disrupted (Lockwood and DeBrey 1990). Today, frozen remains of this species can still be found in glaciers in Montana.

California Coastal Ranges

The ANSP collections revealed that two undescribed species of *Melanoplus* were collected only in what is now downtown San Francisco. Recent revisions of the Marginatus group of the genus *Melanoplus* (Otte 1981, 1994, unpublished data base) reveal that the coastal ranges of California contain numerous members of this group, but that the ranges of many of the species are extremely limited. A subgroup of the Marginatus group speciated around the San Francisco Bay area, two species are known from the Berkeley area, two from San Francisco proper, and several from the north side of San Francisco Bay. The San Francisco species were collected in the first decade of this century when some natural vegetation still existed in San Francisco. South of San Francisco these species are replaced by related species. Several other species in the group are known only from the Monterey Bay region, and one species only from a single locality.

Two Rare Species

Two individuals of an extremely rare grasshopper species (*Eximacris superbum* Hebard) were collected in south Texas. Repeated efforts to collect the species have not met with success, although the species possibly

breeds only during winter or in the early spring and might still turn up when an effort is made to collect it in early spring. The only relative in this genus (*E. phenax* Otte) is known from a single male collected at Big Cedar in the Kiamichi Mountains of Oklahoma. Searches for this species have also been unsuccessful; again, it is possible that the species overwinters in the adult stage and therefore is not present during normal grasshopper breeding times.

Mountain Islands

Some species of grasshopper are known only from mountain tops (sky islands). In the East, some *Melanoplus* species are known from single balds (grassy mountain summits) in the Appalachian region (three new species are presently being described; Otte, unpublished data). In the western United States members of the Montanus group are also known only from single localities (A.B. Gurney, unpublished data). Surveys of mountains in Colorado, New Mexico, Arizona, Utah, and Nevada showed that some of these species have not yet been described and are believed to occur only on single mountains.

Within their limited ranges on mountains, the grasshopper species are further limited by environmental disturbance. I have encountered many overgrazed mountain meadows, sometimes even highly isolated ones surrounded by forest. These differ from ungrazed meadows chiefly in the height of the vegetation and the number of plant species there, and consequently in the incidence of short-winged grasshoppers. Collections from high mountain passes, where meadows are partly protected from cattle by fences along the road, show a clear effect of vegetation length on diversity: in the protected areas, nonflying grasshopper species are present, sometimes in large numbers, but are absent in grazed areas, while flying species, which have wide distributions (weedy species), are common. The principal reason for the difference appears to be that short-winged, nonflying species are highly vulnerable to bird predation, and without protective vegetation are unable to survive.

Pleistocene Islands in Northern Florida

The northern half of Florida contains a number of habitats that remained exposed as islands during interglacial periods. Several grasshopper groups have species associated with these former islands and species' ranges are highly restricted (Hubbell 1932). These areas are also ideal for farming and therefore have been greatly altered during the last 50-80 years. It is extremely likely that some species never collected were lost. It remains to be seen which species collected earlier this century still exist.

Management Implications

Large differences exist in range sizes between species that can fly and those that cannot (Otte 1979). In the latter group are numerous species known from a single or a few localities. Most of these inhabit island habitats (isolated bogs, prairie openings within the eastern forests, balds on the Appalachian range, mountain meadows on western mountaintops, hammocks in Florida, and perhaps coastal islands along the East coast). Many species in these regions have probably already been lost. Others can be saved by creating new sanctuaries and properly modifying existing ones. Within such regions it should be possible to set aside small sanctuaries or strings of sanctuaries from which cattle and other grazing mammals are excluded. Such sanctuaries already exist along highways where cattle are kept away from roadsides and railways.

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The Changing Insect Fauna of Albany's Pine Barrens

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Sand plains and similar inland sand deposits are desertlike islands in a sea of moist land. Because of rapid drainage of rainwater, sand plains are modern-day refugia that represent drier conditions that have existed off and on during the past 10,000 years. Drainage makes for drier soils that mimic prairie conditions and consequently harbor prairie relicts; thus these communities support a specialized flora and fauna. Sand barrens abound with rare or endemic forms, many of which are endangered.

The Albany pine barrens is a sand plains community and one of a relatively few scrub-oak (*Quercus ilicifolia*), pitch-pine (*Pinus rigida*) communities. Around the turn of the century, the Albany pine barrens was the site of intensive collecting by museum entomologists. Consequently, it has a historically well-documented and diverse insect fauna, making it possible to compare the fauna after a century of transition. Today, the region is heavily urbanized, and only 15.5 km^2 (6 mi^2) of the original 104 km^2 (40 mi^2) of natural barrens remain. As this habitat has been lost, 31 species of butterflies, moths, and skippers (Lepidoptera) have become locally extinct during the last century (McCabe et al. 1993). The past two decades have witnessed the most rapid change to the Albany pine barrens as well as the most dramatic decline of its resident insects.

Table. Insect species historically recorded from the Albany pine barrens but now extirpated (modified after McCabe et al. 1993).

Order	Family	Species
Coleoptera	Cicindelidae	*Cicindela patruela*
Diptera	Asilidae	*Cyrtopogon laphriformis*
		Promachus bastardii
Odonata	Libellulidae	*Williamsonia lintneri*
Lepidoptera	Hesperiidae	*Poanes viator*
		Erynnis brizo
		E. persius
	Nymphalidae	*Speyeria idalia*
		Phyciodes batesii
	Noctuidae	*Acronicta lanceolaria*
		A. radcliffei
		Agroperina lutosa
		Anomogyna badicollis
		Argyrostrotis quadrifiliaris
		Catocala pretiosa
		Eugraphe subrosea
		Homohadena badistriga
		Lithophane georgii
		L. lepida
		L. semiusta
		L. thaxteri
		Platypolia anceps
		Psectraglaea carnosa
		Pyreferra ceromatica
		Xylena cineritia
		X. thoracica
		Xylotype capax
	Geometridae	*Metarrhanthis apiciaria*
		Brephos infans
		Semiothisa eremiata
	Megalopygidae	*Megalopyge crispata*
	Saturniidae	*Citheronia sepulchralis*
		C. imperialis
	Sphingidae	*Hemaris gracilis*
		Darapsa versicolor

Insect Surveys and Data Collection

A general survey of all insect species included collections made using malaise traps, light traps, and netting. Because pine barren communities require regular disturbance regimes (e.g., fire) to maintain the unique open habitats that characterize them, we evaluated insects in areas that had been recently burned. Postburn sites of 1, 5, 12, and 30 years of age were sampled. I gathered published records from numerous sources and, through comparison with recent catalogs and museum holdings, I attempted to identify those species that have a restricted distribution or at least are unusual for New York State (McCabe et al. 1993). The population of the Karner blue butterfly (*Lycaeides melissa samuelis*) was the focus of an intensive monitoring program using a visual transect method (Higgins et al. 1991; McCabe et al. 1993; Meyer and McCabe 1993). Better known and easily identified groups have also been evaluated (McCabe and Huether 1985 [1986]; McCabe 1985; McCabe et al. 1993; McCabe and C. Weber, unpublished data).

Changes in Species Composition

The group for which I am able to make the most reliable comparisons is the Lepidoptera, particularly the owlet moths (Noctuidae). Unfortunately, I began investigations too late (1980) to witness the extirpation of many of the species historically recorded from Albany's pine barrens (Table). Of the 31 species of Lepidoptera extirpated from the pine barrens, 5 are partial to wetland habitats, which have suffered severely in the pine barrens: a skipper (*Poanes viator*), a sphinx (*Darapsa versicolor*), and three owlets *(Agroperina lutosa*, *Eugraphe subrosea*, and *Argyrostrotis quadrifiliaris*). Two owlet species (*Xylena cineritia* and *Acronicta lanceolaria*) are known to cycle in and out of an area in unpredictable patterns; thus their recent absence is thought temporary. Most of the remaining species now have distributions to the south (owlets: *Catocala pretiosa*, *Pyreferra ceromatica*, and *Xylotype capax*; flannel moth: *Megalopyge crispata*; giant silkworm moths: *Citheronia sepulchralis* and *C. imperialis*) or to the north (owlets: *Xestia (Anomogyna) badicollis*, *Lithophane georgii*, *L. lepida*, *L. semiusta*, *L. thaxteri*, *Platypolia anceps*, and *Xylena thoracica*; geometer: *Brephos infans*; sphinx: *Hemaris gracilis*). Many of these species are

not restricted to pitch-pine barrens, but the Albany pine barrens represents important habitat at the extreme edges of their ranges.

The species at the margins of their distribution in Albany have witnessed losses almost equally divided between north and south, suggesting that regular "pulses" of an insect species' distribution account for more species losses than can be attributed to the nearly sevenfold loss of habitat. It therefore seems appropriate to look closer at those species whose decline is most relevant to habitat loss.

The owlets *Psectraglaea carnosa* and *Chaetaglaea cerata* are usually found in coastal heath habitats but have been recorded from Albany. *Chaetaglaea cerata* is at precariously low levels in Albany, and *P. carnosa* is now locally extinct. Recent records of *C. cerata* and the last reports of *P. carnosa* were from an area of the pine barrens adjacent to the current landfill.

Another once-common species in the pine barrens is the owlet *Homohadena badistriga*, but I have observed this moth only once during the last 4 years (1989-93). *Homohadena badistriga* caterpillars show a marked preference for the native shrub *Lonicera dioica* over all other *Lonicera* in the area. This shrub species, which appears to be a favorite browse of deer (personal observation), has become far less abundant in the past 12 years (J. Mattox, Bard College, personal communication). None of 27 bushes of *L. dioica* I had visited in 1982 exist today.

The owlet *Agrotis stigmosa*, which favors the periphery of open dunes, has a simpler story. The two most substantial open dunes in the Albany barrens have recently been developed, and *A. stigmosa* has subsequently been rarely encountered and may soon be lost.

The Karner blue butterfly (*Lycaeides melissa samuelis*), now listed as an endangered species, has markedly declined in the Albany barrens (Figure). This species appears to be a barrens relict that has been losing ground over all of the Northeast. Its larvae feed on *Lupinus perennis* (lupine). Another lycaenid butterfly, *Incisalia irus*, also dependent on lupine, has suffered a similar decline. The continued decline of *L. melissa samuelis* on the Albany pine plains (Figure) is illustrated by using both recent data (Higgins et al. 1991; Meyer and McCabe 1993) and earlier population estimates of Cryan (1980) and Schweitzer (1988, 1990). This downward trend continues even though some sites now support more lupine than a decade ago and appear to be well protected.

Pine Barrens Management

Native pine barrens plants such as pitch pines, New Jersey tea, and lupine are very difficult to establish successfully. Seedlings are shaded out by scrub oak. Young pitch pines are heavily browsed by deer and severely attacked by an introduced pine sawfly; younger plants are completely defoliated. Lupines are devoured by cottontail rabbits. Most characteristic pine barrens plants require open, disturbed sites.

Fire has been scientifically employed as a management practice on the Albany barrens only quite recently. Scrub oak successfully regenerates after burns, as does the locust, *Robinia pseudoacacia*, a tree introduced from the Southeast for fence posts. One of the pine barrens rarities is *Chytonix sensilis*, a fungus-feeding moth. The year after a burn, fire-blackened trunks support luxurious growths of this fungus. Despite this, *C. sensilis* was most abundant in 12-year-old burn sites where hardly any fungus had been present. In areas unburned for more than 30 years, only *C. sensilis* females were collected. One 12-year-old site is the same one that supports *Chaetaglaea cerata* and had supported *P. carnosa*, suggesting that a burn frequency of at least 12 years is best to promote some of the choicest pine barrens associates. I trapped moths extensively in postburn sites of 1, 5, 12, and 30 years of age. No site was available with a postburn age between 12 and 30 years; an optimal burn frequency will likely fall somewhere within this range. A frequent burn schedule would be highly detrimental to insect species very susceptible to fires, such as one of the elfin butterflies, *Incisalia henrici*.

Species on the periphery of their range may not be reliable indicators of habitat quality. Natural fluctuation in range limits appears more significant than formerly considered. This can be attested to by the extirpation of 31, and the addition of 32, moth species. The decline of characteristic pine barrens species has to be examined on a case-by-case basis.

The Albany pine barrens has also been adversely affected by vehicular traffic, windbreaks created by roads and buildings, development of open dunes, introductions of exotic species, and even the frequency of fires, which promote some and compromise other pine barren rarities. Cutting to create oak openings should be considered as a management practice. In addition, open dunes may have to be artificially maintained where artificial windbreaks interfere.

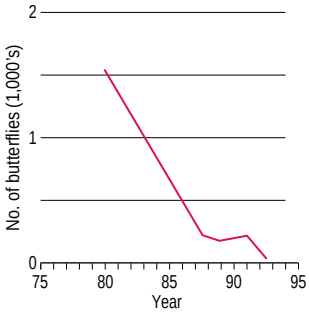

Figure. Decline of the Karner blue butterfly at Willow Avenue site in Albany (McCabe et al.1993).

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Lepidoptera Inventories in the Continental United States

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Lepidoptera (butterflies and moths) make up about 13% of the described and named 90,000 insect species of North America (11,500 named) and are among the better known large orders, although no complete inventory of Lepidoptera species exists for any state, county, or locality in North America.

The rationale for local or regional inventory of insects is related to their importance in biodiversity. Insects make up 75% of all described animals, and in natural communities their species outnumber those of all other higher organisms combined. Thus interrelationships between insects and other organisms form the most prevalent and comprehensive elements of the fabric of biological communities.

Lepidoptera are the major group of plant-feeding insects, and local inventories of Lepidoptera can help indicate the stability and diversity of plant communities. When we have several reasonably complete local inventories of Lepidoptera in different regions of the country, we will be able to make predictions about overall insect—and therefore biological—diversity, and about relationships between plant and insect species richness on a local or regional basis. Such knowledge will lead to more efficient methods of assessing the health and loss of biological diversity.

Once a baseline inventory is done, monitoring of changes in species richness and abundance to assess the ecological health of the community can be carried out. Inventory of a diverse group of insects such as the Lepidoptera must involve various approaches and collecting procedures. This article summarizes the status of local and state inventories of Lepidoptera and suggests a model for planning comparable faunal inventories of major insect groups.

Lepidoptera Surveys

To gather information on the status of current inventories, I mailed a one-page questionnaire to 25 lepidopterists thought to be developing local or state lists. Nearly all responded, and several are conducting more than one census. Early in 1993 I published a request for information on inventories in the *News of The Lepidopterists' Society*, which is distributed to about 1,000 members in North America. The responses were fewer than I had expected; there may be many more inventories in progress than those reported to me. For completed local and state lists, I searched the literature, but the results are likely to be incomplete because such lists are lengthy and often are published in obscure literature not well referenced by abstracting services.

A thorough local inventory must depend upon diverse methods: daytime searches for butterflies and diurnal moths, nighttime collections of moths attracted to ultraviolet (UV) or mercury vapor lights, and rearing caterpillars (larvae) to the adult stage. In some regions a fourth approach, "sugaring," the attraction of moths to sweet, fermenting bait, is effective for many species not readily attracted to lights. Generating an inventory for a large group of insects such as Lepidoptera is difficult because the season that each species can be found may be short; species abundance varies widely from year to year; several techniques and specialists' experience are needed to complete a thorough census; and, beginning early in the survey, individuals of vagrant species are encountered.

A major problem in compiling an inventory is the identification of species. This is easily accomplished for butterflies (6% of the Lepidoptera), and there are hundreds of local and state lists (Field et al. 1974). Identifications are accessible for the larger moths (macrolepidoptera), including inchworm moths (Geometridae), giant silkworm moths (Saturniidae), hawk moths (Sphingidae), owlet moths (Noctuidae), and related families. However, for many so-called "microlepidoptera" (primitive suborders, leaf miner and leaf roller moths, etc.), 10%-90% of the local species in some families are undescribed. As a result, most state and local lists have dealt only with macrolepidoptera or have treated the microlepidoptera species only cursorily.

Inventories and Trends

There are published Lepidoptera lists or surveys in progress from at least 30 states, and

local inventories of at least macrolepidoptera for 35 or more reserves, counties, or islands in the continental United States. The tendency of lepidopterists to compile state and local lists, which had been expressed primarily by faunal studies of butterflies (Field et al. 1974), increasingly has encompassed moths. Half of the state lists and 85% of the local inventories have been published since 1964, and there are an even larger number in progress. More of these include microlepidoptera than before probably because of considerable progress in the descriptive taxonomy of most families during the past 35 years (e.g., Covell 1984).

State Lists

The older and more comprehensive state lists are in the eastern United States (Fig.1). The most complete state lists of Lepidoptera are those for New York (Forbes 1923-60), New Jersey (Smith 1910; Muller 1965-76), and Maine (Brower 1974-86), although these lists have many identification problems. The most active are in Ohio, Kentucky, Mississippi, Florida (Kimball 1965), and Texas. There are lists primarily or only of macrolepidoptera for some states, including Arizona (Bailowitz et al. 1990), Michigan (Moore 1955), Pennsylvania (Tietz 1952), and Maryland (D.C. Ferguson et al., National Museum of Natural History, unpublished data). Lists of described species for the western states are now being done (Fig. 1).

Local Inventories

Thirty-five local inventories have been published or are in progress (Fig. 1). These vary greatly in moth families included, geographic size, and number of years in progress. Several inventories, including those of Martha's Vineyard and Nantucket, Massachusetts (Jones and Kimball 1943); Mount Desert Island, Maine (Proctor 1946); Welder Wildlife Refuge, Texas (Blanchard et al. 1985); Ash Canyon, Arizona (N. McFarland, Sierra Vista, AZ, unpublished data); and three in California (McFarland 1965; Powell, unpublished data) span 10-50 years and are estimated to be 85%-95% complete (Table).

Unfortunately, no two inventories can be meaningfully compared because they vary in important parameters. Many have recorded only macrolepidoptera, often only one sampling approach was emphasized, inventories are made of sites that vary greatly in size, inventory duration ranges considerably (Table), and the methods of recording data are often inconsistent.

A Model Inventory

We have been conducting inventories in California to document species discovery rates and other comparative data. The most comprehensive inventory is at the University of California Big Creek Reserve in coastal Monterey County, an area of diverse habitats and elevations. The census has been carried out primarily by specialists' visits. We have sampled in all months, on 175 dates, recording every species in each sample; we spent 180 personnel-days for diurnal species, recorded more than 260 UV light samples, and processed 1,350 larval collections and their rearing. The census (more than 900 species) is believed more than 90% complete, with 3% or fewer of the species in each three-date sample new to the list during dates 155-175 (Fig. 2). Butterflies and diurnal moths make up 16% of the total, and microlepidoptera recorded only as larvae make up another 9%.

The species discovery rate was slow because we could not sample the whole reserve during each visit, and most of the effort followed a consummate fire in the fourth year of our 12-year inventory; many species were first collected in year 9 or 10. Nevertheless, the results provide a realistic idea of the effort required in a complex community to achieve a reliable species accumulation curve (Fig. 2).

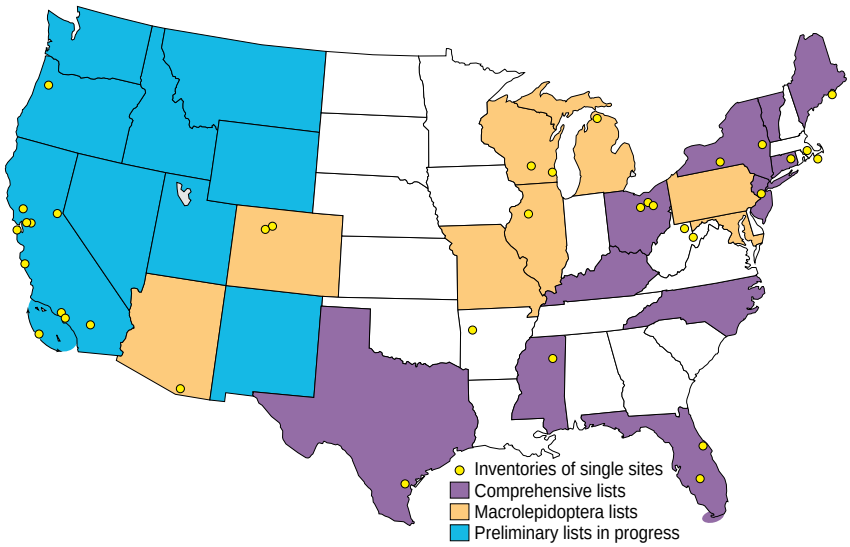

Fig. 1. Distribution of state and local inventories of Lepidoptera in the contiguous 48 United States. States having comprehensive lists (all families) published or in progress, those with macrolepidoptera lists, and those with preliminary lists in progress are indicated. Dots indicate locations of 35 local inventories of single sites, reserves, and islands, either published or in progress.

State*	Area (km^2)	Duration (years)	% est. censused	No. of species
Arizona macro	< 10	13	> 95	900 +
California macro	< 10	10	> 95	278
California micro	< 10	25	80-85	160
California micro	16	12	85-90	376
Florida macro	< 10	2	80-90	318
Illinois micro	200	50	90-95	945
Maine macro	< 10	4	< 70	349
New Jersey macro	< 10	5	90	410
New York macro	100	30 +	> 95	872
Oregon macro	< 10	1.5	70-80	360
Texas macro	30	24 +	50-70 ?	481
West Virginia macro	< 10	6	90	400

* Macro — macrolepidoptera
Micro — microlepidoptera

Table. Comparison of size, duration, estimated percentage completed, and numbers of species recorded in local inventories of Lepidoptera, listed by state.

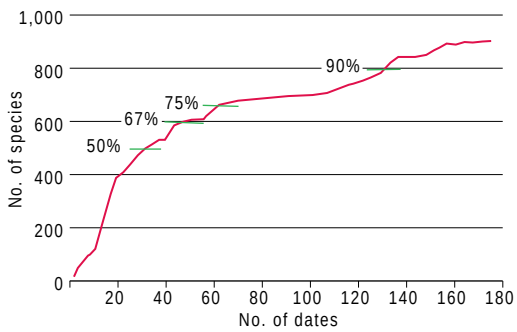

Fig. 2. Species discovery curve for all Lepidoptera at the Big Creek Reserve, Monterey County, California, based on collections during 1980-93. The total (910 species) is believed to be more than 90% of the resident fauna. Points along the curve are indicated when 50%, 67%, 75%, and 90% of the recorded total were reached.

The data from Big Creek and other inventories (e.g., Butler and Kondo 1991) demonstrate that short-term effort is inadequate to inventory insects. We cannot determine faunal composition from a few visits to a site or even comprehensive sampling over one season. If a group under study is relatively uniform in biology, one sampling or trapping technique may be adequate and a steeper species accumulation curve can be attained. At Big Creek, all Lepidoptera accumulation did not reach 50% until 25 dates, or 75% until 65 dates (Fig. 2).

Planning Inventories

A comprehensive inventory should employ diverse sampling approaches, as outlined previously. Light trapping alone may be expected to recover about 75% of the species after extended effort. If monitoring changes in populations is a goal, a subset of the fauna (e.g., one or a few well-known families) should be the focus, with sampling standardized by method (e.g., light trap), site, frequency, and so forth, so as to be repeatable. To make local inventories comparable, data should be identified in several ways: (1) results should be recorded by standardized subsets of the area; (2) sampling effort should be quantified and reported (e.g., number of person-hours or days, dates, UV samples); (3) first records for each species should be recorded to document species discovery rates; (4) voucher specimens should be preserved, especially for small moths, because detailed study by a specialist may be necessary to distinguish species. Ideally, every specimen can be bar-coded to the data base, a rapid process if carried out in tandem with data entry initially as is being done in Costa Rica (Janzen 1992).

We do not know how many species of moths and butterflies live in any state, county, or locality in North America. We need baseline inventories that are standardized by area or sampling effort by which different parts of the continent or tropical faunas can be compared to extrapolate patterns in regional, national, or world biodiversity of Lepidoptera.

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Fourth of July Butterfly Count

by
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International Count Co-editor

The Xerces Society started the Fourth of July Butterfly Count (FJC) in 1975, sponsoring it annually until 1993, when the North American Butterfly Association (NABA) assumed administration. The general methods of the butterfly count are patterned after the highly successful Christmas Bird Count (CBC), founded in 1900 and sponsored by the National Audubon Society (Swengel 1990).

Courtesy A.B. Swengel

Painted lady (*Vanessa cardui*) nectaring on showy milkweed (*Asclepias speciosa*).

The results of the FJC, including butterfly data, count-site descriptions, and weather information on count day, are published annually. The count was designed as an informal program for butterfly enthusiasts and the general public. These counts can never substitute for more formal scientific censusing because data sets from the counts have flaws that impair scientific analysis. Nevertheless, the FJC program does provide data that, with considerable caution, can be useful for science and conservation (Swengel 1990). FJC data have been used to study the biology, status, and trends of both rare and widely distributed species (Swengel 1990; Nagel et al. 1991; Nagel 1992; Swengel, unpublished data).

Analysis and Application

I reviewed FJC count reports and other publications for applications of FJC data to monitor the status and trends of North American butterfly species. These studies varied considerably in sample size, amount of data manipulation and statistical analysis, and degree of variable control. Different methods of using FJC data include, in order of ascending statistical refinement: presence or absence of a species in a subset of counts; highest observed number of a species on a single count; individuals of a species per count for a subset of counts in a given year; and individuals of a species per count hours or per count miles. The subset of counts used to supply data for analysis also varied from a single count to all counts in a certain region or all counts ever reporting a given species during the study period. The sample subset and statistical approach are best determined by the nature and extent of available data.

The rationales, methodologies, shortcomings, and validity of analyzing FJC data have been detailed elsewhere (Swengel 1990), but are based on the substantial ornithological literature regarding the scientific use of CBC and other types of survey data. As ornithologists have clearly indicated, these kinds of data sets must be used with great care because (1) the sample sites and dates depend on when and where volunteer observers choose to conduct a count; (2) the quality of sampling and accuracy of data vary among counts; (3) only certain species are sampled adequately enough to allow data interpretation; and (4) the species complex can vary somewhat from year to year. Even with such constraints, these data sets are valuable because of the numerous sites surveyed, their wide geographic scope, and the relatively low cost of data acquisition.

Interpreting Count Data

For the first 11 years of the count program (1975-85), only a few dozen counts were held annually, but since then the number of annual counts has increased steadily to 209 in North America in 1993. Each FJC annual report since 1982 has provided a table that details how many counts reported each species and which single count found the most individuals of each species. Although informal, this table indicates the frequency and abundance of butterfly species as observed in the counts.

Several rare species with federal status under the Endangered Species Act have been sampled in the counts, as reviewed in the introduction to the 1993 FJC annual report (Opler and Swengel 1994). A researcher using FJC to study rare butterflies must be careful in interpreting the data, however. Unless a number of FJC counts are specifically designed to sample rare species well, it is unlikely that rare species will be sampled adequately enough to allow scientific analysis of status and trends. Even in these cases, however, site data for rare species reported in FJC remain useful as leads to follow in status surveys of extant populations for these species (Opler and Swengel 1994). Most likely, the data should be considered as augmenting additional, more formal scientific study and should be confirmed, either by alternative survey means or by contacting the counters for documentation.

Because of the larger sample size, FJC data may better demonstrate the population trends of more abundant and widespread species. For example, the painted lady (*Vanessa cardui*) is a

Courtesy A.B. Swengel

Monarch *(Danaus plexippus)* nectaring on dwarf blazingstar (*Liatris cylindracea*).

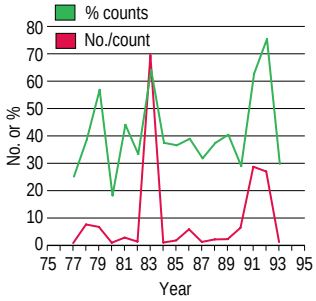

Fig. 1. Number of painted ladies (*Vanessa cardui*) per count and percentage of counts reporting this species, for all counts in North America north of Mexico, 1977-93.

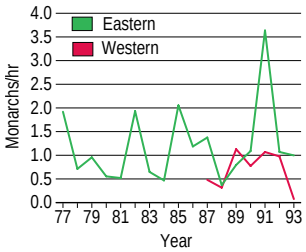

Fig. 2. Mean number of monarchs (*Danaus plexippus*) per party-hour for counts reporting the species east of the Rocky Mountains, 1977-93, and west of the Rocky Mountains, 1987-93.

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subtropical species with a tendency to wander (immigrate) outside its residential range into temperate regions, with periodic years of massive invasions. FJC data clearly reflect this aspect of the species' natural history by showing dramatic fluctuations in painted lady frequency and abundance in the counts in 1979, 1983, and 1992 (Swengel 1993; Fig. 1). These outbreaks may correlate with weather perturbations in the species' residential range (Myres 1985; Swengel 1993).

FJC data have also been used to document fluctuations in other immigrant species (Swengel 1990), but especially to monitor population trends of the migrant monarch butterfly (*Danaus plexippus*; Swengel 1990 and unpublished data) that breeds in temperate North America and overwinters in Mexico and coastal California. The number of these butterflies fluctuates considerably (Fig. 2); fluctuations tend to correlate with major climatic perturbations such as the El Niño Southern Oscillation and major volcanic eruptions (Swengel, unpublished data). Monarchs and painted ladies often show dramatic fluctuations in the same years (e.g., 1978-79, 1982-83, 1991-92), but usually they vary in opposite directions (Figs. 1 and 2), suggesting that the same widespread climatic phenomena tend to affect both species in different ways. Because conservationists are concerned about threats to the overwintering habitat of monarchs, long-term data sets such as FJC are valuable to check for persistent downward trends.

While FJC cannot replace more formal and intensive scientific surveying, it does offer a readily available and ever-enlarging data set that, with caution, is useful for science and conservation because of its relative continuity, inexpensiveness, large size, and widespread sampling.

Courtesy A.B. Swengel

Karner blue (*Lycaeides melissa samuelis*) male basking on grass.

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Species Richness and Trends of Western Butterflies and Moths

by
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Butterflies and large moths are among the best-sampled insects and as such are excellent indicators of ecological conditions or environmental change. Because the caterpillars of most Lepidoptera are herbivorous, their species richness is most often a reflection of plant diversity (Brown and Opler 1990).

Management or restoration of invertebrate diversity requires comprehensive data about the status and occurrence of species. I present the species richness of butterflies and three moth families in the 17 western conterminous states and five smaller subareas in the West.

Data Collection

The species richness of western butterflies and moths (Lepidoptera) was determined by using four county-level atlases and counting the number of species recorded in each state or region (Peigler and Opler 1993; Smith 1993; Stanford and Opler 1993; Opler, unpublished data). The county atlases were developed by using specimen data from field surveys, private collections, museums, and scientific monographs. The records analyzed include all historical data; thus the map for a particular species may not represent its current status.

Butterflies (superfamilies Papilionoidea and Hesperioidea), hawkmoths (Sphingidae), silkmoths (Saturniidae), and tiger moths (Arctiidae) are relatively well-sampled groups and therefore give a good preliminary indication of the geographic patterns of species richness. Populations of the selected butterflies and moths in the 17 conterminous western states and five subregions were selected as sampling units.

The five subregions are the lower Rio Grande Valley of South Texas, the Big Bend region of Texas, the Colorado Front Range, the isolated mountains of southeastern Arizona and adjacent New Mexico (the so-called "sky islands"), and southern California south of the Transverse Ranges (Fig. 1). They were selected

based on *a priori* knowledge of species richness and patterns of endemic species occurrence.

The number of resident butterflies was determined by counting the number of species recorded for each state or region. Species known to be nonresidents (vagrants or sporadic residents) in a particular state or region were excluded. For the three moth families, all species recorded in a particular state or region, including vagrants, were included in the counts.

The reader should be aware that the quantity and quality of the data are not sufficient to analyze temporal trends for individual species. In addition, all geographic units have not been sampled with equal intensity.

Status and Trends

In the 17 western states, 915 species of butterflies and moths in the studied groups are recorded. The number of species ranges from 181 (20% of total species count) for North Dakota to 520 (57% of total species count) for Texas (Table 1). In general, there are fewer species of butterflies and moths in more northern states and in states with less topographic diversity, which creates less variety in terrain. Of course, larger states tend to have more species than smaller states, since large states, on average, have more diverse habitats and topography. These trends are similar to those of other organisms as well.

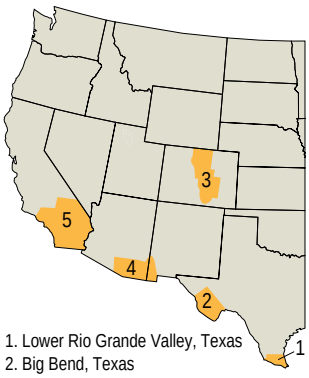
The patterns for butterflies and the three moth families are similar, except that species richness of hawkmoths is unexpectedly high in Nebraska and Oklahoma (Table 1), most likely because of the immigration of nonbreeding tropical species (Smith 1993).

Each of the five subregions is smaller than Washington, the smallest western state, yet species richness is greater in all subregions (except the Lower Rio Grande) than in nearly two-thirds (11 out of 17) of the states studied (Table 2). The richest subregion, with 273 species, is the sky islands of southeastern Arizona and southwestern New Mexico. Species richness is second highest in the Front Range of Colorado, which straddles the Continental Divide and includes a large elevational range and diverse habitats ranging from prairie to alpine tundra. The relatively small Lower Rio Grande Valley has the fewest species of the five subregions, but still has more species than some states that are almost 15 times as large. Moreover, the best remaining native habitats in this subregion amount to only a few thousand hectares. Sampling intensity is relatively high for the Front Range, sky islands, and southern California, but increased sampling efforts in the Lower Rio Grande Valley and Big Bend might add significant numbers of species.

Each subregion has a distinct butterfly and moth fauna that includes many endemics—20 or more are potential candidates for listing as endangered species. Each of the four subregions that adjoin the Mexican border also hosts from a few to many Mexican species that occur nowhere else in the United States.

Table 1. Number of species of selected Lepidoptera by state.

State	Area km^2 (mi^2)	Hawk-moths	Silk-moths	Tiger moths	Butter-flies	Total
Arizona	294.0 (113.5)	49	31	111	246	437
California	404.8 (156.2)	30	17	52	225	324
Colorado	268.3 (103.6)	32	18	71	230	351
Idaho	210.9 (81.4)	16	7	24	154	201
Kansas	211.9 (81.8)	23	9	34	133	199
Montana	376.6 (145.4)	10	6	27	184	227
Nebraska	198.4 (76.6)	36	10	38	170	254
Nevada	284.6 (109.9)	18	9	28	181	236
New Mexico	314.2 (121.3)	31	24	83	272	410
North Dakota	179.5 (69.3)	30	3	16	132	181
Oklahoma	177.9 (68.7)	39	13	30	146	228
Oregon	249.2 (96.2)	23	9	28	154	214
South Dakota	196.6 (75.9)	12	7	32	149	200
Texas	678.6 (261.9)	69	34	127	290	520
Utah	212.6 (82.1)	24	14	46	197	281
Washington	172.2 (66.5)	17	8	27	140	192
Wyoming	251.2 (97.0)	18	7	49	197	271
Totals for western U.S.	4,681.5 (1,807.1)	99	68	219	529	915



1. Lower Rio Grande Valley, Texas
2. Big Bend, Texas
3. Front Range, Colorado
4. Sky islands, Arizona and New Mexico
5. Southern California

Fig. 1. Western United States showing five subregions of high species richness.

Table 2. Number of species of selected Lepidoptera by subregion.

Regions	Area km^2(mi^2)	Hawk-moths	Silk-moths	Tiger moths	Butter-flies	Total
Lower Rio Grande[a]	14.0 (5.4)	33	11	11	115	170
Big Bend[b]	37.3 (14.4)	28	10	10	151	199
Front Range[c]	71.5 (27.6)	26	11	11	176	224
Sky islands[d]	41.4 (16.0)	41	25	25	182	273
Southern California[e]	116.6 (45.0)	23	14	33	159	229

[a]Lower Rio Grande Valley includes all of Cameron, Hidalgo, Willacy, and Starr counties, TX.
[b]Big Bend includes all of Brewster, Jeff Davis, and Presidio counties, TX .
[c]The Colorado Front Range includes all of Boulder, Clear Creek, Custer, Douglas, El Paso, Fremont, Gilpin, Grand, Huerfano, Jackson, Jefferson, Larimer, Park, Pueblo, Summit, and Teller counties.
[d]Sky islands include all of Cochise and Santa Cruz counties, the eastern half of Pima County, AZ, and all of Hidalgo County, NM.
[e]Southern California includes all of Imperial, Los Angeles, Orange, Riverside, San Bernardino, and San Diego counties.

The highest species richness of western Lepidoptera is in the Southwest, usually in areas that adjoin the Mexican border. Invertebrates are seldom considered in management plans for parks, preserves, or refuges, and their management needs are often not the same as those for vertebrate wildlife or plants. Processes unfavorable to Lepidoptera diversity include overgrazing, overuse of controlled burns, urbanization, and excessive modification or recreational use of selected specialized ecosystems such as wetlands and dunes. Because invertebrates account for more than 90% of animal species, it makes good sense for managers to address the health and populations of these species in planning and in making management decisions. Management which favors high Lepidoptera species richness is usually similar to that which favors natural ecosystem processes and the maintenance of extensive native plant populations.

Courtesy P.A. Opler, NBS

Two tailed swallow-tail (*Papilio multicaudata*).

Courtesy P.A. Opler, NBS

Tiger moth (*Gnophaela vermiculata*).

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Courtesy P.A. Opler, NBS

Sphinx moth (*Proserpinus juanita*).

The Tall-grass Prairie Butterfly Community

by
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The prairie biome is a plant community dominated by grasses and nongrassy herbs (wildflowers or "forbs"), with some woody shrubs and occasional trees. Prairie is classified into three major types by rainfall and consequent grass composition. The easternmost and moistest division is the tall-grass prairie (Risser et al. 1981). Although tall-grass prairie once broadly covered the middle of the United States (Fig. 1), this biome is now estimated to be at least 99% destroyed from presettlement by pioneers, who converted it for agricultural uses. Prairie loss continues through plowing, extreme overgrazing, and development, but at varying degrees. Prairie is also lost passively because the near-total disruption of previous ecological processes causes shifts in floristic composition and structure.

As a result of this habitat destruction, butterflies and other plants and animals that are obligate to the prairie ecosystem are rare and primarily restricted to prairie preserves. The Dakota skipper (*Hesperia dacotae*) and the regal fritillary (*Speyeria idalia*) are federal candidates for listing under the Endangered Species Act, and additional prairie butterfly species are on state lists as officially threatened or endangered. Patches of original prairie vegetation remain in preserves, parks, unintensively used farmlands such as hayfields and pastures, and in unused land. These remnants of prairie, however, are isolated and often in some state of ecological degradation.

The existence of prairie depends on the occurrence of certain climatic conditions and disturbance processes such as animal herbivory and fire. These natural processes, however, are severely disrupted today because of the destruction and fragmentation of the prairie biome. Without management intervention, the vegetational composition and structure of prairie sites are altered through invasion of woody species and smothering under dead plant matter. Prairie usually requires active management to maintain the ecosystem and its biodiversity, but it is difficult to know exactly which processes once naturally maintained the prairie ecosystem. Frequent fire, whether caused by lightning or set by native peoples, is usually considered the dominant prehistoric process that maintained prairie; thus management for tall-grass prairie in most states relies primarily or solely on frequent fire (e.g., Sauer 1950; Hulbert 1973; Vogl 1974). Other researchers (e.g., England and DeVos 1969), however, assert that prairie was the result of grazing by large herds of ungulates as in the Serengeti in Africa.

Despite this scientific conflict, it appears certain that successful management for maintaining the prairie landscape and its native species should be based on these natural processes, whatever they were. The vast diversity and specificity of insects to certain plants and habitat features make them fine-tuned ecological indicators. Thus, butterfly conservation is useful not only for maintaining these unique species, but also for helping us monitor and learn about the soundness of our general ecosystem management.

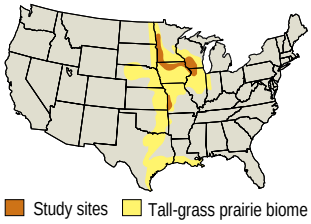

Fig. 1. Original boundaries of the tall-grass prairie biome in the United States (Risser et al. 1981) and locations of study sites (A.B. Swengel, unpublished data).

Survey and Classification

We counted 90 butterfly species and 80,906 individuals in surveys from 1988 to 1993 at 93 prairies varying from 1 to 445 ha (3 to 1,100 acres) in the Upper Midwest (Illinois, Iowa, Minnesota, Wisconsin) and southwestern Missouri (Fig. 1). Most sites are managed principally with fire, with burns averaging about 25% (range 0-99% or more) of the prairie patch per year. Many Missouri sites are managed primarily with summer haying along with a little burning and cattle grazing. The vegetation in each survey unit was relatively uniform.

Any species observed 100 or more times was designated a study species. Before analyzing the results, we classified the study species by habitat niche breadth: prairie specialist, grassland, generalist, and invader. We used population indices (individuals observed per hr in each

unit) to identify which units had relatively greater densities of particular species and which factors might account for this variation. Details regarding the survey and statistical methodologies are provided elsewhere (A.B. Swengel, unpublished data).

Management and Distribution

The overwhelming destruction of prairie habitat has had disastrous consequences for prairie-specialist butterflies, not just because of the outright loss of appropriate living space but also because of habitat fragmentation. Because prairie-specialist butterflies are rarely encountered outside of these fragmented prairie patches, populations at different sites may have minimal gene flow and are rarely able to recolonize sites of local extinctions. For example, the regal fritillary is the most widespread prairie butterfly species, but it requires larger habitat patches or connected networks of habitat patches to maintain populations. The arogos skipper *(Atrytone arogos iowa*) and ottoe skipper (*Hesperia ottoe*) also occur widely in the prairie biome but are more restricted in their habitat requirements, resulting in more localized and spotty distributions. The Dakota skipper and poweshiek skipper *(Oarisma poweshie*k) are most restricted in range, occurring only in northern prairie, and have further habitat restrictions within that range. As a result, the northern Midwest (northwestern Iowa, western Minnesota, and the eastern Dakotas) is the region where tall-grass prairie conservation has the most potential for maintaining the greatest diversity of prairie-specialist butterflies.

Courtesy A.B. Swengel

Regal fritillaries (*Speyeria idalia*) mating on pale purple coneflower (*Echinacea pallida*).

Our surveys show that the management occurring at a prairie critically affects whether prairie-specialist butterflies exist at the site and at what abundance. Although each butterfly species has its own response to fire, the prairie specialists show a pronounced and statistically significant decline after fire; this decline persists 4 or more years (A.B. Swengel, unpublished data). Species with the broadest habitat adaptation (invaders) are most abundant in recently burned units and least abundant in units left unburned the longest. Species of intermediate adaptations (grasslands, generalists) showed milder, intermediate trends.

Unintensive haying management (a single annual or biennial cutting with removal of the clipped vegetation) is more favorable for butterfly diversity. Such haying is more beneficial for butterflies sooner after treatment and causes a less pronounced variation in butterfly abundance between different treatment years. In general, butterflies are more abundant in the first years after haying than after burning; specialists account for much of this difference (Fig. 2). Our limited opportunities to test light grazing show that it may also serve specialist butterflies better than fire.

Prairie-specialist butterflies apparently respond to different management types because of varying degrees of mortality (e.g., fire causes more direct mortality than haying or grazing) and because of differences in continuity of required habitat resources (e.g., fire removes all cover but is followed by regrowth of thick cover, while unintensive haying and grazing can more consistently maintain moderate cover). Management also indirectly affects butterfly populations by altering the abundance and occurrence of plants they depend on as well as the vegetational structure and physical features they require.

These results are consistent with butterfly conservation experience around the world, particularly in Europe and Australia (Butterflies Under Threat Team 1986; Kirby 1992; New 1993). Thus, simply preserving habitat is not sufficient to conserve insect biodiversity; suitable management approaches and land uses compatible with the habitat's native biodiversity must be preserved. It is possible to maintain plants successfully without protecting the associated animals, but it is impossible to maintain the associated animals successfully without protecting the plants.

It appears desirable for managers to aim for diversity and patchiness in prairie-management approaches within and among sites rather than broadly applying a single management formula for prairie everywhere. Whether or not a site is managed specifically to conserve insects, declines and extirpations of insects specialized

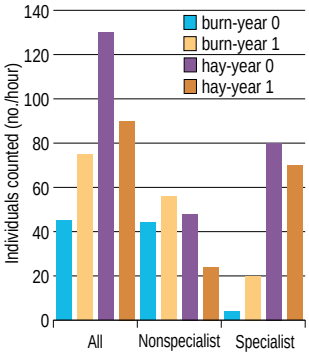

Fig. 2. Abundance of all, nonspecialist (grassland, generalists, and invaders), and prairie-specialist study species in the first years of fire and hay management, Missouri study sites.

to the habitat indicate that ecological degradation has already occurred there, while maintenance of these species indicates success in ecosystem conservation. Because we found that management with mechanical cutting or light grazing appears most effective for maintaining both the prairie habitat and its associated specialist insects (seeming to indicate an ecosystem adaptation to herbivory), we recommend that these methods should have a primary role in modern prairie management for the conservation of biodiversity. There is cause for optimism, however, because no known prairie butterfly species have gone extinct, despite their rarity. Instead, these species have persisted on habitat remnants, showing that appropriate habitat preservation and management should translate into readily measurable conservation successes.

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The Biota of Illinois Caves and Springs

by
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Caves and springs tend to be inhabited by a highly specialized and intolerant diversity of vertebrate and invertebrate species. Ongoing research on the aquatic and terrestrial macroinvertebrates and terrestrial vertebrates inhabiting 105 springs and caves in Illinois (Figure) surveyed from 1990 to 1993 has verified the uniqueness of this biota and highlighted the very fragile ecosystem in which these organisms survive. Data on more than 8,000 invertebrate specimens, representing 4 phyla, 11 classes, and 32 orders, have been collected and the data entered into a data base. More than 2,500 specimens and 27 species of vertebrates (3 fishes, 7 salamanders, 4 frogs, 1 turtle, 4 birds, 1 raccoon, and 7 bats) were observed in caves, dominated by the salamanders and bats.

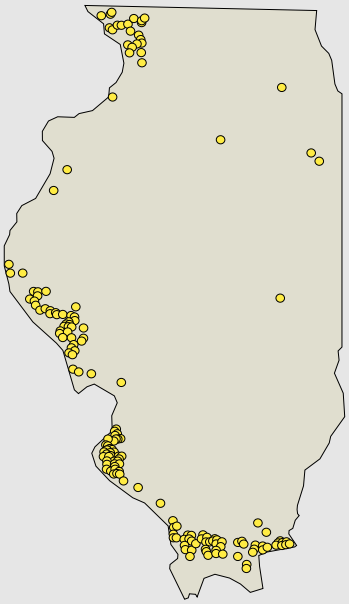

Figure. Distribution of springs and caves in Illinois.

The water chemistry of the Illinois springs and cave streams was typical of most hardwater springs, although nitrate levels in one spring and one cave stream in the karst region of Monroe County exceeded the Illinois Pollution Control Board's Maximum Contamination Level of 10 mg/L (10 ppm), raising concern over the effects of agricultural runoff on the biota of Illinois cave streams. The detection of mercury in the tissue of amphipods and isopods was noted, although no detectable level of mercury was determined in any of the water samples tested.

Karst limestone regions have sinks, underground streams, and caves. Qualitative collections of invertebrates and observations of vertebrates were made to determine species richness and the spatial distribution of each species. In caves, habitat selection and cave preference (entrance, twilight, and dark zones) were examined for aquatic invertebrates and terrestrial vertebrates and invertebrates.

The aquatic macroinvertebrates were dominated in abundance and diversity by noninsect arthropods, several of which are currently on federal and state endangered species lists (e.g., the amphipod *Gammarus acherondytes*). In terms of abundance, the amphipods *Gammarus minus* and *G. pseudolimneaus* and the turbellarian *Phagocata gracilis* dominated surface springs, while the amphipod *G. troglophilus* dominated cave streams. The diversity of oligochaete worms, with 24 taxa, proved to be the most surprising feature of the study, especially because several unidentified taxa of worms were collected that may be new species. *Varichaetadrilus angustipenis*, although previously collected only rarely in Illinois, was recorded from numerous springs. The collection of *Allonais paraguayensis* in Old Driver Spring was the most interesting find; this species has been reported only from a locality in Louisiana and an aquarium in New York. The presence of *A. paraguayensis* in Illinois represents a significant range extension for this species. The occurrence of unidentifiable taxa of Lumbricidae and Lumbriculidae also poses interesting systematic questions.

Aquatic macrophytes were scarce in most springs examined, although the moss *Leptodictyum riparium* was abundant in the spring head of Old Driver Spring and the forb *Mentha piperita* plugged the upper reaches of the outflow channel of Old Driver and Rose springs.

The terrestrial fauna of the cave was dominated by insects (heleomyzid and mycetophilid flies, collembolans, carabid and staphylinid beetles, and camel crickets), amphibians (seven species), and bats (seven species). The federally listed endangered gray bat (*Myotis grisescens*) was observed in one cave, and the Indiana bat (*M. sodalis*) in six caves. The state-listed endangered southeastern bat (*M. austroriparius*) was observed in two caves. The federally listed endangered Pleistocene disc snail (*Discus*

macclintocki) is known from one cave in northwestern Illinois.

Implications of Surveys

In Illinois, the biota of springs and cave streams typifies the hypothesis that hardwater springs in eastern North America are dominated by noninsect macroinvertebrates (Glazier 1991). Although amphipods and turbellarians were the most abundant organisms in surface springs, it was the diversity evident within the oligochaete worms that proved the most exciting feature of surface springs. Twenty-four taxa, four of which may prove new to science, and several new state records were found. Several new localities for the spring cavefish *Forbesichthys agassiz* were also discovered. In the cave streams, the amphipods were the most diverse and abundant macroinvertebrates, in particular the troglobitic amphipod *Gammarus troglophilus*. Six state-endangered macroinvertebrates are known from Illinois caves.

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Freshwater Mussels: A Neglected and Declining Aquatic Resource

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The United States has the greatest diversity of freshwater mussels in the world. Of the five families and roughly 1,000 species occurring globally, nearly 300 species and subspecies in the families Unionidae and Margaritiferidae reside here (Turgeon et al. 1988). The number of mussels historically known for each state varies tremendously (Fig. 1), but the diversity of freshwater mussels in just the Southeast is unmatched by any other area in the world.

Mussels were an important natural resource for Native Americans, who used them for food, tools, and jewelry. During the late 1800's and early 1900's, mussel shells supported an important commercial fishery; shells were used to manufacture pearl buttons until the advent of plastic buttons in the 1940's. Today the commercial harvest of freshwater mussel shells is exported to Asia for the production of spherical beads that are inserted into oysters, freshwater mussels, and other shellfish to produce pearls.

There are no federal regulations on the harvest of mussels, except those species on the federal list of endangered or threatened species. Several states, however, regulate size, species, gear used, and season that mussels can be taken. Japanese demand for the high-quality U.S. mussel shells in recent years pushed the price to $13/kg ($6/lb) in 1991. Shell exports peaked in 1991 at more than 8 million kg (9,000 tons), but demand declined in 1992 and 1993 and has leveled off to about 4 million kg (4,500 tons; Baker 1993).

Determining Status

In reviewing the conservation status of freshwater mussels, we included all species and subspecies recognized in the American Fisheries Society list of common and scientific names of mollusks from the United States and Canada

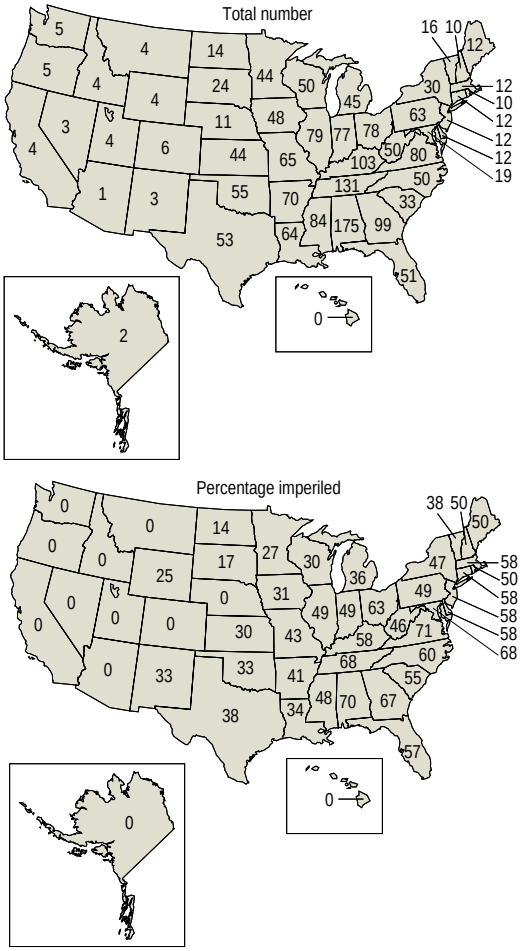

Fig. 1. Number of species and subspecies of freshwater mussels historically known to occur within each state and the percentage now classified as imperiled.

(Turgeon et al. 1988). Distribution data and conservation status were obtained from research publications, books, original data from biologists, and a recent synopsis by Williams et al. (1993).

The status categories were based on information for each species throughout its geographic range. The conservation status categories for a mussel species were defined as follows: endangered—in danger of extinction throughout all or a significant portion of its range; threatened—is likely to become endangered throughout all or a significant portion of its range; special concern—may become threatened or endangered by relatively minor disturbances to its habitat; undetermined—historical and current distribution and abundance have not been evaluated recently; and currently stable—distribution and abundance are seemingly stable, or may have declined in portions of range but not in need of immediate conservation.

Courtesy J.D. Williams, NBS

Freshwater mussels from the Tombigbee River at Memphis Landing, Pickens County, Alabama. Southern combshell (*Epioblasma penita*); female, top, male, bottom.

Decline of Mussels

The decline of freshwater mussels, which began in the late 1800's, has resulted from various habitat disturbances, most significantly, modification and destruction of aquatic habitats by dams and pollution. Freshwater habitats suffer not only from direct alterations by humans but indirectly from abuse of terrestrial habitats, such as from siltation, especially evident if one compares the levels of imperilment of aquatic versus terrestrial species. Master (1990) recognized 55% of North America's mussels as extinct or imperiled, compared to only 7% of the continent's bird and mammal species.

Aquatic habitat loss comes in a variety of forms such as from effects of dams, dredging, and channelization, or from more subtle effects of siltation and contaminants associated with construction and agriculture. Dams, with their altered flow regimes and attendant reservoirs, have caused the extirpation of 30%-60% of the native mussel species in selected U.S. rivers (Williams et al. 1992; Layzer et al. 1993). Siltation resulting from deforestation, poor agricultural and land-use practices, and removal of riparian vegetation can destabilize the stream bottom and eliminate benthic organisms such as mollusks (Ellis 1931). Many streams that look healthy can be polluted by contaminants like heavy metals, pesticides, and acid mine drainage. The effects of pollution and habitat alteration on mussels were reviewed by Fuller (1974).

Competition from non-native mollusks also has contributed to the loss of native mussel populations. The Asian clam (*Corbicula fluminea*), introduced to the U.S. west coast in the 1930's, has invaded nearly every watershed nationwide (McMahon 1983). Local population explosions of the Asian clam have adversely affected some, but not all, native mussels (Belanger et al. 1990; Leff et al. 1990). The recently introduced zebra mussel (*Dreissena polymorpha*) appears poised to decimate many of the remaining mussel populations. Zebra mussels were discovered in the United States at Lake St. Clair in 1988 and spread rapidly throughout the Great Lakes. In 1991 they were found in the Illinois River, and by late 1991 had spread to the Tennessee River (Nalepa and Schloesser 1992). They are now found throughout the Mississippi River and portions of its major tributaries, even to southern Louisiana. During the next 10-20 years, zebra mussels will most likely spread throughout most of the United States and southern Canada.

The adverse modification and destruction of aquatic habitats, along with the introduction of nonindigenous species, have resulted in the decline of freshwater mussels. The percentage of imperiled mussel species for eastern states is high (Fig. 1). Of the 297 native mussel species in the United States, 71.7% are considered endangered, threatened, or of special concern (Fig. 2), including 21 mussels that are endangered and presumed extinct. Seventy species (23.6%) are considered to have stable populations (Fig. 2), although many of these also have declined in abundance and distribution. Many

species in the latter group occur in larger rivers and reservoirs and are projected to suffer severe declines as the zebra mussel invades these ecosystems.

The rapid decline of mussels during this century went almost unnoticed until the past 30 years. Although most of the described threats to survival of mussels have existed for more than a century, the increased geographic area covered by these threats and the cumulative effects of human expansion and development have now overwhelmed aquatic systems.

The demise in both populations and species diversity of our mussel fauna is likely occurring in other freshwater mollusks (especially snails) and aquatic organisms, but too few surveys have been conducted to record such trends. Conservation and restoration should focus on the ecosystem and watershed level instead of directing concerns to the individual species. To effectively carry out such a broad recovery effort will require an unparalleled level of cooperation and coordination of private, state, and federal agencies. Perhaps even more critical to the success of ecosystem and watershed conservation is the involvement of the general public, conservation organizations, and private corporations. If the decline of aquatic mollusks continues, we will witness the greatest extinction of these organisms experienced in modern times.

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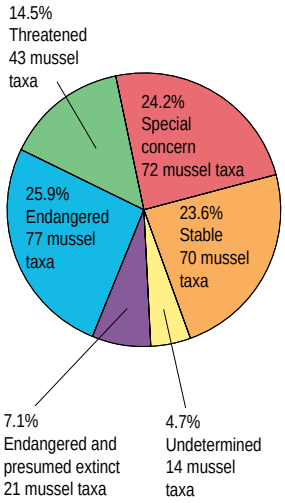

Fig. 2. The percentage of the U.S. mussel fauna classified by conservation status category: undetermined, endangered and presumed extinct, endangered, threatened, special concern, and stable.

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Freshwater Mussels in the Lake Huron-Lake Erie Corridor

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An early indicator of adverse human effects on large open-water systems in North America was western Lake Erie, part of the Lake Huron-Lake Erie corridor of the Laurentian Great Lakes (Fig. 1). Local pollution of tributaries of western Lake Erie was recognized as early as 1890, when populations of whitefish (Salmonidae) and lake herring (*Coregonus artedi*) in the Detroit River declined (Beeton 1961). Waters of western Lake Erie stopped yielding whitefish and herring in the 1920's-30's, but not until the 1950's, after extensive biological investigations, were the open waters of western Lake Erie believed to have been polluted by human "local" activities (National Academy of Sciences 1970). Eutrophication (the addition of nutrients) of western Lake Erie created unsuitable conditions (primarily low dissolved oxygen concentrations) for fish and other animals in a major portion of Lake Erie—the world's 12th largest lake. By the early 1960's, Lake Erie was declared "biologically dead" (Burns 1985).

Among the many ecosystem components affected by human-induced changes to western Lake Erie (Burns 1985) is the native mussel fauna (Bivalvia: Unionidae). Reduced mussel populations that survived degraded conditions of the 1950's have been used in status and trends studies to evaluate traditional forms of pollution in western Lake Erie. Studies in the 1990's have focused on evaluating the effects of exotic species on mussel populations in the Lake Huron-Lake Erie corridor. Exotic species have recently been characterized as "biological pollution," a new concept in evaluating status and trends data. Our study shows both historical, long-term effects from human activities and recent, dramatic effects from exotic species on mussel populations in waters of the Great Lakes.

Sampling Populations

The Lake Huron-Lake Erie corridor receives water from three of the five Laurentian Great Lakes, the largest freshwater system in the world

(Fig. 1). Relatively pristine water enters the St. Clair River, passes through Lake St. Clair and the Detroit River, and enters western Lake Erie.

Freshwater native mussels were collected by scuba divers in the Lake Huron-Lake Erie corridor (Fig. 1) at 46 stations during six sampling periods from 1961 to 1992. In Lake St. Clair, mussels were collected at 29 stations in 1986, 1990, and 1992. Ten replicate quadrate samples (0.5 m^2 each [5.4 ft^2]) were obtained at each station and sampling date. In western Lake Erie, mussels were collected four times at one index station in 1989-91 and once at 17 historically sampled stations in 1961, 1982, and 1991. Sampling at the index station was performed with an epibenthic sled (46 x 25 cm [18 x 63 in]). Sampling at the 17 historically sampled stations was performed with a Ponar grab sampler. Three replicate Ponar (0.05 m^2 [0.5 ft^2]) samples of the substrate were collected at each station. Mussels were identified following Clarke (1981) and comparisons with bivalve taxonomic reference collections. Taxonomic nomenclature follows Turgeon et al. (1988) and Williams et al. (1993).

Fig. 1. The Lake Huron-Lake Erie corridor, including Lake St. Clair and western Lake Erie (in red).

Historical Status

Around 1900 the Lake Huron-Lake Erie corridor was characterized as having one of the most abundant freshwater mussel faunas in North American lakes (Goodrich and van der Schalie 1932; Mackie et al. 1980): 39 species (Table 1).

Before 1990 mussel populations existed in most areas of the Lake Huron-Lake Erie corridor (Fig. 2). In Lake St. Clair, mussel populations were similar in 1986 and 1990 (Table 2). Numbers of mussels per unit area were relatively low (2/m^2 [0.2/ft^2]), but consistent, and there were 16-18 species found throughout the lake in 1990. The relatively healthy populations of mussels are attributed to the pristine water flowing into the lake from Lake Huron (Herdendorf et al. 1986).

In western Lake Erie, mussel populations that had survived low water quality in the 1950's declined between 1961 and 1982 (Table 2). Numbers declined from 10/m^2 (0.9/ft^2) to 4/m^2 (0.4/ft^2), and the number of species

Table 1. Species of native mussels historically found in the Lake Huron-Lake Erie corridor of the Great Lakes (modified from Clarke and Stansbery 1988).

Species
Mucket (*Actinonaias ligamentina [carinata]*)
Elktoe (*Alasmidonta marginata*)
Slippershell mussel (*A. viridis*)
Threeridge (*Amblema plicata plicata*)
Cylindrical papershell (*Anodontoides ferussacianus*)
Purple wartyback (*Cyclonaias tuberculata*)
Spike (*Elliptio dilatata*)
Northern riffleshell (*Epioblasma torulosa rangiana*)
Snuffbox (*E. triquetra*)
Wabash pigtoe (*Fusconaia flava*)
Wavy-rayed lampmussel (*Lampsilis fasciola*)
Pocketbook (*L. ovata*)
Eastern lampmussel (*L. siliquoidea*)
White heelsplitter (*Lasmigona complanata complanata*)
Creek heelsplitter (*L. compressa*)
Fluted-shell (*L. costata*)
Fragile papershell (*Leptodea fragilis*)
Eastern pondmussel (*Ligumia nasuta*)
Black sandshell *(L. recta*)
Threehorn wartyback (*Obliquaria reflexa*)
Hickorynut (*Obovaria olivaria*)
Round hickorynut (*O. subrotunda*)
Round pigtoe (*Pleurobema coccineum*)
Ohio pigtoe (*P. cordatum*)
Pink heelsplitter (*Potamilus alatus*)
Pink papershell (*P. ohiensis*)
Kidneyshell (*Ptychobranchus fasciolaris*)
Giant floater (*Pyganodon grandis*)
Mapleleaf (*Quadrula quadrula*)
Pimpleback (*Q. pustulosa pustulosa*)
Salamander mussel (*Simpsonaias ambigua*)
Squawfoot (*Strophitus undulatus*)
Lilliput (*Toxolasma parvus*)
Fawnsfoot (*Truncilla donaciformis*)
Deertoe (*T. truncata*)
Pondhorn (*Uniomerus tetralasmus*)
Paper pondshell (*Utterbackia imbecillis*)
Rayed bean (*Villosa fabalis)*
Rainbow (*V. iris*)

Table 2. Number of species of native mussels and average (mean) density (number/m^2) in Lake St. Clair and western Lake Erie of the Lake Huron-Lake Erie corridor, 1961-92.

Lake/year	Total no. of species	Average (mean) no/m^2
Lake St. Clair		
1986	18	2
1990	16	2
1992	12	<1
Western Lake Erie		
1961	8	10
1982	5	4
1991	0	0

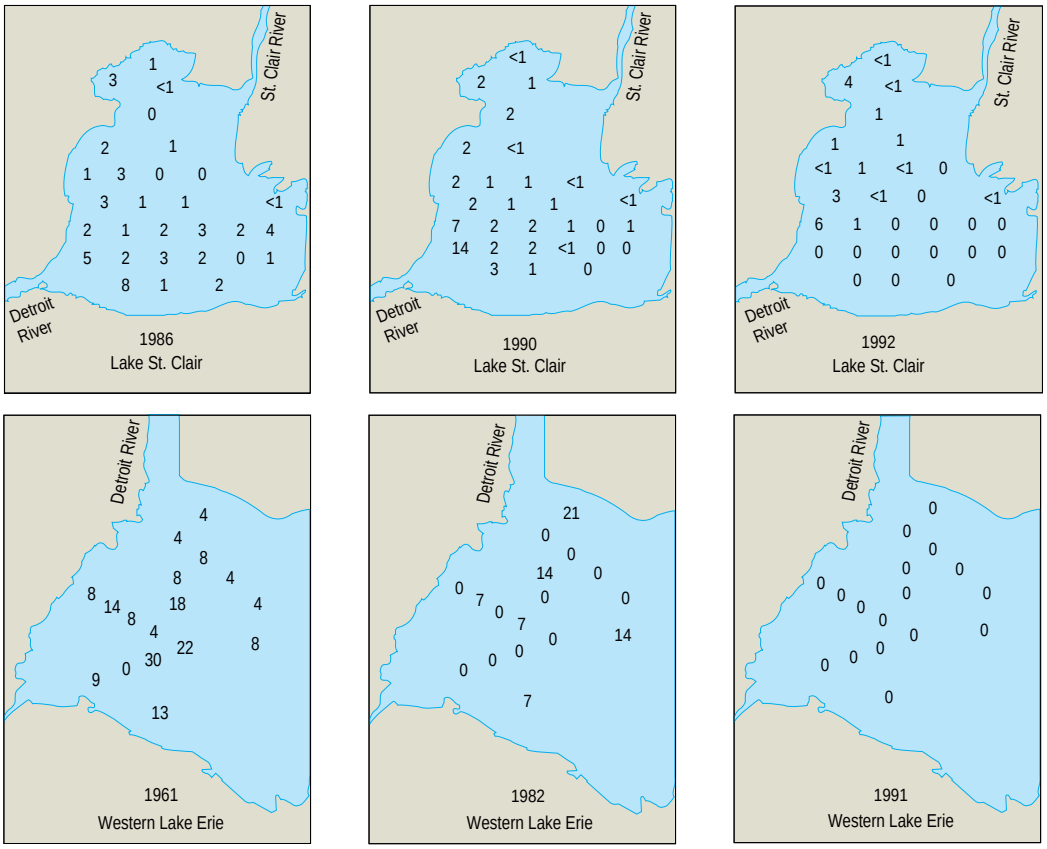

Fig. 2. Average (mean) densities (number/m^2) of native mussels in Lake St. Clair and western Lake Erie of the Lake Huron-Lake Erie corridor of the Great Lakes, 1961-92.

declined from eight to five between 1961 and 1982. The declining populations of native mussels are attributed to pollution that originated from tributary rivers of the lake prior to the 1970's. In the mid-1970's, pollution-abatement programs were begun, and water and substrate quality began to improve in western Lake Erie by the mid-1980's. By the late 1980's, environmental quality improved dramatically and pollution-sensitive indicators such as burrowing mayflies (*Hexagenia* spp.) began to return to western Lake Erie (Farara and Burt 1993; Schloesser, unpublished data).

Current Status

In the early 1990's, however, native mussel populations declined dramatically in the Lake Huron-Lake Erie corridor, despite improvements in water and substrate quality (Fig. 2; Table 2). In Lake St. Clair, substantial declines of mussels were documented between 1990 and 1992. Numbers and species of mussels were about half those found only 2 years earlier. Most changes in mussel populations in Lake St. Clair occurred in the southern portion of the lake, where mussels are no longer found (Fig. 2). In Lake Erie, mussel populations virtually disappeared in offshore waters between 1982 and 1991 (Fig. 2; Table 2).

Recent changes in native mussel populations in the Lake Huron-Lake Erie corridor are attributed to mortality caused by the exotic zebra mussel (*Dreissena polymorpha*); these exotics attach to the surface of mussels in such high numbers that native mussels are unlikely to be able to breathe and eat (Fig. 3). Intensive sampling indicated that native mussel populations declined rapidly between September 1989 and May-June 1990 (Fig. 4). Zebra mussels became abundant the summer of 1989, when infestation on clams increased from 24 mussels to 7,000 mussels per clam (Schloesser and Kovalak 1991; Nalepa and Schloesser 1992).

Erosion caused by deforestation, poor agricultural practices, and destruction of riparian zones, and organic and inorganic pollution have long been recognized as other causes for mussel mortality (Williams et al. 1993). Our knowledge of the zebra mussel, however, and its colonization on native mussels indicates that native mussel mortalities in the 1990's are attributable to

Courtesy D.W. Schloesser, NBS

Fig. 3. Typical native mussel (*Potamilus alatus*) uncolonized (left) and colonized (right) by the exotic zebra mussel (*Dreissena polymorpha*) in the Lake Huron-Lake Erie corridor of the Great Lakes.

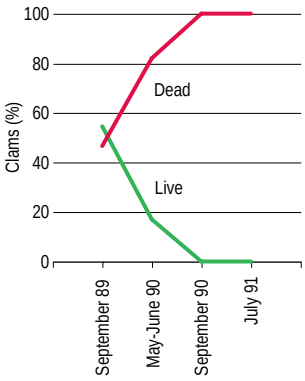

Fig. 4. Percentage of live and dead native mussels collected at an index station in western Lake Erie of the Lake Huron-Lake Erie corridor of the Great Lakes, 1989-91.

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biological pollution. Exotic species such as zebra mussels are being recognized as new and widespread threats to ecosystem stability throughout North America (Office of Technology Assessment 1993).

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Aquatic Insects As Indicators of Environmental Quality

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Aquatic insects are among the most prolific animals on earth, but are highly specialized and represent less than 1% of the total animal diversity (Pennak 1978). Most people know the 12 orders and about 11,000 species of North American aquatic insects (Merritt and Cummins 1984) only by the large adults that fly around or near wetlands.

Aquatic insects are excellent overall indicators of both recent and long-term environmental conditions (Patrick and Palavage 1994). The immature stages of aquatic insects have short life cycles, often several generations a year, and remain in the general area of propagation. Thus, when environmental changes occur, the species must endure the disturbance, adapt quickly, or die and be replaced by more tolerant species. These changes often result in an overabundance of a few tolerant species, and the communities become destabilized or "unbalanced."

Members of the order Diptera, or true flies, are especially good "bioindicators" of aquatic environmental conditions because, in addition to the attributes of other aquatic insects, they occupy the full spectrum of habitats and conditions (Paine and Gaufin 1956; Roback 1957; Mason 1975; Hudson et al. 1990).

Although considerable information on aquatic insects and other macroinvertebrates has been collected since the 1950's, most studies have been abbreviated surveys. There are few good examples of long-term biomonitoring of aquatic insects in the United States because of the discontinuance of most routine biomonitoring in the 1980's. We present ongoing and past examples of surveillance monitoring of aquatic insects of the Ohio and Mississippi rivers. Our interest here centers on the immature stages of aquatic insects that, although usually unnoticed, are part of the framework of natural ecosystems (Fig. 1).

Ohio River Aquatic Insects

During 1963-67, aquatic insects (primarily midges [Diptera], caddisflies [Trichoptera], mayflies [Ephemeroptera], and stoneflies [Plecoptera]) and other benthic invertebrates were monitored at 80-161 km (50-100 mi) increments along the 1,582 km (963 mi) of the mainstem Ohio River from Pittsburgh, Pennsylvania, to Cairo, Illinois (Mason et al. 1971). Rock-filled basket samplers were a preliminary collection device in addition to Ponar substrate grab collections.

In the upper Ohio River from river mile 0 to 260 (418 km) at Addison, Ohio, during 1965-67, the aquatic insect diversity (Fig. 1a) and individuals (Fig. 1b) in rock-filled basket samplers were low compared with collections from downriver sites. The macroinvertebrate fauna consisted mostly of pollution-tolerant midge larvae and worms, indicating poor to fair water quality. In the lower reach from Louisville to Evansville (distance of about 200 river miles or 322 km) the fauna was double to triple that of

the upriver stations and contained facultative and some clean-water taxa, indicating improved water quality.

Although the total aquatic insect diversity in the baskets at river mile 601 (968 km) in 1965 exceeded those at river mile 788 (1,268 km) by about one-third, during the next 2 years the diversity at Evansville increased over that at Louisville by 30%-40%. This significant increase was probably caused by environmental changes (e.g., increased eutrophication that provided more foods for these insects) that favored Chironomidae nonbiting midges and Hydropsychidae net-spinning caddisflies. During the 3-year period, pollution-tolerant species replaced some of the clean-water "green" species.

Aquatic insects are also useful indicators of contamination of the sediments and waters that may have gone unnoticed by routine physicochemical measurements. Uptake of toxic substances, such as heavy metals and organochlorine compounds, causes various kinds of deformities of the larval and pupal Chironomidae (Hamilton and Saether 1971; Lenat 1993). Depending on the severity of the pollution, these deformed individuals do not reach maturity and the populations are eventually reduced (van Urk et al. 1992). During the 1963-67 Ohio River monitoring program, Mason and Lewis observed larval deformities in samples taken from the sediments from the upper reaches of the Ohio River near Pittsburgh, Pennsylvania, the lower Monongahela River, and Kanawha River (Mason, unpublished data).

Management Implications

There is a need to establish long-term monitoring and reporting on macroinvertebrate populations such as that carried out during 1963-67. A monitoring program could evaluate the success of pollution clean-up and identify biological indicators to help balance water uses among urban centers, transportation, industry, and fishing and other recreation. Water chemistry and physical measurements alone are not sufficient to determine subtle shifts in aquatic populations.

Locating point sources of contaminants or thermal wastes so that they discharge directly to trout streams and lakes usually results in loss of stonefly populations, which, in turn, adversely affects fisheries. The effects of aerial spraying and other types of insecticide applications on stonefly and other sensitive aquatic organisms should be considered during site-preparation planning. Natural resource managers often recommend set backs, or buffer strips of untilled land adjacent to streams, as an effective way to minimize harm from pollution runoff.

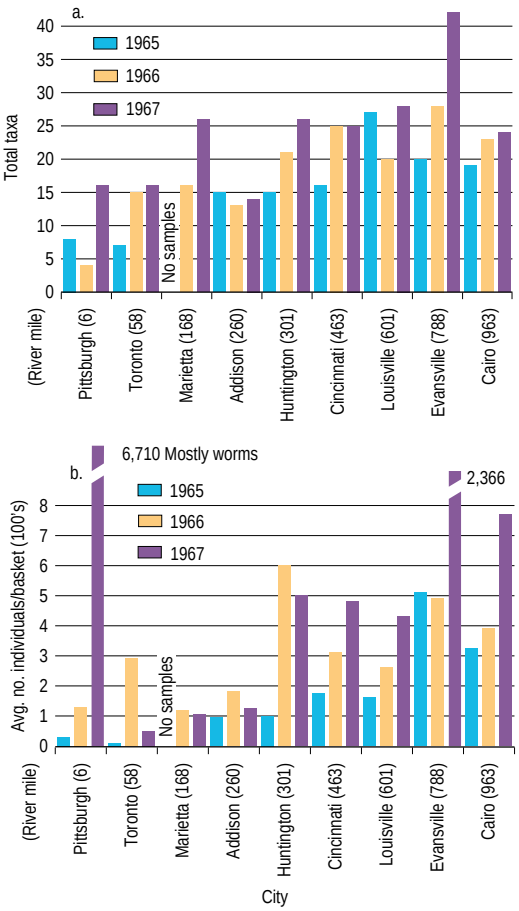

Fig. 1. (a) Total number of aquatic insect and other macroinvertebrate taxa and (b) average number of individuals collected in basket samplers in the Ohio River, 1965-67 (Mason et al. 1971).

Mississippi River Ephemeroptera

The nymphs of burrowing mayflies (Ephemeroptera) live in U-shaped tubes in the silt bottoms of shallow, slow-moving waters (Berner and Pescador 1988). Although mass emergences of adult burrowing mayflies in the Upper Mississippi River have been considered a nuisance (Fremling 1968), their abundance represents a wealth of fish food biomass; their abundance also reflects environmental health.

During 1957-69, three species of burrowing mayflies (*Hexagenia bilineata*, *H. limbata*, and *Pentagenia vittigera*) were monitored in the 3,218-km (2,000-mi) reach of the Mississippi River from Minneapolis, Minnesota, to New Orleans, Louisiana (Fremling 1964, 1970). In the 1930's, 29 navigation dams were built in the upper reaches of the Mississippi River, and burrowing mayflies became abundant in the slow-moving silted shallows. The insects were much less abundant downstream from St. Louis, Missouri, where no dams existed. The surveys of Mississippi River mayflies continue today.

During the years 1957-69 and 1976, about 1,300 collections of *Hexagenia* showed that most of the navigation pools and impoundments upstream from Minneapolis and St. Paul, Minnesota, supported large populations of burrowing mayflies. Both *Hexagenia* species were

conspicuously rare in the 48-km (30-mi) reach downstream from the Twin Cities. There, a heavy pollutant load caused low dissolved oxygen levels on the river bottom for much of the year. The mayflies were also rare in the upper reach of Lake Pepin, a large (32-km [20-mi]) natural impoundment farther downstream, where they had been abundant in years past. Apparently Lake Pepin was a settling basin for pollutants and decaying algae caused by overfertilization from the Twin Cities area.

A 1986 mayfly survey revealed that recent pollution abatement measures in the Twin Cities created favorable conditions for mayflies to return to densities of the 1950's-60's. The distribution of *Hexagenia* species reflects the status of aquatic life inhabiting a large river that was otherwise difficult to monitor effectively or economically by standard chemical testing (Fremling 1989, 1990).

Management Implications

As with the Ohio River insects, there is a need to maintain a network of routine monitoring stations along the 3,218 km (2,000 mi) of the Mississippi River to learn when atypical emergences of mayflies and other aquatic insects occur. This information will allow public officials and administrators to pinpoint more intensive and detailed analytical surveys that could determine causes of the emergences.

Today, the greatest future threat to the burrowing mayflies in the Mississippi River lies in accelerated siltation and subsequent filling of the navigation pools. These filled areas are rapidly becoming floodplain forests, a conversion that eliminates them as burrowing mayfly habitat, thereby reducing food stocks for fisheries.

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Biodiversity Degradation in Illinois Stoneflies

by
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Preliminary analysis of the recent collections of Illinois stoneflies indicates a reduction in the species richness in Illinois, a reduction in the spatial distribution of many species, the dominance of more generalist species more tolerant to environmental perturbations, and the extirpation of several species.

These general trends can be expanded for all of the central United States. The reduction in stream flow through the construction of locks and dams and the resulting effect of increased sedimentation have severely affected the habitat and niche selection available to species such as stoneflies that require rapidly flowing streams. This situation has been compounded by the erosional effects of deforestation and agricultural practices, which are maximizing the amount of land put into cultivation, as well as the increased problems related to nonpoint pollution from agricultural pesticides and fertilizers. To properly delineate these trends, the status of stoneflies and most other groups of aquatic organisms in the central United States needs to be evaluated.

In Illinois, stoneflies (Insecta: Plecoptera) were collected extensively from 1926 through 1940 by T.H. Frison (Frison 1929, 1935, 1937, 1942), with additional winter-emerging stoneflies collected from 1960 to 1970 by H.H. Ross's "Winter Stonefly Club" (Ricker and Ross 1968, 1969; Ross and Ricker 1971). From the thousands of specimens collected, the Illinois Natural History Survey has an exceptional record of species diversity and spatial distribution of Illinois stoneflies.

In 1990 we began a reevaluation of the species richness and spatial distribution of Illinois stoneflies (Webb and Harris 1993). The focus of this study was to compare current species richness and distribution patterns with those determined by Frison, Ross, and Ricker. To do this, we developed a data base for the Illinois specimens in the collections of the Illinois Natural History Survey, and we extensively resurveyed stoneflies in each of the 25 major drainages within the state (Figure).

Status

We evaluated the status of each stonefly species on the basis of the locality information and classified each species as rare, uncommon, or common (Table). This evaluation revealed that 39% of the 61 species reported were known from three localities or fewer. In addition, we developed a checklist of the Illinois species and updated their varied nomenclature.

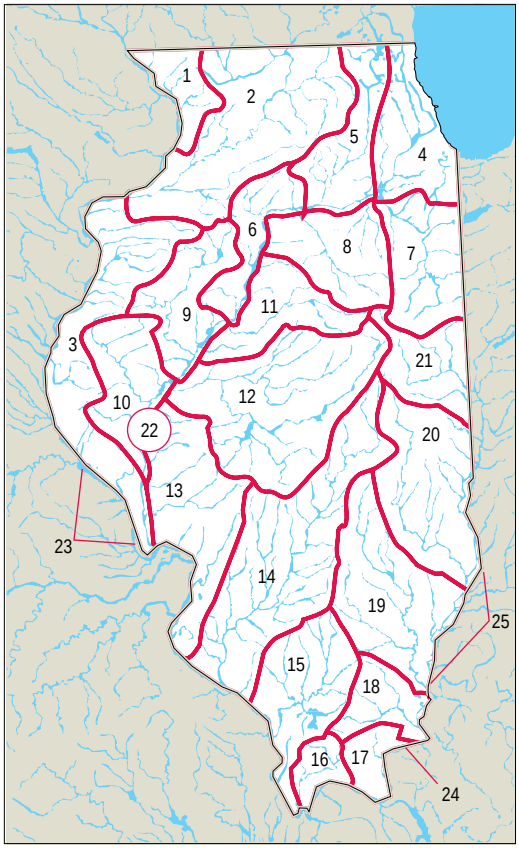

Figure. Twenty-five major river drainages in Illinois.

After 4 years of collecting we consider 13 Illinois stonefly species rare (*Acroneuria filicis* Frison; *A. perplexa* Frison; *Allocapnia nivicola* [Fitch]; *A. smithi* Ross and Ricker; *Haploperla brevis* [Banks]; *Isoperla burksi* Frison; *Nemoura trispinosa* Claassen; *Paragnetina media* [Walker]; *Prostoia completa* [Walker]; *Shipsa rotunda* [Claassen]; *Soyedina vallicularia* [Wu]; *Zealeuctra fraxina* Ricker and Ross; and *Z. narfi* Ricker and Ross). We found that 6 have been extirpated from Illinois (*Allocapnia illinoensis* Frison; *Alloperla roberti* Surdick; *Amphinemura nigritta* [Provancher]; *Isoperla conspicua* Frison; *I. marlynia* [Needham and Claassen]; *Leuctra tenuis* [Pictet]); 4 species have possibly been extirpated (*Isogenoides varians* [Walsh]; *Leuctra sibleyi* Claassen; *Nemocapnia carolina* Banks; *Paracapnia angulata* Hanson), and 1 rare species (*Alloperla caudata* Frison) is common. One species, *Soyedina vallicularia* [Wu], has been added to the state list.

Data from over 50,000 Illinois stonefly specimens in the collections of the Illinois Natural History Survey are being analyzed to determine the species richness and spatial distribution of Illinois stoneflies by drainage basin. This assessment will be based separately on earlier data (Frison 1929, 1935, 1937, 1942; Ricker and Ross 1968, 1969; Ross and Ricker 1971) and will evaluate these data relative to collections since 1990.

Apparent Trends

In reevaluating the current status of Illinois stoneflies, our first concern was the status of so many "rare" species in Illinois. We wanted to determine if the limited locality records for these species reflect actual rare distribution in Illinois, inadequate sampling, or an accidental occurrence (i.e., the species is not normally a part of the indigenous Illinois fauna). It is now apparent that 13 of these species are truly rare in Illinois; many of these are at the edge of their distributions. The eastern deciduous forest with its gravel- and cobble-bottomed streams extends only slightly into Illinois and several of these rare species are found only in these habitats. Similarly, the limestone and sandstone outcroppings of the Shawnee Hills in southern Illinois offer another area of high-quality streams and are home for several rare species of Illinois stoneflies. To a very limited extent, springs in Illinois are a refugia for a few rare species. For only one species, *Alloperla caudata*, does it appear that inadequate sampling during April and May produced a biased picture of

Courtesy M.R. Jeffords, Illinois Natural History Survey

Pteronarcys pictetii, one of the largest stoneflies in Illinois, is common to big rivers. In the nymphal stage, this species serves as an important food for fish.

Table . Relative abundance of Illinois stoneflies. R — rare (1-3 localities); U — uncommon (4-14 localities); and C — common (more than 14 localities). Surnames within or outside parentheses refer to the authors of the species name.

Species	Relative abundance
Group Euholognatha	
Capniidae	
Capniinae	
Allocapnia	
forbesi Frison	U
granulata (Claassen)	C
illinoensis Frison	R
mystica Frison	C
nivicola (Fitch)	R
recta (Claassen)	U
rickeri Frison	C
smithi Ross & Ricker	R
vivipara (Claassen)	C
Nemocapnia	
carolina Banks	R
Paracapnia	
angulata Hanson	R
Leuctridae	
Leuctrinae	
Leuctra	
rickeri James	U
sibleyi Claassen	R
tenuis (Pictet)	R
Zealeuctra	
claasseni (Frison)	U
fraxina Ricker & Ross	R
narfi Ricker & Ross	R
Nemouridae	
Amphinemurinae	
Amphinemura	
delosa (Ricker)	U
nigritta (Provancher)	R
varshava (Ricker)	U
Nemourinae	
Nemoura	
trispinosa Claassen	R
Prostoia	
completa (Walker)	R
Shipsa	
rotunda (Claassen)	R
Soyedina	
vallicularia (Wu)	R
Taeniopterygidae	
Brachypteryinae	
Strophopteryx	
fasciata (Burmeister)	C
Taeniopteryginae	
Taeniopteryx	
burksi Ricker & Ross	C
lita Frison	U
metequi Ricker & Ross	U
nivalis (Fitch)	C
parvula Banks	U
Group Systellognatha	
Chloroperlidae	
Chloroperlinae	
Alloperla	
caudata Frison	R
roberti Surdick	R
Haploperla	
brevis (Banks)	R
Perlidae	
Perlinae	
Acroneuriinae	
Acroneuriini	
Acroneuria	
abnormis (Newman)	C
evoluta Klapalek	U
filicis Frison	R
frisoni Stark and Brown	C
internata (Walker)	U
perplexa Frison	R
Attaneuria	
ruralis (Hagen)	C
Perlesta	
decipiens (Walsh)	C
Perlinella	
drymo (Newman)	U
ephrye (Newman)	U
Perlinae	
Neoperlini	
Neoperla	
clymene (Newman) complex	C
Perlini	
Agnetina	
flavescens (Walsh)	C
Paragnetina	
kansensis (Banks)	U
media (Walker)	R
Perlodidae	
Isoperlinae	
Clioperla	
clio (Newman)	C
Isoperla	
bilineata (Say)	C
burksi Frison	R
conspicua Frison	R
decepta Frison	C
longiseta Banks	U
marlynia (Needham & Claassen)	R
mohri Frison	R
nana (Walsh)	C
richardsoni Frison	U
Perlodinae	
Perlodini	
Hydroperla	
crosbyi (Needham & Claassen)	U
fugitans (Needham & Claassen)	U
Isogenoides	
varians (Walsh)	R
Pteronarycidae	
Pteronarcyinae	
Pteronacrcyini	
Pteronarcys	
pictetii Hagen	C

its distribution, as this species is found commonly across the Shawnee Hills. The apparent or possible extirpation of 10 species of stoneflies from Illinois creates serious concern. None of the species were collected in Illinois during 1990-94, although we are still unsure about the extirpation of four of these species, since they are large-river species and we are not satisfied with our collecting techniques for these habitats.

In evaluating the changes in spatial distribution of Illinois stoneflies, the "winter stoneflies," in particular, the genus *Allocapnia*, offer the best examples (Frison 1929, 1935, 1937, 1942; Ricker and Ross 1968, 1969; Ross and Ricker 1971; Webb and Harris 1993). One striking example is *A. granulata*. In the 1920's, 30's, and 60's, this species was distributed and abundant from southeastern to northern Illinois. A drastic reduction in the distribution of this species has occurred since 1970, and in the past 4 years, this species has only been collected within the Rock River drainage of northern

Illinois. As yet, no cause for this reduced distribution has been proposed. This is the most spectacular example we have discovered, but similar distribution patterns have been noted in other species, particularly within the genus *Acroneuria*. Our recent collections reveal that generalist species—those tolerant of a variety of environmental perturbations—apparently are becoming the dominant species in Illinois. *Allocapnia vivipara*, *Taeniopteryx burksi*, and *Isoperla bilineata* are examples of this trend; all are widespread throughout Illinois in many ecological habitats.

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