PROCEEDINGS OF THE THIRD ANNUAL SYMPOSIUM ON THE NATURAL HISTORY OF LOWER TENNESSE AND CUMBERLAND RIVER VALLEYS

Held at Brandon Spring Group Camp
Land Between The Lakes
2 and 3 March 1990

Sponsored by:

The Center for Field Biology,
Austin Peay State University, Clarksville, Tennessee

and

Tennessee Valley Authority - Land Between The Lakes
Golden Pond, Kentucky

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PREFACE

On the 2nd and 3rd of March 1990 over eighty students of regional natural history and field biology gathered for the Third Annual Symposium on the Natural History of Lower Cumberland and Tennessee River Valleys held at Brandon Spring Group Camp in the Land Between The Lakes. This symposium was sponsored by The Center for Field Biology at Austin Peay State University and the Tennessee Valley Authority's Land Between The Lakes.

Environmental assessment was the focus of Friday's invited papers session. Dr. Thomas Barr from the University of Kentucky spoke on ecology and evolution of our region's cave fauna and the human impact on this interesting, but threatened ecosystem. Dr. James Gore, formerly of the University of Tulsa and now with The Center for Field Biology, presented a summary of his activities in stream disturbance ecology and discussed the potential role of island biogeography models for predicting stream recovery from disturbance. Dr. Stephen Klaine of the Environmental Health and Toxicological Research Institute at Memphis State University spoke about the tremendous environmental burden of agricultural nonpoint source pollution and the Institutes research concerning pesticide mobility and fate in soils. The papers written by the invited speakers are published in full here.

Following the evening meal Mr. Ralph Ward of Land Between The Lakes' Homeplace - 1850 gave an interesting presentation on efforts of the Minor Breeds Conservancy to preserve genetic diversity of domesticated livestock through the maintenance of hardy, health, and productive minor breeds. The remainder of the evening was spent in casual conversation - biological and otherwise.

Eleven botany and nine zoology papers were presented during two concurrent contributed papers sessions on Saturday morning. The speaker in these sessions had the opportunity to publish in these proceedings either complete papers or abstracts of their presentations.

The style and format of these proceedings are based on those established in the previous two symposia proceedings. Journal abbreviations used in the literature cited sections of these papers follow the 1988 *Serial Sources for the BIOSIS Data Base*, volume 1987, printed and distributed by BIOSIS, 2100 Arch Street, Philadelphia, PA 19103-1399.

Steven W. Hamilton and Mack T. Finley
November 1990

ACKNOWLEDGMENTS

Although, as the editors of these proceedings, we feel we have completed the trials of Hercules, we would be remise not to recognize those who have helped complete many of the herculean tasks needed to finish the editing and printing of these proceedings. We are grateful for the prompt response of the anonymous reviewers whose efforts have greatly improved these proceedings. Manuscripts were typed by Ms. Dina Cotton, Ms. Donna Davis, Ms. Marilyn Griffy, and Ms. Connie Sonnier. Ms. Cotton and Ms. Davis formatted most of the manuscripts. Drs. Edward Chester and Floyd Scott were generous with their editorial advice. Proofreading assistance was willingly provided by Mr. Joe Barnes, Ms. Debbie Lingle-Gillis, Ms. Joanne Jones, Ms. Kristen Page, Ms. Sheila Smith, and Ms. Patty Stinger. We are sincerely grateful to all of those, mentioned and not, who assisted us throughout the editorial process. We, of course, take full credit for remaining editorial errors.

The symposium was organized and administered by Dr. Benjamin P. Stone, Director for The Center for Field Biology. We would like to acknowledge Dr. Thomas Forsythe for his liaison activity as Coordinator of Research and the professional staff of LBL's Brandon Spring Group Camp for assisting the Director in administering the symposium program.

SYMPOSIUM REGISTRANTS

Following in alphabetical order is a list of those individuals who registered at the 1990 symposium. Institutional affiliation (when available), city (of the person's institution or home), and state are also given.

Ms. Sherrie Adcock, Austin Peay State University, Clarksville, TN; **Ms. Patricia Alicea**, Austin Peay State University, Clarksville, TN; **Dr. Vincent Anigbogu**, Austin Peay State University, Clarksville, TN; **Ms. Amy Atkins**, Dunbar Cave Natural Area, Clarksville, TN; **Mr. Joeseph Barnes**, Austin Peay State University, Clarksville, TN; **Dr. Thomas C. 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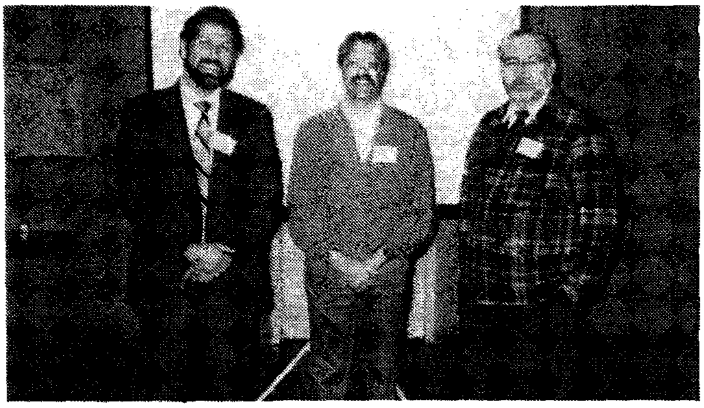
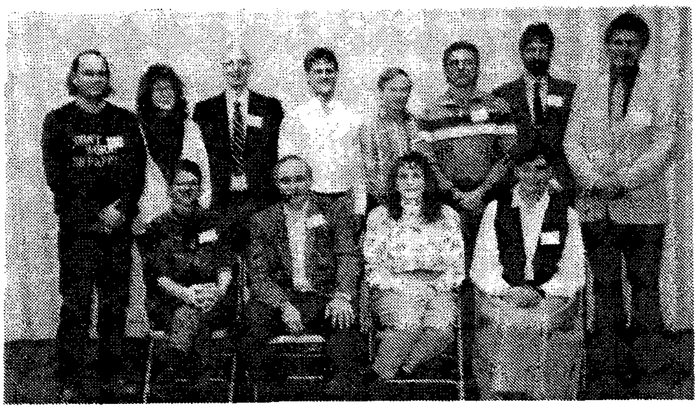
SYMPOSIUM PARTICIPANTS



Invited Papers (from left) - Stephen Klaine, James Gore, Thomas Barr.



Contributed Papers Session I: Zoology - (row 1, from left) Ann Phillippi, Floyd Scott, Debbie Lingle-Gillis, Kristen Page; (row 2, from left) Tony Gerard, Jodie Richter, George Feldhamer, Ron Klann, Ray Burkett, Tom Forsythe, Steven Hamilton, and Dave Easterla.

Contributed Papers Session II: Botany - (row 1, from left) Neil Miller, Sallie Noel, Jerry Baskin, Walter Sundberg, G.K. Sharma; (row 2, from left) Scott Franklin, H.R. DeSelm, Joe Schibig, Steve Kettler, Bill Bryant, Dave Pelren.

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INVITED PAPERS

Friday, March 3, 1990

Moderated by:

Benjamin P. Stone
The Center for Field Biology
Austin Peay State University

ECOLOGY AND EVOLUTION OF CAVE FAUNAS

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ABSTRACT. Major cave regions of the eastern United States include the Appalachian Valley (AV) and Interior Low Plateaus, in which the component eastern and western Mississippian plateaus (MP) are biologically especially interesting because of their high dispersal potential for troglobites. Principal barriers to subterranean dispersal of troglobite species are stratigraphic and fluvial, with stratigraphic barriers predominating in the AV but less frequent in the MP. Cave environments are characterized by relatively constant temperature, low vapor pressure deficit, and total darkness, but movement of cold, dry winter air into caves seasonally dries out areas near entrances, and annual flooding disrupts constancy of aquatic cave microhabitats. Energy sources in caves come from the surface, principally through agencies of trogloxene species and dripping or flowing water. In temperate zone caves the energy budget is a spartan one, and food chains are relatively short and uncomplicated.

Cave communities are composed of coevolving species that colonized caves at different times and different places in the past. The opportunity for evolution of more complex communities with more species is much greater in MP caves than in AV caves. Speciation of cave faunas often involves relictual elements whose ancestors no longer exist at the surface in the cave region. Alternating cool/wet and warm/dry climates of the Pleistocene have driven this process. Ancestors of cave species were in most instances already preadapted to existence in cool, dark, moist (or aquatic) microenvironments and probably passed through a troglophile (facultative) stage before becoming troglobites. Trechine beetles passed through an edaphobite (deep soil) stage prior to colonizing caves. Vicariance has played a major role in this process, and post-colonization dispersal varied with barrier frequency, body size, and vagility. Aquatic troglobites often have more extensive geographic ranges than terrestrial ones. Some troglobite morphospecies may include several to many more or less geographically isolated populations selected for stable phenotype, but genetically distinct. The overall picture is complicated by the ability of some species to disperse to a limited extent through deep soil or groundwater in non-karst regions.

Regression of eyes and pigment in troglobites is best explained by selection of pleiotropic genes with both adaptive and neutral effects. Slender bodies and elongate appendages are adaptive characters in a food poor environment, permitting predators or scavengers to search a greater area for food while incurring minimal increase in biomass.

Many cave species are threatened with loss of habitat (or have already lost it) through sewage, industrial, and oil spill pollution; flooding by newly constructed reservoirs; cave commercialization; suburban expansion; and heavy recreational traffic, even though the inventory of troglobites in eastern United States is not yet complete.

INTRODUCTION

Cave faunas are of special biological interest because a) they include a variety of species with evolutionary modifications associated with an unusual, marginal habitat; b) they offer an opportunity to investigate evolution of highly conspicuous regressive modifications; c) many groups of them include large numbers of vicariant species that reflect past climates and geographies; and d) cave communities are far less complex than surface, or epigean communities, presenting a chance for more tractable studies of ecosystem dynamics.

DISCUSSION

Biological Significance of Cave Faunas.

Although we are far from completing an inventory of the rich diversity of life on earth, and the press of civilization is leading to a rapid extinction of species, many of which are still undescribed, support for basic descriptive taxonomy is dwindling. The great majority of obligate cave species in the United States has been described only in the past 3 years, but several widespread groups have been scarcely investigated taxonomically because of a limited number of taxonomists. Meanwhile, access to type localities or other critical habitat is made more difficult day by day, as more and more caves are closed, polluted, or flooded. In the temperate zones, many groups of cave fauna are relics of cooler Pleistocene climates and early- or pre-Pleistocene drainage patterns, thus might appropriately be called "refugees of the Ice Age" (Barr, 1973).

We know a great deal about progressive evolution, or at least we think we do. On the other hand, evolutionary modifications involving loss of structures or physiological or behavioral patterns are the other, somewhat obscure side of the evolutionary coin. In cave animals, with their reduced eyes, lack of pigment, and non-circadian rhythms, we creatures of light, who receive about 90 percent of sensory input through our eyes, are confronted with life forms that exist in perpetual darkness. As it was for Charles Darwin, our primarily adaptive theory of evolutionary mechanism is found wanting when asked to explain the loss of structures (regression or rudimentation). Cave animals surely hold no monopoly on regressive evolution, but the rudimentations they exhibit are particularly striking, and they do present a variety of readily accessible species with which we can study regression employing testable models.

A patch of mixed mesophytic forest, a small woodland stream, a meadow, a pond, or a cedar glade are representative of the ostensibly "simple" ecological communities we attempt to investigate. However, each of these may include a hundred or more ecologically significant species, with thousands of potential species interactions, whereas cave communities, with marginal food supplies and spartan energy budgets, are rarely anywhere near as complex. Cave communities have only 5, 10, or perhaps (in the most richly diverse caves) 20-30 interacting species, and food chains are often rather short, with only three or four trophic levels. They are comparatively simple, more easily controlled models for study of community dynamics. However, to what extent these simpler communities can contribute to general ecological theory is unknown; e.g., Hairston (1989) believes that interpretations of environmental phenomena in different habitats may be quite different and discounts the possibility of developing general theory.

Ecological and Evolutionary Classification of Cavernicoles.

Habitually cavernicolous animals can be divided ecologically into a) **troglobites**, species found only in caves or other deep subterranean environments, and so modified by rudimentation of eyes and pigment that they are unable to live elsewhere; b) **troglophiles**, species able to live out their entire life cycles in caves, but also found in other damp, cool microenvironments above ground; and c) **trogloxenes**, species dependent upon caves for shelter by day, but feeding outside caves at night in epigean environments. This classification is sometimes blurred, because some terrestrial troglobites are also edaphobites (obligatory inhabitants of deep soil). Similarly, many aquatic troglobites are also phreatobites (obligatory inhabitants of subterranean groundwater habitats; many authors prefer the more general term stygobiont). The term troglomorph is an evolutionary/morphological one based on existence of regressive and more obviously adaptive traits associated with a hypogean mode of life, irrespective of whether a species is a troglobite, an edaphobite, or a phreatobite/stygobiont (Christiansen 1962).

Cave Regions in Eastern United States.

Caves throughout the world are inhabited by a variety of animal species, some of which are found only in subterranean environments. Although the bulk of such species are concentrated in the temperate zones (Vandel 1965, Barr 1968a), recent papers have reported an increasing number of species that are obligate inhabitants of tropical caves (Howarth 1987, Reddell 1981). Our special focus in this paper is on cave faunas of the Interior Low Plateaus, especially those in the lower Tennessee and Cumberland river valleys in western Kentucky (the "Pennyroyal") and the northwest portion of the Highland Rim in Tennessee, a region underlain by strata of Mississippian age and called MP-I by Barr (1985a).

The major cave regions of eastern United States (Fig. 1) are a) the Appalachian Valley (AV), b) the Interior Low Plateaus, especially (but not limited to) the western and eastern Mississippian plateaus (MP-I and MP-II, respectively) that flank the Cincinnati arch, c) the Greenbrier Valley of West Virginia (MP-III), and d) the karst region of north-central Florida. The thick, highly cavernous, widespread limestones of MP areas permit considerably more dispersal of cave animals, in contrast to the discontinuous limestone patches in the AV, where limestones and caves are largely confined to anticlinal strike valleys separated by synclinal ridges of non-cavernous clastics. This contrast in continuous karst and the resulting dispersal potential of cavernicoles has produced a series of ecological and biogeographic contrasts between the MPs and the AV. In the MPs, a) species have typically more extensive geographic range; but b) there are fewer species per unit area of karst--a function of fewer extrinsic barriers to dispersal; c) sympatry of cave species is much more common, resulting in more complex cave communities; d) modal size of species is larger, perhaps reflecting greater mobilization of food energy and less dependence of predators on single prey species; and e) population density is higher and less subject to wide fluctuations than in many AV caves (Barr 1968a). The AV vs. MP situations are extremes (although the areas include a major proportion of eastern caves), and intermediate situations obtain in the Bluegrass, Central Basin, and the western valley of the Tennessee River, as it flows over Silurian and Devonian rocks between MP areas from north Alabama to western Kentucky.

The majority of caves in the lower Tennessee and Cumberland river valleys exhibit these MP patterns (Fig. 2). In the absence of major stratigraphic (enhanced locally by structural discontinuities, such as faults) or river barriers, many troglobitic species have

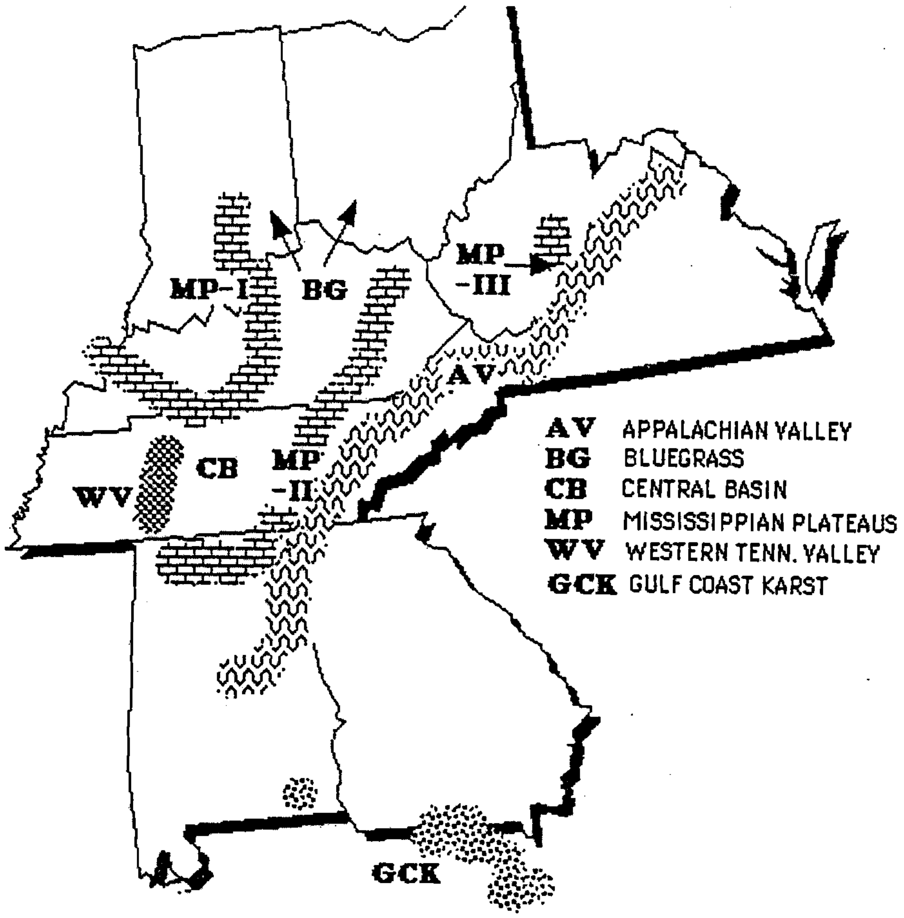

Fig. 1. Major cave regions of eastern United States. AV--Appalachian Valley; BG--Bluegrass; CB--Central Basin; MP-I--Western Mississippian Plateau; MP-II--Eastern Mississippian Plateau; MP-III--Greenbrier Valley; WV--Western Tennessee River Valley; GCK--Gulf Coast Karst regions.

relatively extensive ranges, and large troglobites, including blind cavefishes (*Typhlichthys subterraneus*) and crayfishes (*Orconectes pellucidus*) are present. The Cumberland River is an absolute barrier to most terrestrial troglobites from its juncture with Big South Fork in southeastern Kentucky, and the Tennessee River is a barrier for its entire course. The Ohio River is at present a total barrier to terrestrial troglobites (though not aquatic ones), but pairs of sister species of cave beetles near Louisville suggest that the pre-Kansan Ohio River was not a barrier (Barr 1985a). Smaller, youthful streams in MP karst areas are almost never barriers, because frequent bends in youthful streams produce many limestone bluffs along their banks, offering small crevices for, e. g. , cave arthropods washed out of caves on one side to be deposited near crevices leading into cave systems on the opposite bank. Thus, the Red River along the Kentucky-Tennessee border shows no indication that it is a barrier to cave beetles. The lower Barren River (below Barren River Dam) near Bowling Green, Kentucky, separates mutually exclusive cave beetle guilds on opposite sides, but in its winding, more youthful upper reaches, the Barren is not a barrier to these same related beetle taxa. As a rule, streams with a meander frequency of less than 1.0/km are barriers; in other words, a stream is empirically not a barrier if it has one or more bends per kilometer (Barr 1985a).

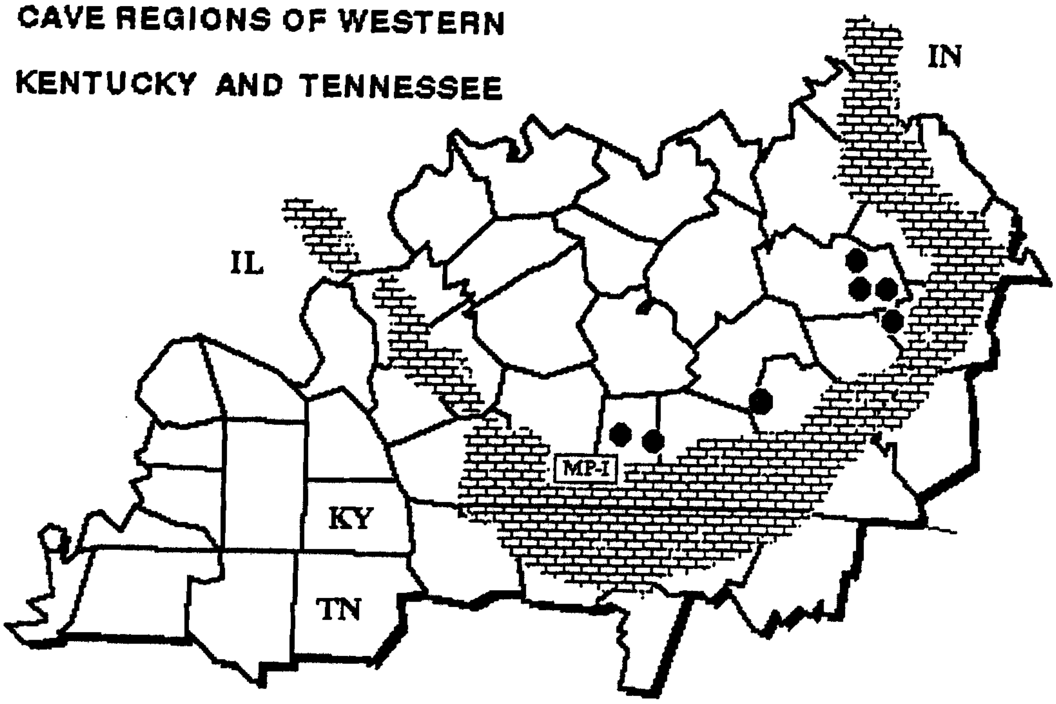

Fig. 2. Cave regions of western Kentucky and Tennessee; patterned area is the Western Mississippian Plateau surrounding the Western Kentucky Coal Basin; dots are small karst islands, stratigraphically isolated from the "Pennyroyal," or major karst plain of MP-I.

Major stratigraphic barriers in the region include a fault zone between the Hopkinsville and Princeton, Kentucky, cave areas and extensive smaller faults in Crittenden County, Kentucky. Endemic species of cave beetles exist in an isolated graben in northern Todd County and in karst islands in Glen Dean limestone in Todd, Warren, Butler, and Logan counties. The dip of Mississippian strata farther west has resulted in limestone exposures in stream valleys with interfluves capped by residual chert. Thus, cave beetles in the valleys of Blooming Grove and Indian creeks west of Clarksville are extrinsically isolated not only from each other, but also from cave areas near Clarksville, Hopkinsville, and the Caledonia district of Trigg County, Kentucky. Farther upstream in both the Tennessee and Cumberland river valleys karst areas become patchy and more localized, reflecting the transition to thinner and less cavernous Devonian, Silurian, and Ordovician strata. Stratigraphic barriers are much more frequent here, and different local cave faunas occur.

Ecological Properties of the Cave Environment.

The physical cave environment is characterized by relatively constant temperature, which approaches the regional mean temperature (13.5-15°C in the lower Cumberland and Tennessee river valleys), usually very low vapor pressure deficit, and total darkness. However, movement of colder, denser, drier winter air into caves alters this regimen. The most serious effect on stenohygrobic cave animals is the increase in rate of evaporation from their integuments. Similarly, winter and early spring floods disrupt relative constancy of aquatic cave communities, although a significant side effect is transport of organic materials into cave ecosystems, increasing the meager food supply (Barr and Kuhene 1971). Many small arthropods take refuge in and among stream gravels, particularly when mixed with organic flood debris. Widespread deposits of silicate clays in caves is the result of deflocculation when acid, flood-borne slurries come in contact with limestone, and their pH increases, causing precipitation of clays. These clays are utilized by burrowing cavernicoles and are believed to be important in temporary absorption of water-borne organic materials which may serve as food.

All energy sources in caves are allochthonous and come from the surface, thus ultimately from sunlight energy, but the total energy budget in a temperate zone cave is typically minuscule compared with epigean habitats. The two major agents of food transport between surface and cave are a) trogloxenes, such as bats, wood rats, and cave crickets, and b) vadose ground water, in both sinking streams and water that percolates downward through humus layers of the overlying soil mantle. The cave cricket *Hadenoecus subterraneus*, which occupies most caves of the Kentucky MP-I from the Ohio River to Russellville , Kentucky, is an extremely important food source for terrestrial troglobites, and the complexity of cave communities is substantially diminished beyond its geographic range. This omnivorous, gregarious trogloxene feeds outside at night but roosts in caves by day, and its contribution to the cave energy budget includes juveniles and eggs eaten as prey as well as dead bodies and fecal deposits of imagines eaten by saprophagous troglobites. The geographic distribution of *Neaphaenops*, a genus of cave beetles that feed almost exclusively on eggs of *H. subterraneus*, is approximately the same as that of this cave cricket (Barr 1979). Four related (same species group), parapatric species of *Hadenoecus* occur in the western margin of the Cumberland plateau from northeast Kentucky to north Alabama (MP-II), and their effect on ecology of regional caves is similar (Hubbell and Norton 1979). Feces of bats (particularly of *Myotis grisescens* in western Kentucky and adjacent Tennessee), though often abundant, are seldom utilized directly by troglobites, harboring instead a special fauna of guanobites, most of which are troglophiles. However, predatory troglobites may lurk about the margin of guano piles and capture guanobite prey.

Annual flooding is an important source of food energy for both aquatic and riparian troglobites, depositing organic material ranging in size from microscopic particles to leaves, sticks, and even large logs. Small, threadlike oligochaetes (tubificids and enchytraeids) in the mud along streams depend on this material, and in turn these worms form a major diet item for many cave beetles, including almost all larger species (such as *Pseudanophthalmus ciliaris*) in the lower Tennessee and Cumberland river valleys. Leaching of humus and transport of microorganisms by percolating ground water, which enters caves through vertical shafts ("domepits") or drips from stalactites, adds very small but significant amounts of organic matter to cave energy budgets (Barr and Kuehne 1971, Barr 1976) (Fig. 3). Some of this material is absorbed on silicate clay crystals, which have amphoteric properties, and is possibly released by pH changes within the guts of troglobites, both aquatic and terrestrial. Surges in total organic carbon (TOC) in late fall, when the summer's accumulation of organic materials is leached out, may possibly be stored and "doled out" over the winter by a mechanism of this sort.

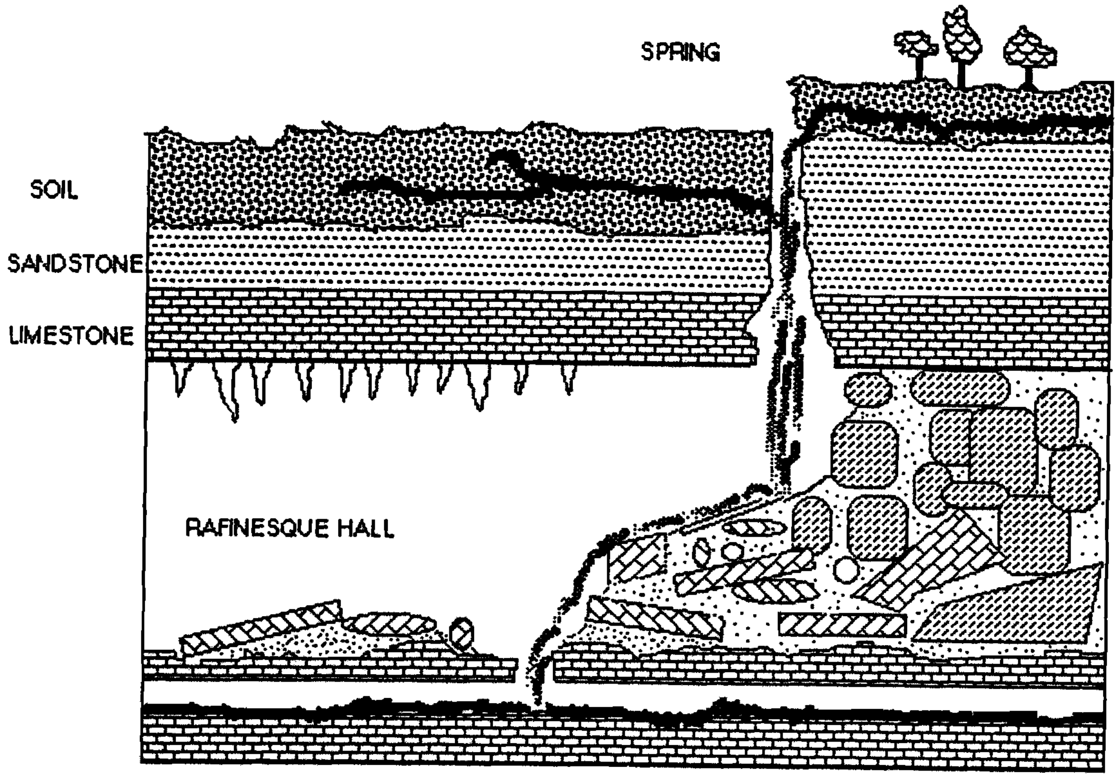

Fig. 3. Diagramatic vertical section of end of Rafinesque Hall, Mammoth Cave, Kentucky, illustrating flow of vadose water sampled for total organic carbon (from Barr 1976).

Food chains and food webs in caves are seldom very complex and usually include no more than three or four trophic levels. Some examples are: 1) stream debris→ isopod→ blind cavefish; 2) epigean food→ *Hadenoecus* (eggs)→ *Neaphaenops*; and 3) stream debris→ microbial decomposers→ small oligochaetes→ *Pseudanophthalmus ciliaris*.

Comparatively little information about interspecific competition between troglobites is available. This is a potentially fruitful field for investigation. However, in carabid cave beetles the larger species are almost always cursorial predators, while smaller species are interstitial feeders, found in debris, gravel, or between laminae of moist clay. Barr and Crowley (1981) noted that, of 125 sympatric pairs of these beetles known from eastern United States, approximately 70 percent included a significant size disparity associated with these feeding modes. Three *Pseudanophthalmus* species of subequal size in the Mammoth Cave area have distinct preferences for different microenvironments. In Parker Cave, near Park City, Kentucky, a large series of mixed species included *P. menetriesi*, *P. striatus*, and *P. pubescens;* all *P. menetriesi* specimens were collected in an upper level near the cave entrance, all *P. striatus* specimens were collected along the stream in the lower level of the cave, and a majority of *P. pubescens* specimens occurred along the stream, with about 5 percent in the upper level (Barr 1985a, McKinney 1975). In the Mammoth Cave system, there are 6 species of carabid beetles, *Neaphaenops tellkampfi* and 5 species of *Pseudanophthalmus----P. menetriesi*, *P. striatus*, *P. pubescens*, *P. inexpectatus*, and *P. audax*. *Neaphaenops tellkampfi* feeds predominantly on eggs of cave-crickets which it digs from the cave silt floor. The *Pseudanophthalmus* species have never been observed digging and will not dig cave-cricket eggs in captivity. While *P.menetriesi* and *P. striatus* are assigned to the same species group (though in different sections), each of the other three is the type species of its own group, i.e., there is low taxonomic affinity between them. *Pseudanophthalmus menetriesi* is much more frequent in upper level microhabitats, *P. striatus* is almost always confined to streams in lower levels, and *P. pubescens* is rare except during very wet weather in the main part of the Mammoth Cave system, but abundant in the shallow sinkhole plain caves toward its periphery. *Pseudanophthalmus inexpectatus* is a small interstitial feeder known only from wet, rotting wood in single localities in Mammoth, White, and Great Onyx caves (all part of the Mammoth Cave system). *Pseudanophthalmus audax* is a robust, depressed species of intermediate size (< 4 mm). It is extremely rare, known only from a single collection in the type locality cave near Cave City a century ago and from two specimens collected in White Cave in the early 1960s (Barr 1966-67). A closely similar but more abundant sister species (undescribed) from caves near Greensburg and Campbellsville, Kentucky, appears in caves only at the driest time of the year, in the fall. This seasonal appearance in caves, together with its robust, depressed form and reduced setae of the elytral disc, suggests that the normal habitat of both species may not be caves at all, but rather deep soil, from which they retreat into more humid cave environments when the soil becomes very dry.

Speciation in Caves.

Many cave species appear to be relics that have survived epigean climatic changes in the relatively stable cave/hypogean environment. Consequently, closely related epigean species seldom occur in the same region, at least in temperate zone caves. The principal speciation model presented here is for trechine beetles (Carabidae:Trechinae) in eastern United States (Barr 1985, Barr and Holsinger 1985).

The trechine model. Trechines are a nearly worldwide subfamily of small carabids (median length about 4-5 mm). In eastern United States *Trechus* is represented in the higher Appalachians and Cumberland Pleatau by at least 60 taxa, however, the genus is not directly ancestral to the troglobitic species, whose progenitors were probably similar to genera now found in western Europe and the Carpathian-Transylvanian Alps, or are unknown. An apparent European origin for ancestors of eastern United States trechines may reflect the breakup of Laurasia. Cave genera include *Pseudanophthalmus* (estimated 240 species, mostly in IN, KY, TN, AL, VA, and WV, with 1-4 species each in IL, GA, OH, and PA); *Neaphaenops* (4 semispecies, confined to the Kentucky Pennyroyal); *Nelsonites* (4 species, eastern KY and TN); two remotely related genera in southeast Kentucky, *Darlingtonea* (one polytypic species, *D. kentuckensis*) and *Ameroduvalius* (5 species); and *Xenotrechus* (2 species, eastern MO), a remarkable relic whose closest relatives now occur in eastern Europe (Barr 1967a, 1985a, 1979; Barr and Krekeler 1967; Valentine 1952).

Cave trechines have arisen by a two- (or three-) stage process, each stage involving dispersal and subsequent vicariance (Barr 1985, Barr and Holsinger 1985). In Stage 1 formerly winged, oculate species became edaphobites, obligatory inhabitants of deep soil, and in Stage 2, presumably in response to inimical climatic changes during warmer, drier, Pleistocene interglacials, local edaphobites became still further restricted and isolated in deep caves within their original ranges. Although only one species in Stage 1 is known from eastern United States (*Pseudanophthalmus sylvaticus* Barr 1967b, from high elevations in West Virginia), such deep-soil species are not at all uncommon in southern Europe and Japan. Typically cave trechines are limited to karst (limestone) areas, however, species previously known only from caves have recently been found in three abandoned eastern Kentucky coal mines, 15-25 km distant from limestone outcrops (Barr 1986 and unpublished). In highly fractured rocks in Europe and Japan, but not yet in the United States, highly troglomorphic species of trechines have been obtained in buried traps; they are believed to inhabit the spaces around loose rocks at the interface between the mantle and bed rock (the so-called *milieu souterrain* of Juberthie et al. 1980). The Allegheny plateau has been suggested as the major refugium (Fig. 4) from which ancestral trechines dispersed east into Appalachian Valley caves and west into Interior Low Plateau caves in several pulses during Pleistocene time (Barr 1981, 1985a). Most species groups of *Pseudanophthalmus* on opposite sides of the Alleghenies are quite different and difficult to relate phylogenetically, and there are no AV equivalents to the smaller genera in MP caves, such as *Darlingtonea* and *Ameroduvalius*.

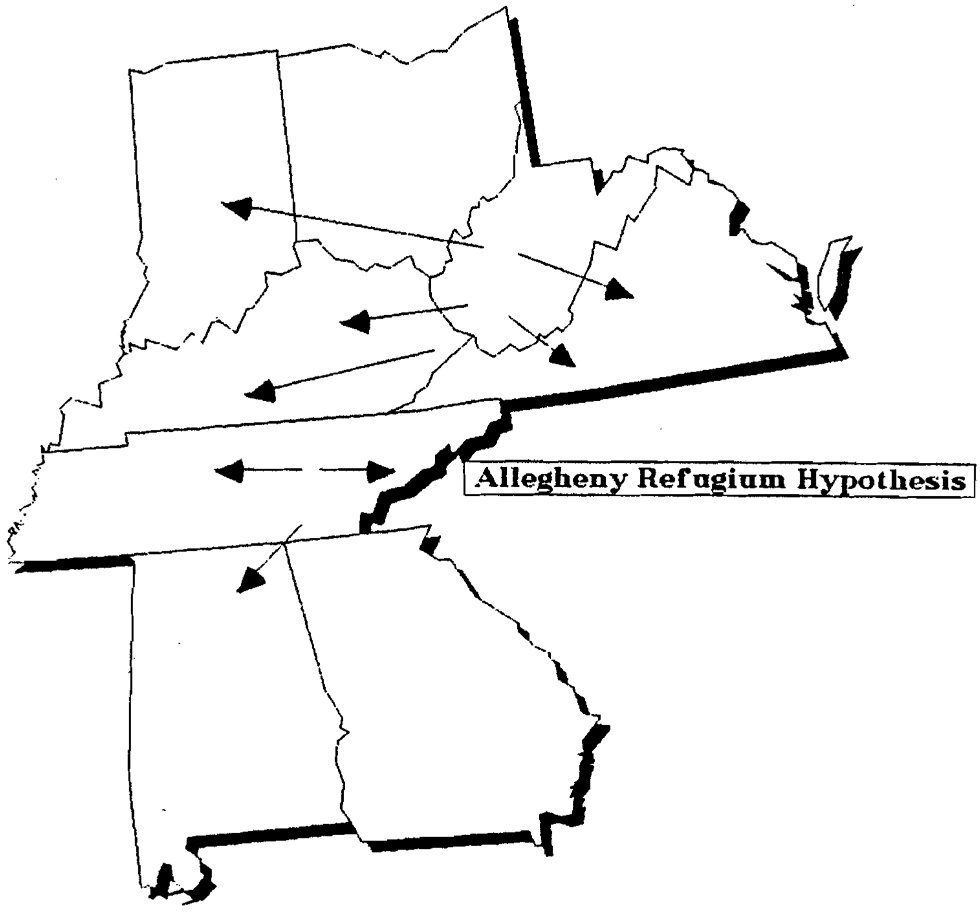

Fig. 4. Peripheral dispersal of ancestral cave trechines outward from the Allegheny plateau into the Appalachian Valley and Interior Low Plateaus to the west, as postulated by the Allegheny Refugium Hypothesis.

Frequency of stratigraphic barriers is directly proportional to the degree of vicariance in Stage 2 of this model. Stratigraphic barriers are especially numerous in the AV, but they also occur to a limited extent at the margins of MP-I and other cave regions. In western Kentucky, for example, peripherally isolated species distinct from, but closely similar to the widely ranging species of the Pennyroyal karst plain are known from isolated karst patches toward the interior of the Western Kentucky Coal Basin, from Grayson, Hart, Warren, Butler, and Todd counties. For species in the MPs and in a few unusually large patches of continuous karst in the AV there may be a Stage 3, principally a further dispersal phase. In the lower Cumberland and Tennessee river valleys, trechines are represented by allopatric or parapatric species of the *pubescens* group of *Pseudanophthalmus* (Fig. 5), as well as a few scattered species of the *cumberlandus* group (otherwise widely distributed in the Central Basin; Barr 1980). The *pubescens* group ranges eastward to the Mammoth Cave region (Barr and Crowley 1981).

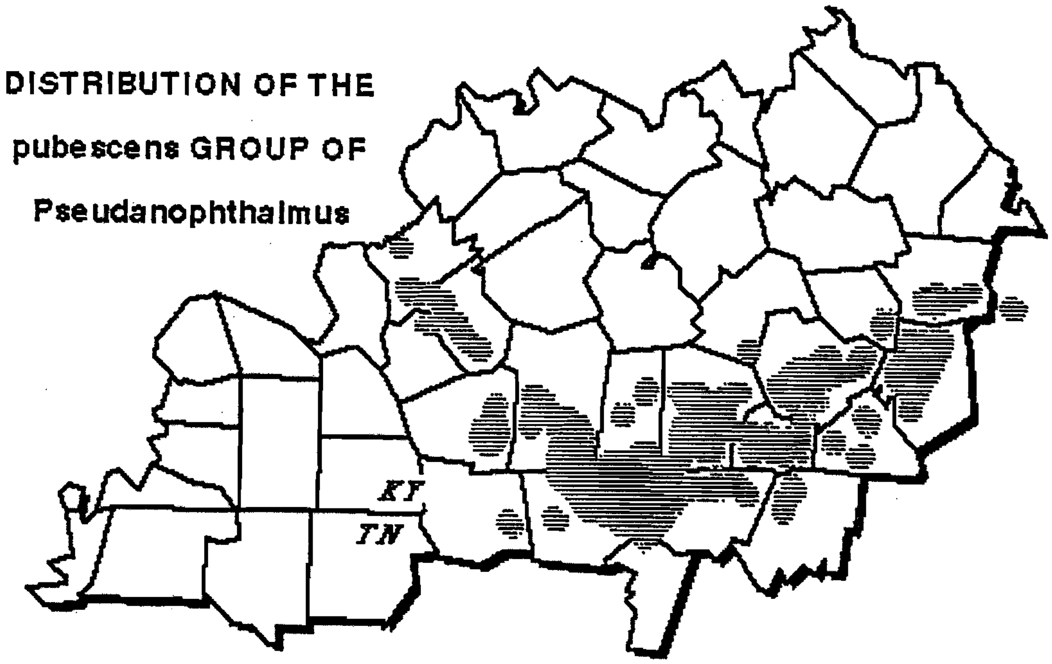

Fig. 5. Distribution of the *pubescens* species group of *Pseudanophthalmus*; includes 18 taxa confined to MP-I in southwestern Kentucky and adjacent Tennessee, as well as a few karst islands near its margins.

Neaphaenops tellkampfi in the Mammoth Cave region is separated by the lower Barren River from *N. meridionalis*, whose range extends to easternmost Logan County, Kentucky. *Pseudanophthalmus menetriesi* (east) and *P. transfluvialis* (west) are vicar species divided by the same barrier, and *P. pubescens* (east) and *P. loganensis* (west) are similarly allopatric on opposite sides of the Barren River. Distributions of groups of related species are often explainable in terms of Pleistocene drainage patterns, rather than existing patterns. For example, species of the *tenuis* group of *Pseudanophthalmus* are distributed throughout most karst areas within the lower Teays River drainage basin, from MP-I in southern Indiana and northern Kentucky to isolated karst islands within the Western Kentucky Coal Basin as far west as Rough River Dam. When a species of cave trechine was discovered in Hardin County, Illinois, near the mouth of the Wabash River (*P. illinoisensis* Barr and Peck 1966), it was anticipated that it would belong to the *pubescens* group, which is prevalent throughout MP-I in western Kentucky, including just across the Ohio River near Marion, Kentucky. However, it clearly belongs to the *tenuis* group, and the nearby mouth of the Wabash is the alleged lower end of the Teays. This suggests that the lower Ohio River was large enough to be a barrier even in early Pleistocene time, but such is not the case for the early Ohio in the vicinity of Louisville prior to Kansan glaciation. Two similar modern species occupying MP-I caves were apparently divided by the post-Kansas Ohio in Indiana (*P. tenuis*) and Kentucky (*P. barberi*). Despite very similar morphologies, these two species are biochemically quite dissimilar, based on allozyme electrophoretic studies, with genetic similarities of only 0.50-0.52 (Barr 1985a; Kane and Barr, in preparation).

Classical polytypic species among eastern cave trechines are unknown in the AV and found only in MP areas. However, intergradation is less frequent than parapatry, and in every case of hybridization between putative subspecies, the hybrid zones are very narrow, limited to one or two caves only. Hybridization of *P. ciliaris ciliaris* X *ciliaris orlindae* occurs in Bell Witch Cave, Robertson County, Tennessee (Barr 1979). *Pseudanophthalmus c. orlindae*, which occupies caves of the upper Red River drainage basin, is 1.2 times longer than *P. c. ciliaris*, which represents a biomass increase of about 73 percent (1.2^3). All species of the *pubescens* group are allopatric or at least parapatric, with one notable exception--*P. loganensis* coexists with both *P. c. orlindae* and *P. princeps*. *Pseudanophthalmus loganensis* (and two closely similar, peripheral vicar species) is the only interstitial feeder and the smallest species (>4.5 mm) of the group. Where the ranges of *P. ciliaris* and *P. loganensis* overlap, *P. ciliaris* is always represented by the large geographic race *P. c. orlindae*. The larger size of *P. c. orlindae* has the effect of increasing the size difference between these two sympatric species, which suggests--as implied above--that size, and the predation role that it supports, is an important component of niche in cave trechines. This observation, together with other evidence cited in this paper (and in Barr 1985a) indicates the significance of body size as a major component of trechine niches, in disagreement with the theoretical conclusion of Wilson (1976) that size is unimportant in small arthropods. After all, trechines are often top carnivores in their respective cave communities or the forest floor litter microhabitat.

Though *Neaphaenops tellkampfi* and *N. meridionalis* are separated at Bowling Green, Kentucky, by the Barren River, *N. tellkampfi* crosses the upper Barren near Scottsville, Kentucky, and hybridizes with *N. meridionalis* in Friendship Cave. Morphological and electrophoretic indicators of hybridization (Barr 1979, Brenner and Kane 1981) are of sufficient magnitude that I have interpreted this as a hybridization between semispecies (Barr 1985b). One might argue the case for gradual primary divergence between these taxa, in tandem with maturation of the Barren River between them, but the pronounced variation in the very narrow hybrid zone suggests a long period of extrinsic isolation.

Other Speciation Models. Most aquatic troglobites have more extensive ranges than terrestrial ones, and the smaller species are often found in non-cave habitats such as springs and wells in non-limestone terrains. The blind cavefish *Typhlichthys subterraneus* ranges from southern Kentucky (Mammoth Cave is the northern limit in MP-I) to north Alabama and west into the Ozark plateau. However, extensive biological inventories in caves, together with regional stratigraphy, indicate that the distribution is discontinuous throughout much of this range, and the electrophoretic studies of Swofford et al. (1980) suggest that it may be a morphospecies including a number of more or less genetically distinct, extrinsically isolated, local populations. Three similar species of troglobitic crayfishes of the genus *Orconectes* may have vicariously diverged in the headwaters of the Green (*O. pellucidus*), Kentucky/Teays (*O. inermis*), and Cumberland (*O. australis*) river basins (Hobbs and Barr 1972). Other terrestrial troglobites exhibit a range of patterns resulting from apparently different processes. The pseudoscorpion genus *Kleptochthonius,* prevalent in the "cave heartland" of eastern United States, includes many extremely local species, perhaps a reflection of exceptionally low vagility (Muchmore 1965). Cave millipedes of the genus *Pseudotremia* also include many local species, both troglobitic and troglophilic, but in the genus *Scoterpes* (perhaps an "older" cave group, because all of its species are troglobites, and it is more highly troglomorphic than *Pseudotremia*) the pattern is one of regional groups of closely similar taxa which may be polytypic species or perhaps superspecies. Laing, *et al.* (1976) found substantial electrophoretic differences between several cave populations of *S. copei*, which may prove to be a morphospecies. The spider *Phanetta subterranea* is the most widely distributed troglobite in eastern caves, but it strains credibility to assume that all its populations currently share a common gene pool. The highly variable collembolan morphospecies *Pseudosinella hirsuta,* found throughout much of MP-I in Kentucky and Tennessee (and also MP-II and even the edge of the AV), consists of many local populations with some evidence of gene flow between them, perhaps with gene flow taking place over non-karst "gaps" assisted by occasional intermediate populations in deep soil. Accordingly, Christiansen and Culver (1968) maintain that the biospecies paradigm is not readily applicable in such complexes. However, if the "ring species" of *Parus major* and *Larus argentatus* (see May 1963 and included references) and the "syngameons" (population groups of self-fertile and cross-fertile plants assigned to the same morphospecies) described by Grant (1985 and included references) can be accommodated within the biospecies concept, so can this interesting case of incomplete speciation in *P. hirsuta*.

Evolution of Cave Communities.

We begin with the assumption that communities of troglobitic species have arisen from coevolution of different species that colonized caves at different times and places in the past. *A priori*, given the greater dispersal potential of troglobites in thick, relatively undisturbed, highly cavernous limestones, we would predict far more complex communities in caves of the MPs compared to less complex communities in the AV. This is indeed the case. (Circular reasoning is not involved in this argument, as dispersal potential can be estimated from geographic ranges that species occupy in different karst terrains, and the prediction of more complex communities is based on those data.) The simpler cave communities in karst islands of Glen Dean limestone downdip from the Pennyroyal reflect this phenomenon, too. For example, *Pseudanophthalmus simulans* is the only cave trechine beetle in Cub Run Cave, Hart County, Kentucky, an isolated cave in Glen Dean limestone (Barr 1985b). Farther east in the Pennyroyal ("sinkhole plain") are *Neaphaenops tellkampfi, Pseudanophthalmus pubescens.* and *P. striatus.* Morphology suggests a close relationship between *P. menetriesi* and *P. simulans*, which have been interpreted as vicar species descended from populations of the same ancestor that colonized Cub Run Cave as well as one or more caves of the Pennyroyal. No such vicar species similar to *N. tellkampfi, P. striatus*, or *P. pubescens* occur in Cub Run Cave, indicating absence of connecting crevices between that cave and the much more extensive cave systems of the Pennyroyal. Relatively few other troglobites--mostly those species suspected of existing not only in caves but also in deep soil in non-karst areas--occur in Cub Run Cave.

Species diversity, measured in numbers of species per unit area of exposed karst, is three times higher for trechines in the AV, but community complexity (numbers of component species) is much greater in MP regions, where greater dispersal potential permits gradual dispersal of many troglobites into the same cave systems from different points of origin. Greater community stability in MP areas is inferred, because predators are not necessarily dependent on single prey species, thus can turn to other prey in years when prey they normally eat is less abundant. Relatively few troglobites have narrow niches, despite species packing in caves with richly diverse faunas, such as the Mammoth Cave system, where the troglobitic community includes about 30 species (Barr 1968b). A "rich" community in the AV rarely includes more than 10 species; among trechine beetles about 30 AV caves are inhabited by two species, and only one cave has an exceptionally rare third species.

The many isolated caves of the AV seem to exhibit a "shotgun" pattern (Barr 1981, 1985a) in which related beetle species occur in the geographic area presumably occupied by a common epigean ancestor, but there appears to be a random element in which caves were successfully colonized.

Six species of cave trechine beetles coexist in the Mammoth Cave community, as do two species of *Kleptochthonius* pseudoscorpions, two species of amblyopsid cavefishes, two species of gammarid amphipods, two species of kenkiid flatworms, and so forth. As discussed by Barr (1968b), Mammoth Cave lies at a sort of "crossroads" of troglobite dispersal routes, with some species having affinities in both directions along the Pennyroyal and others with affinities to the south, in the Cumberland saddle. The huge size of the system and its diversity of terrestrial and aquatic microhabits, together with its geographic position, have contributed to the evolution of an unusually complex community. Mammoth Cave holds the record for the number of coexisting trechines in North American caves, but guilds of 4-5 species are also found in a few caves of Wayne County, Kentucky (MP-II) or the Greenbrier valley of West Virginia (MP-III). Within the lower Cumberland and Tennessee river valleys, community diversity is lower than in the "heartland" of MP-I and MP-II, probably a reflection of the distance from the Allegheny refugium, but quite probably also the absence of cave crickets of the *Hadenoecus subterraneus* group (west of Russellville, Kentucky). All coexisting trechine beetles in this region -- and there are never more than two species within the area under consideration -- include a large cursorial predator and a smaller interstitial feeder.

Mean body size is greater in MP caves than in AV caves (or the intermediate situation caves of the western valley of the Tennessee River or the Central Basin), not only among trechine beetles, but in other troglobite groups as well (Barr 1967a). Few really large troglobites occur in the AV. and blind crayfishes (*Orconectes, Cambarus*) and cavefishes

(*Typhlichthys, Amblyopsis*) are creatures of MP caves not found in the AV. Even the troglobitic *Gyrinophilus* salamanders are represented by several MP species in Tennessee and Alabama but only one (*G. gulolineatus*) in a single cave in the AV. Among trechines the great majority of AV species are 3-4 mm long, but in MP regions the mean size is about 5 mm. There are also smaller species in the MPs, but larger size, perhaps "permitted" by more abundant prey, is very common in MP caves. As previously indicated, coexistence of trechine species is facilitated by different predator niches, those of "cruising predator" and "interstitial feeder."

Troglomorphic Evolution.

Evolutionary modifications associated with cave life include both regressive and progressive (i.e, putatively adaptive) changes. Over a century ago August Weismann (1889) supposed that eyes and pigment were selectively neutral in caves. But mutation pressure acting alone is considered too slow to account for widespread loss of eyes and pigment in cave animals, consequently explanations in which the process is accelerated by natural selection have usually been invoked. Barr (1968a) reviewed the regression mechanisms that have been most often suggested, especially the energy conservation and pleiotropy-polygeny theories. According to the first theory, energy is at a premium in food-poor caves and is wasted by building eyes, pigment, and other structures not required in total darkness, so selection has led to their rudimentation. The difficulty with this theory is that similar rudimentation occurs in food-rich tropical caves. Activity rhythms lose their circadian periodicity and become highly variable in troglobites, an observation not readily reconciled with an energy conservation theory, but easily explained by relaxation of normalizing selection. The second theory is based on the concept of an epigenotype with interlocking relationships between genes and characters (Mayr 1965) that has emerged from the realization that many genes are pleiotropic and many characters are polygenic (Wright 1964). The total fitness of a gene depends on the net effect of its deleterious and adaptive pleiotropic features. Fitness of specific genes in epigean and hypogean environments may be quite different. A hypothetical gene that causes rudimentation of eyes and reduces basal metabolic rate would be favored in a food-poor cave, and the now essentially neutral eye rudimentation would be carried along by selection that differentially increases the adaptive trait over alternative alleles.

The accumulation of post-speciation adaptive (progressive) traits by troglobites is well-documented, but the reasons why they are adaptive are not always obvious. I cite two examples out of many.

Christiansen (1961, 1965) demonstrated that cave collembolans can be arranged in an evolutionary series with respect to progressive lengthening of the unguis and tenent hair of the foot. Careful observation in caves showed that the extreme modifications permit their possessors to walk on the surface tension film in cave pools, while collembolans with feet similar to those of species that inhabit surface forest floor litter are trapped in the film and perish. Other species have evolved a convex thoracic hump to accommodate huge furcular extensors, enabling them to jump a meter or more when attacked by predators, a behavior feasible in the open spaces of caves but not in litter or debris.

Certain lineages of cave trechines are quite slender, a morphology called "aphaenopsian" (from the European genus *Aphaenops*) by Jeannel (1926-30). The head becomes subparallel, with short frontal grooves that do not continue around the head behind the genae; the pronotum is small and convex; elytra are narrow and convex, with strongly oblique prehumeral borders; and antennae and legs are elongate and very slender. The commonly held view of troglobites is of blind, depigmented, very slender and elongate creatures. Though slenderness -- often attributed to the necessity to creep through narrow crevices -- is, indeed, widespread, it is by no means universal. In trechines, an aphaenopsian or semi-aphaenopsian body is found exclusively among cruising predators, which clamber over floors, walls, and flowstone in search of prey, while the interstitial feeders, found among debris and gravels, are more or less robust and frequently more or less depressed. This suggests that a slender, elongated body is somehow an adaptation to mode of feeding rather than to squeeze through narrow crevices.

Cruising trechines are often larger species, as previously noted. A larger species can cruise a larger area than a smaller species, the area searched for prey proportional to the square of a linear increase in size. Larger size can be maintained by the increased prey captured in an environment where food is very scarce. However, total biomass will increase proportional to the cube of a linear increase, so that the additional prey is never enough to justify the investment of energy in building a larger body. A compromise can be struck, however, if length is increased, but body and appendages are kept as slender as possible--the area searched is still proportional to the square of linear increase, but the total biomass is now proportional to significantly less than its cube (Barr 1985a). Both *Neaphaenops* and *Darlingtonea* are aphaenopsian and search for cave cricket eggs. *Nelsonites*, believed to feed primarily on small juveniles of cave crickets, is aphaenopsian except for its huge head, with very large mandibles and massive mandibular adductors, presumably highly adaptive in seizing small, active prey. So slender bodies with elongate, spidery appendages probably reflect selection for searching a wider area in a food-poor environment, not "adaptations" to moving about through narrow crevices in caves. The hypothesis can perhaps be extended to other predatory troglobites, notably blind crayfishes and certain neotenic salamanders.

Loss and Destruction of Cave Communities.

Recently I prepared a checklist of *Pseudanophthalmus*; of 175 available names, 140 species were recognized, in addition to 5 subspecies-group names and 25 subjective synonyms (Barr, unpublished). Another 80 taxa are in my collection awaiting description. I was startled to see that 20 type locality caves were already lost through closure from urban sprawl, inundation by reservoir impoundments, or permanent closure by property owners. Fully 50 additional taxa (including both described and undescribed taxa) are known only from single caves or two or three closely approximate caves, that are potential candidates for extinction. This is over 29 percent of the known fauna of the genus! *Pseudanophthalmus nickajackensis* (Barr 1981) was known only from Nickajack Cave, a large cavern flooded by the waters of the TVA reservoir to which it gave its name. *Pseudanophthalmus tullahoma* (Barr 1959, see also Barr 1980) was known only from Carroll and Riley Creek caves, both of which were inundated by Normandy Reservoir on the Duck River. Several large cave "strategically" located for determining distribution of beetle species were flooded by the U.S.

Army Corps of Engineers by construction of Center Hill Dam on Caney Fork River in central Tennessee. Whatever species of troglobites these caves may have harbored will forever remain unknown.

Pseudanophthalmus hubbardi has not been collected since the late 1920s. It is endemic to Luray Caverns, Virginia, an outstanding and heavily visited commercial cave. Commercialization of a small, unattractive cave on the property of the Natural Bridge Company, Virginia, threatens the existence of *P. pontis*, known only from that cave. In suburban St. Louis, Missouri, the type locality of *Xenotrechus condei*, in a subdivision, has been permanently closed because it was judged a hazard to neighborhood children. The remarkable relic status of this genus has been noted above. In suburban Louisville, Kentucky, Oxmoor Cave, the type locality and only known habitat for *Pseudanophthalmus troglodytes*, one of two vicar species separated in Kansan time by the "new" Ohio River, was bulldozed shut only last fall to make way for a new subdivision; the site of the entrance is now occupied by a new house.

Sewage pollution threatens Hoy Cave, Simpson County, Kentucky, type locality of *Neaphaenops meridionalis* and *P. princeps*. The cave is in an expanding subdivision, yet sewage-polluted streams flow through many of its passages. Limited sewage pollution favors some troglobitic species over others. In Banner's Corner Cave, southwest Virginia, huge populations of isopods and flatworms occur on a flowstone slope over which septic tank effluent percolates (Holsinger 1966). The overall effect of such perturbations on cave communities is unknown. Some species may increase dramatically under pollution, while others decline. Increased BOD from raw sewage challenges adversely affects some troglobites, although troglobitic flatworms can avoid anoxia by crawling on the surface tension film, and the reduced metabolic rate of many troglobites prolong their survival in contrast to that of epigean relatives experimentally exposed to the same sewage concentrations (Barr 1976). This suggests that occasional transitory sewage slugs might be tolerated. Laboratory experiments with a troglobitic isopod, *Caecidotea stygia*, and an epigean isopod, *Lirceus fontinalis*, showed that the troglobite was better able to survive brief challenges of raw sewage or heavy metal pollution, but the long-term effects may well be quite different. A "recent" troglobitic amphipod, *Crangonyx packardi*, typically found only in food-rich areas in caves, where it is very active, was killed much sooner by exposure to sulfite (a respiratory poison) than an "older" slowly-moving troglobite, *Stygobromus exilis* (Barr 1976). At present sewage from Park City, Kentucky, drains directly into the headwaters of Mammoth Cave's Echo River, threatening the rich, historically important fauna of two species of blind cavefishes (the only known site where both *Amblyopsis spelaea* and *Typhlichthys subterraneus* coexist), blind crayfishes (*Orconectes pellucidus*), and cave shrimp (*Palaemonias ganteri*).

Oilwell pipes and oil storage tanks may leak. Environmental damage, "out of sight, out of mind," varies. In Friendship Cave, between Bowling Green and Scottsville , Kentucky, a sulphurous odor and long streamers of *Leptothrix* in the cave stream do not appear to have significantly affected the rich troglobitic fauna; an oil pipe penetrates the cave. However, a Lee County cave in eastern Kentucky has all upward-facing surfaces along the cave stream coated with crude oil dumped from a holding tank upslope from the cave, a type locality for the very rare *Pseudanophthalmus exoticus*. High levels of cadmium are attributed to oil pollution in Parker's Cave, near Park City, Kentucky. A number of dead crayfishes (*Orconectes pellucidus*) in stream pools were observed, and analysis of tissues from a small series of these crayfishes revealed high levels of several heavy metals. Spelunkers exploring parts of Mammoth Cave have reported an unusual number of dead *O. pellucidus* in a stream near the Park boundary in Joppa Ridge.

Fertilizer and pesticide pollution effects on cave communities have not been investigated. The sudden decline in many cave populations of the gray bat, *Myotis grisecens*, in the early 1960's may reflect increased use of organophosphate insecticides during that period, but the decline appears to be reversed at the present time.

An insidious effect of low level heavy metal pollution on cave faunas may result from the extreme chronological age of blind crayfishes and possibly cavefishes, also. In a 5-year study of three species of troglobitic crayfishes in Shelta Cave, Alabama, Cooper (1975) found extremely low rates of growth through marking/release/recapture experiments. Sexually mature crayfishes with a carapace length of 100 mm may be 30 to 125 years old, based on analysis of Cooper's data. Further, in food-poor years ripe eggs may be reabsorbed. With increased longevity and low levels of recruitment, the age structure of these populations is not pyramidal, but columnar. Extensive elimination of adults through pollution is likely to so damage the delicate ecosystem balance that it would take hundreds of years to recover from a single short episode of destruction. A limited amount of heavy metal tolerance may be possible through binding of cations in metallothioneins, but the capacity of these substance to detoxify heavy metals is probably inadequate to overcome frequent or long-term environmental insults during the considerable lifespan of these large aquatic troglobites.

Finally, there are problems arising from heavy cave visitation by spelunkers. The ecological effects of heavy traffic on cave fauna are unknown; most National Speleological Society members carefully remove their trash and spent carbide, but there are many transient spelunkers who are less cautious. Most caves are located on private property, and owners react differently to a constant stream of cavers entering their caves. Some owners have been treated so shabbily that they have closed their caves permanently, and some of these caves unfortunately include type localities. In the vicinity of Clarksville, Tennessee, cave owners are often openly hostile to anyone who wants to enter their caves, because of frequent trespass by recreation-seeking Army personnel from Fort Campbell. Property owners often fear lawsuits from cavers who might be injured on their property, and their solution is to deny anyone access.

There are no easy solutions to loss or pollution of caves, but it is incumbent on biologists and geologists to make known their significance as irreplaceable scientific and educational resources. Both private and governmental agencies can and should be enlisted in this effort.

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PREDICTING RECOVERY OF STREAM ECOSYSTEMS FROM DISTURBANCE: POTENTIAL FOR APPLICATION OF COLONIZATION THEORY AND HYDRAULIC STREAM ECOLOGY

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ABSTRACT. Recent studies conducted by the U.S. Environmental Protection Agency and the National Science Foundation have indicated that current theory in lotic ecology must be supported by additional research to develop the ability to predict recovery from disturbance. One critical need is the elucidation of the relationships between geomorphology, hydrology, lotic ecosystem structure and function, and the ecosystem's ability to resist or recover from disturbance. In this review, potential for application of colonization theory and hydraulic stream ecology to predict recovery rates are analyzed. The MacArthur-Wilson island biogeographic views of colonization and equilibrium (immigration-emigration) have been examined in many types of studies. Although still debated, current ideas support the theory that initial colonization is a stochastic process with variation in density and competitive abilities of species directing final community assembly. If this is the case, invertebrate colonization of lotic ecosystems could be examined as a function of the importance of colonizing mechanisms (drift, upstream migration, hyporheic movement, and aerial oviposition) at the time of disturbance.

The concept of hydraulic stream ecology suggests that primary niche dimensions for lotic invertebrates are composed of strict preferences for combinations of velocity, depth, and substratum. Interactions of these variables as complex hydraulics (shear stress) provide a limited range of flow conditions in which biota can compensate for differences in pressure and friction drag. Thus, the hydraulic quality of each stream element should determine the rate of retention of colonizers and influence the success of species during deterministic phase of community development. The Instream Flow Incremental Methodology (IFIM) provides the ability to predict the hydraulic quality of individual stream elements and combine with habitat preferences to predict flows that will maintain a given species or functional group. I suggest a series of colonization experiments that will allow the development of habitat criteria that support the fastest rate of colonization or attainment of equilibrium. In turn, these data could be used in IFIM by stream managers to predict flows which will maximize hydraulic conditions to allow the most rapid or effective recovery of stream biota from various levels of disturbance.

INTRODUCTION

Recently, the National Science Foundation and the U.S Environmental Protection Agency have held national symposia to produce working documents to assess the state of basic theory regarding the structure and function of lotic ecosystems (Stanford and Covich 1988) and the application of this theory to predict recovery from disturbance (Yount and Niemi 1990). In both instances, considerable emphasis was placed on increasing our knowledge of the interactions of geomorphological phenomena on basin and stream dynamics (Gore *et al.* 1990a). Of course, geomorphology has a profound effect on the hydrologic characteristics of the basin which, in turn, influences stream hydrographs. The change in discharge characteristics of the stream should also affect the distribution of lotic organisms. Statzner *et al.* (1988) demonstrated that a considerable amount of the variation in distribution of running water organisms can be attributed to changes in complex hydraulic conditions (turbulence, shear stress, sublayer thickness, etc.). Benthic organisms, particularly invertebrates, which provide a crucial link in the trophic dynamics of stream ecosystems, are especially tied to certain hydraulic conditions in order to complete their life cycles. That is, the depth, water velocity, and substrate roughness determine critical hydrodynamic conditions that allow benthic organisms to maintain position (by compensating for conditions of pressure and friction drag) in streams during each instar or transitional phase of their life histories. From a management perspective, maintenance of hydraulic heterogeneity may be a key to preserving or enhancing the diversity of stream communities altered by various forms of disturbance.

Currently, virtually every major river system in the United States is regulated by impoundment, diversion, or abstraction. The number of impoundments will only increase in developing nations as they seek to control riverine ecosystems to insure agricultural and industrial growth. In addition, the phenomenon of global warming and the potential change in global weather patterns will likely result in dramatic changes in the hydrograph of most rivers and streams. Other levels of disturbance, both mechanical and chemical, may occur along the length of a river. All of these changes must be ameliorated or mitigated in order to promote restoration and/or maintenance of lotic ecosystem integrity. Although river regulation initiates a substantial array of community alterations (Petts 1984), there is evidence that habitat for lotic organisms can be maintained with proper management of flows (Gore and Petts 1989). In order to provide adequate restoration programs, there must be construction of a model that, at the most basic levels, combines colonization theory to predict recovery from disturbance along with hydrologic and hydraulic models which predict habitat conditions related to changes in discharge. In this paper, I examine current ideas of the value of colonization theory to predict recovery from disturbance along with hydrologic and hydraulic models which predict habitat conditions related to changes in discharge. I focus on evaluation of benthic colonization rates as well as suggest research needed in order to combine these pieces of information into a model which might aid stream managers in mitigating or restoring damaged lotic ecosystems.

ISLAND BIOGEOGRAPHY/COLONIZATION THEORY

Recently, Gore and Milner (1990) reviewed current perceptions of island biogeographic theory. As proposed by MacArthur and Wilson (1963, 1967), the rate of immigration of new species to the island decreases as the number of species on the island increases and, conversely, the rate of extinction increases with the number of species. Additionally, rates of colonization are considered a function of the distance of the recipient island from the mainland, while rates of extinction are a function of recipient island size. Equilibrium is reached when immigration and emigration rates are equal. As it stands, this theory is essentially stochastic involving no species interactions. Because the chance of arrival is greater with shorter distance to the source and increased probability of arrival on the recipient island will likely reduce species extinction rates, Brown and Kodric-Brown (1977) suggested that extinction is unlikely to be independent of mainland distance. Seagle and Shugart (1985) were able to demonstrate that the balance between colonization and extinction was a result of habitat dynamics with succession and disturbance interacting to promote more constant habitat diversity on larger islands. Thus, island size also influences immigration.

Although there has been considerable support for the stochasticity of colonization and the formation of communities (Simberloff 1978, Conner and Simberloff 1979), more recent opinion has stressed the importance of competition as an organizing factor. Diamond (1975) proposed a series of assembly rules in which species co-adjustment to niches and abundances in order to resist immigrating species could be a major factor. This diffuse competition as an assembly rule depends greatly upon the types of organisms involved, trophic status, and habitat condition (Lawton 1987).

In lotic ecosystems, Fisher (1983) suggested that stochastic rather than deterministic colonization is more likely. However, Minshall and Petersen (1985) suggest that although species accumulation in early phases of colonization may be random and non-interactive events, later (equilibrium) phases feature directed interactive events. Simulations by Seagle and Shugart (1985) also indicate that species turnover is dependent upon species pool composition, competitive abilities of colonists, and vegetation/habitat dynamics during recovery. If some sort of deterministic activity during community assembly is a critical factor in lotic ecosystems, then we should expect that rates of colonization will depend on the sources and mechanisms of colonization and interactions with the physical habitat which may also be recovering from disturbance. Thus, it will be necessary to predict mechanisms, species composition of colonizers, and structural condition of the habitat.

COLONIZATION MECHANISMS OF LOTIC BIOTA

Generally, colonizing species are characterized by the ability to occupy a broad potential niche; that is, tolerance of extreme physical conditions and plasticity in resource utilization (Parsons 1987). It should be expected that colonizing benthos will use allochthonous inputs because these are likely to accumulate early in the development of the recovering lotic ecosystem (Gore 1982). Most colonizing lotic invertebrates, then, possess high vagility, high reproductive rates, and relatively poor competitive abilities (Resh *et al.* 1988).

Four colonization mechanisms and sources are common for stream macroinvertebrates, namely: (1) downstream migration or drift, (2) upstream migration, (3) vertical migration from within the substrate (hyporheic source), and (4) aerial adult sources (Williams and Hynes 1976, Williams 1981). Depending upon the intensity or frequency of disturbance, some or all of these sources are available to the recovering ecosystem.

Drift is most often designated as the dominant source of colonizers in lotic ecosystems. Drift has been considered to be the result of competition for food or space (Muller 1954, Townsend and Hildrew 1976), predator escape (Peckarsky 1980, Walton 1980), or as a result of competitive displacements (Wiley 1981). There is also evidence that drift is density independent (Brusven 1970, Statzner and Mogel 1984). Regardless of the interactions that cause benthic organisms to leave the substratum and enter the water column, drift is a cyclic daily event which makes a significant contribution to the redistribution of benthic species (Waters 1972). Although individual drift distances are reasonably low (< 2 m) (Townsend and Hildrew 1976), continual drift activity means that drift at any one point in a stream represents the summation of all passive and active mechanisms which occurred 50 m or more upstream (Minshall and Petersen 1985).

Upstream migrations of stream invertebrates have been reported but the numbers of individuals is usually far less than numbers drifting (Hultin *et al.* 1969, Williams 1977). However, distances travelled over a short period of time (<6 weeks) by some invertebrates can be quite substantial (over 10 km) (Gore 1977).

The migration of benthic invertebrates from hyporheic habitat can also provide a significant colonization source. As a protective mechanism against unfavorable discharges, the surface fauna have been observed to move into the hyporheic zone (Clifford 1966, Harrison 1966), which may extend several meters to several kilometers beyond the streambanks (Williams 1983, Stanford and Ward 1988). With disturbances related to dewatering and subsequent increase in discharge, hyporheic contributions to recovery may be quite substantial.

Aerial dispersal is an important colonization mechanism for aquatic insect species (Williams 1981), occurring between late spring and early autumn. While the pool of potential adult aerial colonizers may be substantial, oviposition behavior may alter colonization success (Sheldon 1984). Muller (1982) proposed that upstream flight of ovipositing aerial adults would compensate for the observed downstream drift of the nymphal and larval forms. However, some evidence indicates that this upstream flight can not always be demonstrated (Jones and Resh 1988). Thus, the contribution of aerial colonizers, even during the times of most active flight, is variable at best.

SPATIAL AND TEMPORAL CONSIDERATIONS

The importance of considering spatial and temporal differences in colonization studies has been reviewed by Wiens *et al.* (1986). The majority of colonization studies in lotic ecosystems have involved relatively short colonization periods with short dispersal distances (implanted artificial substrates) (Gore and Milner 1990). Thus, times for attaining equilibrium have varied from 14 days to over 150 years, depending upon the severity and frequency of disturbance (Table 1).

A complicating aspect to development of predictive models is seasonal variation in colonization rates and sources of colonizers. Colonization has been reported to occur more rapidly in summer than in winter (Shaw and Minshall 1980), possibly because of differential temperature effects on behavior (Williams 1981). Algal colonization has been reported not to occur during winter in spite of high algal standing crops (Gale and Gurzynski 1979) or, at the least, to occur at very low rates (C. E. Cushing; personal communication). Similarly, aerial contribution may be expected to vary seasonally, depending upon emergence periods of colonizers and their dispersal abilities. For example, Brudin (1967) considered that small winged and relatively light chironomids have a high passive dispersal capacity while most Ephemeroptera, Trichoptera, and many Plecoptera are weak fliers and Odonata, some

Table 1. Levels of disturbance, defined extent of disturbance, sources of colonizers, mode of community organization, and range of recovery/colonization times reported in the literature. Sources of colonizers are: (1) upstream [drift], (2) downstream, (3) hyporheic, and (4) aerial. Primary succession (1) and secondary succession (2) refer to floral community organization. Primary faunal organization (1) indicates stochastic determination of initial colonizers with competition organizing community structure after an equilibrium condition is reached. Secondary faunal organization (2) is deterministic as a result of the competitive abilities of the remnant populations after disturbance. Adapted from Gore and Milner (1990).

Disturbance Level	Extent	Community source	Remnant colonizing assembly flora/fauna	Recovery time
1A	Entire river	None	1/1	5 to > 25 years
1B	Entire river	3	1/2	1 to > 25 years
2A	Entire reach	1,2,4	1/1	90 to 400 days
2B	Entire reach	1,2,3,4	1/2	40 to 250 days
3	Partial reach	1,2,3,4	2/2	21 to 150 days
4	Patch	1,2,3,4	2/2	10 to 100 days

Coleoptera, and Hemiptera being typically active, directional fliers (Williams 1981). This variability in composition of the colonizing pool probably accounts for the variability reported in importance of dispersal mechanisms and sources. Townsend and Hildrew (1976) estimated that drift accounted for 82% of the colonizers of artificial substrates while the remaining 18% were from movements in contact with the substrate (upstream migration or hyporheic contribution). In contrast, Doeg *et al.* (1989), in short-duration summer experiments, found that drift was a major contributor of colonizing fauna only to trays containing sand substrates while gravel and stone-filled trays received the majority of colonization from substrate-contact origins. Williams and Hynes (1977) found that drift was initially the most important source of colonizers but, after one year, almost 50% of the species present in the stream had arrived aerially.

From the previous information, I suggest that it will be necessary to consider temporal factors in predicting rates of recovery by colonization. Because substrate also appears to play an important role in the rate of colonization and composition of colonizers, it will be necessary to consider substrate conditions in colonization success. Substrate is a primary determinant of complex hydraulic conditions along the substrate and it is likely that the hydraulic conditions associated with changes in depth and velocity as they determine habitat suitability must also be considered for effective prediction of recovery.

HABITAT SUITABILITY, IFIM, AND HYDRAULIC STREAM ECOLOGY

In introducing the concept of "hydraulic stream ecology," Statzner *et al.* (1988) proposed that analysis of the complex physical environment near the surface of the substratum in lotic ecosystems can a useful tool in describing the distribution of benthic organisms within a stream reach and along the longitudinal length of the river. Indeed, because metabolism, feeding, and behavior are often influenced by flow characteristics, Statzner *et al.* (1988) suggested that complex hydraulics represent a critical characteristic of organism responses. That is, the combined influences of depth, velocity, and substrate character are primary niche dimensions for lotic organisms. Although Statzner (1981), Statzner *et al.* (1988), and, to some extent, Gore and Judy (1981) and Morin *et al.* (1986) demonstrated data to support density and distribution predictions based on flow, the assumed dependence of riverine biota on flow characteristics is an implicit component of the Instream Flow Incremental Methodology, a regulated flow management tool (Bovee 1982, Gore and Nestler 1988).

The Instream Flow Incremental Methodology (IFIM) is a technique that combines hydrologic and hydraulic data with habitat criteria in order to predict gains or losses of suitable habitat under new discharge regimes. IFIM has been found to be a defensible technique for reserving minimum flows in river systems of the United States (Sweetman 1980, Gore 1989). The Physical Habitat Simulation (PHABSIM and revised PHABSIM II [Milhous *et al.* 1989]) is the computer simulation which combines the field measured hydrologic and biological data. The hydraulic information is provided by selecting transects across typical stream reaches and recording values of substrate, instream cover (hydraulic or predation refugia), mean water column velocity, and depth for each interval (called a "cell") along each transect at flows ranging from low to high discharges. Discharge values (in terms of changes in water surface elevation) between the measured flows are predicted through other routines contained in PHABSIM or are supplied externally from other hydraulic programs or directly from stream gauging data. Because IFIM is based on the assumption that biotic distribution are controlled in a large sense by changes in flow characteristics, habitat suitability criteria are represented by curves which mimic niche characteristics for these limiting factors. That is, habitat suitability curves are expressed as preference curves (ranging from 0% to 100%) derived from frequency of occurrence of individuals in each increment of that factor as weighted by the frequency of occurrence of that factor in the habitat of concern. Bovee (1986), Gore (1987), and Gore and Nestler (1988) have provided summaries and evaluations of techniques to produce these velocity, depth, and substrate/cover criteria.

The output of any of the habitat simulations (HABTAT, HABEF, etc.) is a prediction of available habitat, expressed as weighted useable area (WUA) or volume (WUV), as a function of discharge. That is, the product of the joint habitat quality of each cell is summed over all transects and expressed in terms of total area or volume of available highest quality habitat. This plot of values has been used by stream managers to predict allowable flows to maintain certain levels of habitat quality or availability under new discharge regimes. For example, the point of inflection along a WUA/discharge plot below which WUA declines rapidly with declining discharge may be considered the minimum allowable flow to manage reservoir releases or abstractions. Similarly, the point of inflection along that same curve where WUA declines rapidly with increasing discharge may indicate discharge levels to consider in using flood control structures or peaking hydropower dams. Gore and King (1989) have suggested that any life history stage or condition that can be related to hydraulic conditions may have a use in management of the ecosystem. For example, the habitat suitability values for spawning may be utilized in the PHABSIM simulation to determine a discharge level that might effectively eliminate or reduce spawning success as a control measure to regulate introduced species. In turn, this suggests that IFIM and the concepts of hydraulic stream ecology might also have use in predicting discharges that would allow the fastest rates of colonization or return to pre-disturbance community taxonomic structure or function.

THE POTENTIAL FOR COMBINING TECHNIQUES

The concept of hydraulic stream ecology has demonstrated that many lotic organisms have hydraulic conditions as a primary niche dimension. Indeed, Statzner and Higler (1985, 1986) have suggested conditions (particularly location of major breaks in stream gradient) and the heterogeneity of hydraulic conditions within a stream reach are critical factors that determine the distribution of all lotic biota. This also suggests that certain cells (*sensu* PHABSIM) that contain the most suitable hydraulic conditions for the majority of colonizing fauna or flora should be maintained during mitigation and recovery from disturbance. Regulating flows that provide the highest number of quality cells would, in essence, attract the greatest number of colonizers to remain in the area because the best available physical habitat of the recipient "island" would have been organized prior to initiation of the recovery process. This, in turn, implies that IFIM techniques could be used to provide predictions of recovery for each cell, if the extent of disturbance is known. That is, HABTAT could provide an indication of the discharge(s) that would provide the greatest amount of high quality cells for a single critical invader or the greatest diversity of habitat cells for the potential assemblage of colonizers. In order to predict this discharge it will be necessary to conduct research on the rates of colonization under various hydraulic conditions, on appropriate endpoints indicating recovery, and the relationship between discharge, diversity of hydraulic conditions, and the diversity of colonizing biota. Initial research into some of these areas has begun while other projects must yet be started.

A number of endpoints of colonization have been suggested (Gore and Milner 1990). In general, achievement of equilibrium conditions, highest diversity, or highest density have been most often used. Gore (1982) suggested that a simultaneous comparison of community composition at colonization source areas with the recovering system is the most appropriate as this indicates the attainment of similar taxonomic and functional structure. Gore *et al.* (1990a) still view the final definition of an acceptable endpoint in recovery to be a much needed condition before more effective predictions can be obtained.

In a single study of the Sabie River, South Africa, Gore *et al.* (1990b) suggested that there is a significant correlation between diversity of hydraulic conditions, as predicted by PHABSIM, and the diversity of fish species at various discharges. Although they used this technique to predict minimum flows for the conservation of threatened riverine biota or ecosystems, this technique might also have value for predicting the discharges that will allow greatest rates of colonization success. This application yet demands more conclusive data.

Finally, it will be necessary to conduct a long-term series of colonization experiments to determine the differences in rates of colonization and attainment of endpoints under various flow conditions. Because there is a temporal variability in the contribution of the four major colonization sources and mechanisms to recovery, this will require a project of several years duration with replication. This will also require a multiple stream and river comparison to determine if generic applications of the suitability criteria for highest rates of colonization are warranted. Gore and Milner (1990) have suggested that the colonization patterns of some artificial substrates mimic level 4 disturbances. As an initial approach, then, to examining the question of the influence of flow on colonization success, examination of an array of implanted artificial substrates for which daily flow conditions are known will be the first step in obtaining the correct data. IFIM techniques have the potential to provide flow conditions for each cell in which an artificial substrate is placed (Gore *et al.* 1989) and the techniques of Gore and Judy (1981) or Bovee (1986) should be able to provide the habitat suitability criteria for flows yielding highest rates of colonization or fastest attainment of equilibrium conditions.

Because some of the critical research suggested here has not been conducted, it is impossible to predict the success of the combination of colonization theory and hydraulic stream ecology, but previous successes in independent application of these techniques suggest that employment of both techniques to predict rates of colonization or achievement of recovery is a useful tool in management of lotic ecosystems. I suggest that examination of the relationships between hydraulic habitat of lotic organisms and the influence of changing flows on the ability of lotic communities to recover from disturbance will be not only a valuable tool in applied ecology, but will help in the validation of certain aspects of island biogeographic theory (especially the stochastic or deterministic nature of community organization). Ultimately, these colonization experiments must be conducted in streams suffering level 1, 2, and 3 disturbances and on a series of rivers ranging from lowest to highest orders. These data should aid stream ecologists in producing a model for generic guidance in predicting recovery of stream ecosystems for disturbance regardless of the scale of disturbance or the size of the stream.

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AGRICULTURAL NONPOINT SOURCE POLLUTION: CAUSES, EFFECTS, AND EVALUATION

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ABSTRACT. Agricultural nonpoint source pollution is a serious problem that will require a significant amount of research to develop appropriate methods for reducing the contamination of surface and ground waters. This paper briefly reviews some of the major consequences of agricultural nonpoint source pollution on aquatic ecosystems including bacterial contamination, phosphorus loading, and the contamination of ground waters with pesticides. In addition, specific research is discussed concerning the migration of three pesticides, atrazine, metolachlor, and chlordane, in soils in west Tennessee. Soil and water characteristics that dictate the ultimate fate of these chemicals are discussed. It is concluded that atrazine migration is primarily controlled by the high water content, low pH, and the clay content of the soils resulting in a rapid rate of hydrolysis to hydroxyatrazine. The mobility of metolachlor is determined by soil organic carbon and clay content. The high water content of the soil may enhance metolachlor leaching by competing with metolachlor for binding sites on the soil particles. Chlordane is tightly absorbed to the organic fraction of the soil. Dissolved organic carbon (DOC), however, may enhance desorption and solubility, thus increasing overall migration of the pesticide.

INTRODUCTION

In the 1970s it became apparent that the streams, lakes, estuaries, and aquifers of our nation were receiving significant pollutant loads from nonpoint sources. Today nonpoint sources are the principal sources of the conventional pollutants for which the U.S. EPA has established water quality criteria (Gianassi and Peskin 1981). Agricultural nonpoint pollution significantly affects water quality in 68% of all drainage basins in the United States (USEPA 1978). Agricultural lands are now the principal nonpoint sources of such conventional pollutants as biochemical oxygen demand (BOD), phosphorus, suspended solids, and bacteria. It has been estimated that agricultural pollution contributes 60% of the five-day BOD, 64% of the suspended solids, and 76% of the total phosphorus discharged into this nation's waters (Duda and Johnson 1985).

In west Tennessee, soil erosion due to agricultural practices overloads streams and lakes with massive quantities of sediment. In fact, Tennessee has the highest average erosion rate in the nation, approximately 31 tonnes per hectare per year and some local erosion rates exceed 220 tonnes per hectare per year (Tennessee Department of Health and Environment 1985). An example of this problem is Reelfoot Lake, an important wintering ground of the American bald eagle. Since about 1811, when the Reelfoot Lake was formed by a major earthquake, this valuable natural lake has decreased in size from 20,000 ha to 5,000 ha due to soil erosion and sedimentation (Petit 1984). On a national scale, eroded soil particles are estimated to have a net off site damage cost of $2.2 billion annually (Clark 1985).

Another serious consequence of agricultural practices is the migration of pesticides and fertilizers from the fields. Pesticide use increased 40-fold from 1946 to 1976 and this trend has continued to the present (Ridgeway *et al.* 1978). Pesticides, nitrogen, and phosphorus are transported from cropland either absorbed onto eroding soil particles or dissolved in runoff water. Pesticides may be acutely toxic to aquatic life or they may bioaccumulate in fish tissue. In some west Tennessee rivers, pesticides have been detected in fish tissue at levels exceeding Food and Drug Administration (FDA) limit, consequently, certain reaches of these rivers have been closed to commercial fishing. Elevated nitrogen and phosphorus levels in receiving streams accelerate eutrophication resulting in significant deterioration of water quality.

In many central and western states, where very high percentages of the land are used for cattle production, fecal coliform bacteria are a prominent and troublesome conventional pollutant (Nebraska Department of Environmental Control 1982). It is the purpose of this paper to briefly review the causes and impacts of agricultural nonpoint pollution. Further, the processes that control pesticide migration will be examined.

DISCUSSION

Causes and impacts of agricultural nonpoint source pollution.

Land availability and the need for food encourages the cultivation of marginal or unsuitable land. In the Midwest portion of the United States, the economic forces of the 1970s pressured farmers into unwise decisions concerning soil and water conservation. Up until 1973 the area of erodible land under cultivation was declining because it was not profitable to farm. Large increases in the price of corn, wheat and soybean brought large amounts of low-quality land into production. Of the 3.8 million hectares brought into production in 1974, the Soil Conservation Service estimated that nearly one-half was land suspect to severe erosion (Langdale and Sharader 1982). Economic pressures have not subsided; in many areas they have become worse as farmers cling to a livelihood. Unfortunately, in times of economic pressures little thought is given to preserving environmental quality. Agricultural nonpoint source pollution is not just erosion, rather it may include bacterial contamination, increased phosphorus loading, and pesticide contamination of both surface and ground waters.

Bacterial contamination results from land application of manure as well as feedlot operations. Robbins *et al.* (1972) studied six typical agricultural sites in the Piedmont region of North Carolina. Five of the six sites were watersheds (2 to 26 ha) subjected to landspread wastes, including pasture and feedlot operations. A sixth watershed, described as free from animal wastes, was used for control. Samples were analyzed for total coliforms (TC), fecal coliforms (FC), five-day and ultimate BOD, chemical oxygen demand (COD), total solids, volatile solids, total organic carbon (TOC), total Kjeldahl nitrogen, nitrate-N, nitrite-N, ammonia-N, total phosphorus, ortho-phosphorus, specific conductivity, and pH.

Average bacteriological quality in streams arising in all six watersheds "greatly exceeded" quality limits generally set for bathing waters. Since bacterial densities from the control watershed were also high, the authors suggest that the pollution effects of animal wastes (when properly spread on watersheds) might be overshadowed by hydrologic factors such as rainfall, temperature, slope, soil permeability, surface culture, drainage pattern, degree of erosion, and antecedent moisture conditions (Robbins *et al.* 1972).

Harms *et al.* (1975a, 1975b) collected surface runoff from snowmelt and rainfall from seven agricultural sites in eastern South Dakota. Total coliform densities in snowmelt runoff exceeded the recommended limits for treated public water supply (10,000/100 ml) with a frequency of 25% for oat (*Avena* sp.) stubble and alfalfa-bromegrass (*Medicago* sp.-*Bromus* sp.) hay field, 35% for pasture, 85% for fall-plowed fields, and > 95% for grazed corn stubble. Fecal coliform densities in snowmelt runoff exceeded recommended limits for treated public water supply (2000/100 ml) with a frequency of 9% for grazed corn stubble, 15% for alfalfa-bromegrass hay field and 50% for pasture. Sites with minimum ground cover (eg., fall-plowed and corn stubble) yielded higher densities of fecal streptococci in snowmelt runoff than well-covered fields (eg., oat stubble). Rainfall runoff from cultivated fields bore fecal coliform densities that exceeded recommended limits for primary contact recreation (200/100 ml) with a frequency of 90%. Fecal streptococci densities were comparable to total coliform densities; both exceeded 5000/100 ml with a frequency of 90%.

These authors concluded that surface runoff waters from agricultural lands carry indicator microorganism densities that frequently exceed water quality standards, and suggested that the contributions of nonpoint sources be considered when estimating the water quality benefits to be derived from further point source regulation. Nonpoint source pollution from agricultural runoff was regarded as unredressable and the authors suggested that water quality parameters be reviewed.

The importance of soluble phosphorus transport in agricultural runoff as an immediate source of phosphorus for biological uptake, and thereby accelerating the eutrophication of surface waters, is well documented (Vollenweider and Kerekes 1980; Sharpley and Manzel 1987). Klaine *et al.* (1988) monitored nutrient runoff from a 10 ha field in west Tennessee for two years. Approximately 2% of the applied phosphorus was lost in the runoff each year.

Sharpley and Smith (1989) examined the leaching and mineralization of phosphorus in the presence of surface and incorporated crop residue. Mineralization and movement through soil of inorganic phosphorus was consistently greater for surface than incorporated residues. The lower amount of ortho-phosphate leached from surface-applied compared to incorporated residue is consistent with an increased mineralization of surface residue phosphorus.

Characterization of agricultural pesticide migration has become a primary concern (see reviews by Wauchope [1978] and Willis and McDowell [1982]). It is important to note that agricultural pesticides pose a contamination threat to both surface and ground water supplies. Until recently, ground water contamination by these chemicals was often considered minor when considering overall environmental risk.

Since the 1980s, however, an increasing number of agriculturally applied pesticides have been found in more ground water samples (Cohen *et al.* 1984, 1986). Reasons for this include the following: (1) more projects initiated to define degree and extent of contamination; (2) analytical detection limits are 3 to 6 orders of magnitude lower than they were 20 yrs ago; and (3) as more is learned about processes controlling pesticide leaching, more projects are directed to the most vulnerable sites. The obvious candidates are those sites where pesticide usage is greatest, percolation rates are highest, pesticide residence times in the soil zone is least, and dilution is least.

One of the most likely agricultural situation fulfilling these criteria are irrigated sands or nonirrigated sands in humid areas that produce high value crops and overlie shallow water tables. Some of the earliest and most severe cases of pesticide contamination of ground water have been documented in Long Island in New York State, Florida, central Wisconsin, and southern California, largely in this type of system (Holden 1986). Another situation fulfilling these criteria are agricultural area underlain by limestone with a well-developed karst topography. Here, ground water recharge may be aerially very concentrated or include direct surface water entry through sink holes thus bypassing normal soil filtration. Generally, however, pesticide solubility, adsorptivity and degradability are controlling factors. Most pesticides that appear in ground water are among the more soluble, less adsorbed and longer-lived pesticides in that area (Cohen *et al.* 1984, 1986).

Cohen *et al.* (1984) suggested that the potential for pesticide contamination of ground water was highest when certain pesticide and field characteristics appeared in combination. The pesticide characteristics and guideline threshold values were given as follows: water solubility > 30 mg/l; adsorptivity, $K_{oc} < 300$ to 500; Henry's law constant < 0.01 atm-m^3/mol; negatively charged at soil pH; soil half-life > 2 to 3 weeks; hydrolysis half-life > 25 weeks; and photolysis half-life > 1 week. The field characteristics and guideline threshold values were as follows: total ground water recharge > 250 mm/yr; presence of high NO_3 concentrations as an indicator of agricultural recharge source; unconfined aquifer with permeable soil above it; and soil pH consistent with low pesticide degradation rates.

With recent attention focusing on nonpoint source pollution of both surface and ground waters, farmers may now be facing environmental regulations that could cost them significant amounts of money. Best management practices (BMPs) designed to reduce the loss of soil, fertilizers, pesticides, bacteria, and salts typically represent financial burdens to the farmer that may force them out of business. Fortunately, recognition of this dilemma has caused the U.S. Department of Agriculture to initiate cost share programs that will allow farmers to implement BMPs to improve water quality.

Best management practices that are economically and environmentally sound are not always available to farmers. Much research is necessary to understand chemical movement in agroecosystems. Simply monitoring chemical concentrations in receiving streams does not tell the entire story, nor does it provide the basis for development of BMPs to reduce chemical loss. Understanding the processes that control chemical mobility in soil and water systems is critical to development and implementation of BMPs.

Pesticide Migration in Soils

Pesticide migration in soils has been of interest to the Environmental Health and Toxicology Research Institute at Memphis State University for a number of years. The remainder of this paper presents a synopsis of what we have learned concerning the mobility of pesticides in soils.

Pesticide mobility in west Tennessee soils. Research at MSU has concentrated on factors in saturated and unsaturated soil systems that determine the fate of three pesticides: atrazine (2-chloro-4-(ethylamino)-6-(isopropylamino)-s-triazine), metolachlor (2-chloro-N-(2-ethyl-6-methlyphenyl)-N-(2-methoxy-1-methylethyl acetamide), and chlordane (1,2,4,5,6,7,8,8-octachloro-2,3,3a,4,7,7a hexahydro-4,7-methanoindane). These pesticides represent a wide range of physical and chemical characteristics (Table 1). The first two were studied in an agricultural situation over a three-year period. Chlordane migration was studied in a U.S. EPA superfund site. The purpose of this research was to determine the processes that control pesticide mobility.

Table 1. Physical and chemical characteristics of atrazine, metolachlor and chlordane

Chemical	Water Solubility	Half-life	Soil Sorption index (K_{oc})	Ref.
Atrazine	33 mg/L	20-100 d	160	SCS (1988)
Metolachlor	530 mg/L	10-100 d	200	SCS (1988)
Chlordane	9-56 ug/L	8-10 yr	10,000-20,000	Conway (1982)

Atrazine and Metolachlor. Atrazine and metolachlor are herbicides that are used extensively on crops in the United States. Atrazine is used primarily on corn and metolachlor on corn and soybeans. This research characterized soil-chemical interactions by determining partition coefficients at different soil depths for both herbicides. Soil characteristics were then determined in an effort to discern which soil property(s) was responsible for chemical sorption. All of this research was performed on a 10 ha experimental field at Agricenter International, Shelby County, Tennessee. Four sites on the field were sampled to determine spatial variability in the soil.

Particle size distribution and organic carbon content were determined by standard methods (Nelson and Sommer 1975, Gee and Bauder 1986). Soil:water distribution coefficients were determined for each chemical using radiolabled pesticide according to methods described by Anderson *et al.* (1980).

Particle size distribution and organic carbon content of the soils are shown in Table 2. The Ap horizon (0-15 cm) for each of the four sites was classified as a silt loam using the texture triangle method (Buol *et al.* 1980). This horizon consisted of 75% silt. The same was true for the C1 (15-33 cm), the C2 (33-48 cm) and the C3 or Cg (48-89 cm) horizons. The Cg horizon was gleyed as a result of high moisture retention and contained gray and brown mottles. Formations of iron and manganese concretions in this reducing environment are additional evidence of a high water table throughout much of the year. Soils in the 60-75 cm level at the four sites were classified as silt loams, each containing approximately 60% silt. Site C2, at this depth, contained significantly more sand than the other three sites. Soils in the 75-90 cm depth were classified as silt loams containing approximately 72% silt.

Organic carbon content was highest in the Ap horizon (0-15 cm), but differed among the four sites samples. In general, organic carbon content was very low throughout the soil profile.

Table 2. Particle size distribution and organic carbon content of experimental field.

	Depth (cm)	% Sand	% Silt	% Clay	% O/C
SITE E4	0-15	4.5	86.6	8.9	0.29±0.02
	15-30	7.5	81.8	10.7	0.30±0.03
	30-45	10.9	81.9	8.2	0.25±0.03
	45-60	10.1	73.9	15.9	0.13±0.01
	60-75	1.6	80.6	17.8	0.14±0.04
SITE A4	0-15	3.8	84.3	11.9	0.50±0.04
	15-30	1.2	86.2	12.7	0.30±0.04
	30-45	2.3	82.7	15.0	0.20±0.02
	45-60	1.0	84.0	15.0	0.12±0.04
	60-75	1.0	83.5	15.5	0.27±0.01
	75-90	1.0	80.0	18.9	0.38±0.02
SITE C4	0-15	11.8	79.9	8.3	0.64±0.06
	15-30	14.1	78.1	7.9	0.29±0.07
	30-45	7.2	81.5	11.4	0.20±0.01
	45-60	1.0	78.8	20.2	0.35±0.05
	60-75	1.0	76.7	22.3	0.34±0.03
	75-90	7.5	72.9	19.6	0.18±0.03
SITE C2	0-15	12.8	74.5	12.6	0.36±0.03
	15-30	15.0	71.9	13.1	0.33±0.02
	30-45	16.6	68.9	14.6	0.10±0.04
	45-60	36.2	49.2	14.6	0.14±0.01
	60-75	27.3	59.6	13.1	0.12±0.04
	75-90	1.7	72.0	26.3	0.40±0.01

Partition coefficients were determined at each depth to correspond with particle size and organic carbon content determinations (Table 3). Partition coefficients (K_d) were normalized for soil organic carbon content to produce K_{oc}. If organic carbon was the predominant soil characteristic that determine adsorption, K_{oc} values would be more similar than the K_d values at the different soil depths. An examination of the K_d and K_{oc} values for atrazine in Table 3 illustrates that, in fact, K_{oc} values are more dissimilar than K_d values between depths. Data suggest another soil parameter is driving the adsorption of atrazine to the soil. While the K_{oc} values for metolachlor appear to be closer than those for atrazine, they still do not reduce the variability illustrated in the K_d values for metolachlor. Again, another soil parameter is associated with soil adsorption of metolachlor.

The adsorption isotherms for atrazine exhibited an "L" shape similar to what Weber (1966) reported. The L-type isotherm implies that the adsorbent has a moderate affinity for the solute; the isotherm tends to level off at certain adsorption maximum. The adsorption of a chemical to soil is strongly correlated with the percent organic carbon in the soil and, therefore, for a given non-polar chemical, K_{oc} is more nearly constant among soils than K_d. Walker and Crawford (1968), in an earlier study with atrazine, illustrated that indeed K_d values were highly correlated with organic matter content of the soils as long as the organic content was above 8%. When soil organic content was less that 8% K_d values were correlated with clay content and organic matter together. In our study, organic carbon content of the soil was always less than 1%, suggesting that clay content might be responsible for atrazine adsorption in this system. Simple regression, however, did not indicate that atrazine K_d values were correlated with soil clay content. Multiple regression did indicate a highly significant correlation ($r^2 = 0.944$) between atrazine K_d values and the combination of percent organic carbon and soil clay content.

Adsorption isotherms for metolachlor exhibited an "S" shape similar to what Weber and Peter (1982) and Kozak *et al.* (1983) found. S-type adsorption isotherms suggest that at low concentrations the solid has a higher affinity for the solvent than the solute and that the solute is probably adsorbed in a vertical position on the surface; bonding is monofunctional. Therefore, at low concentrations metolachlor may have a higher potential for leaching because it competes with water molecules for adsorption sites. Simple regression indicated that percent organic carbon was correlated with metolachlor K_d values ($r^2 = 0.799$) while multiple regression indicated a very high correlation between K_d values and the combined variables of percent organic carbon and soil clay content ($r^2 = 0.964$). Braverman *et al.* (1986) found similar correlations with a silty clay loam soil.

From these data, and the field data suggesting high water content of the soil and slightly acidic soil pH, a model of pesticide mobility in these soils can be represented. Mobility of metolachlor in these soils is strongly influenced by the high water content causing significant competition with water molecules for binding sites on the soil. This keeps metolachlor molecules in the mobile water phase, thereby enhancing potential for leaching. The reason metolachlor does not leach further than 70 cm is that water does not readily percolate in these tightly compacted Falaya silt loams.

Table 3. Partition coefficients for atrazine and metolachlor at different depths.

LEVEL	ATRAZINE (ug/ml)	Cs (ug/g)	Cw (ug/ml)	K_d	K_{oc}
0-15cm	0.66	0.823	0.354	2.03	317.20
	6.66	8.033	3.940		
	13.20	12.623	5.977		
15-30cm	0.66	0.560	0.404	1.21	417.24
	6.60	5.354	4.397		
	13.20	7.931	7.093		
30-45cm	0.66	0.483	0.408	1.36	1364.00
	6.60	4.601	4.600		
	13.20	8.765	6.018		
45-60cm	0.66	0.401	0.408	0.94	668.60
	6.60	4.578	4.880		
	13.20	8.063	5.608		
60-75cm	0.66	0.878	0.357	0.93	771.00
	6.60	4.416	4.515		
	13.20	6.111	5.498		
75-90cm	0.66	0.942	0.259	3.14	785.00
	6.60	10.497	3.323		
	13.20	25.172	6.058		

LEVEL	METOLACHLOR (ug/ml)	Cs (ug/g)	Cw (ug/ml)	K_d	K_{oc}
0-15cm	1.00	1.555	0.529	2.28	355.60
	10.00	14.127	6.220		
	20.00	29.971	8.200		
15-30cm	1.00	0.904	0.631	1.23	424.14
	10.00	9.105	7.390		
	20.00	15.986	9.592		
30-45cm	1.00	0.731	0.661	0.99	991.00
	10.00	7.276	7.340		
	20.00	15.854	9.420		
45-60cm	1.00	0.757	0.479	0.80	574.30
	10.00	5.644	7.050		
	20.00	10.115	8.660		
60-75cm	1.00	0.537	0.682	1.03	860.80
	10.00	7.652	7.395		
	20.00	15.171	11.128		
75-90cm	1.00	1.296	0.564	2.35	586.50
	10.00	14.644	6.240		
	20.00	26.531	8.488		

Atrazine, in these soils, adsorbs to clay sites and readily undergoes hydrolysis to hydroxyatrazine. The driving force for this phenomenon is the high water content of the soil, low soil pH, and low organic carbon content.

Chlordane. Chlordane represents a very different pesticide than atrazine and metolachlor. An insecticide used to protect buildings from termite attack, chlordane is much more recalcitrant and toxic than the two herbicides previously discussed. Our research with chlordane has focused on the factors that determine its mobility in soils. To this end, we have characterized the particle size distribution and organic carbon content of the soils in question and determined soil-water partition coefficients for chlordane. All research has been performed with soil from the North Hollywood Dump, Memphis, Tennessee, a U.S. EPA superfund site known to have chlordane levels exceeding 100 mg/kg in the soil (Jordan 1984).

Results immediately indicated a strong correlation between K_d values and soil organic carbon content (Fig. 1). This was expected given the low solubility of the compound and the high octanol/water partition coefficient (log K_{ow} = 5.58).

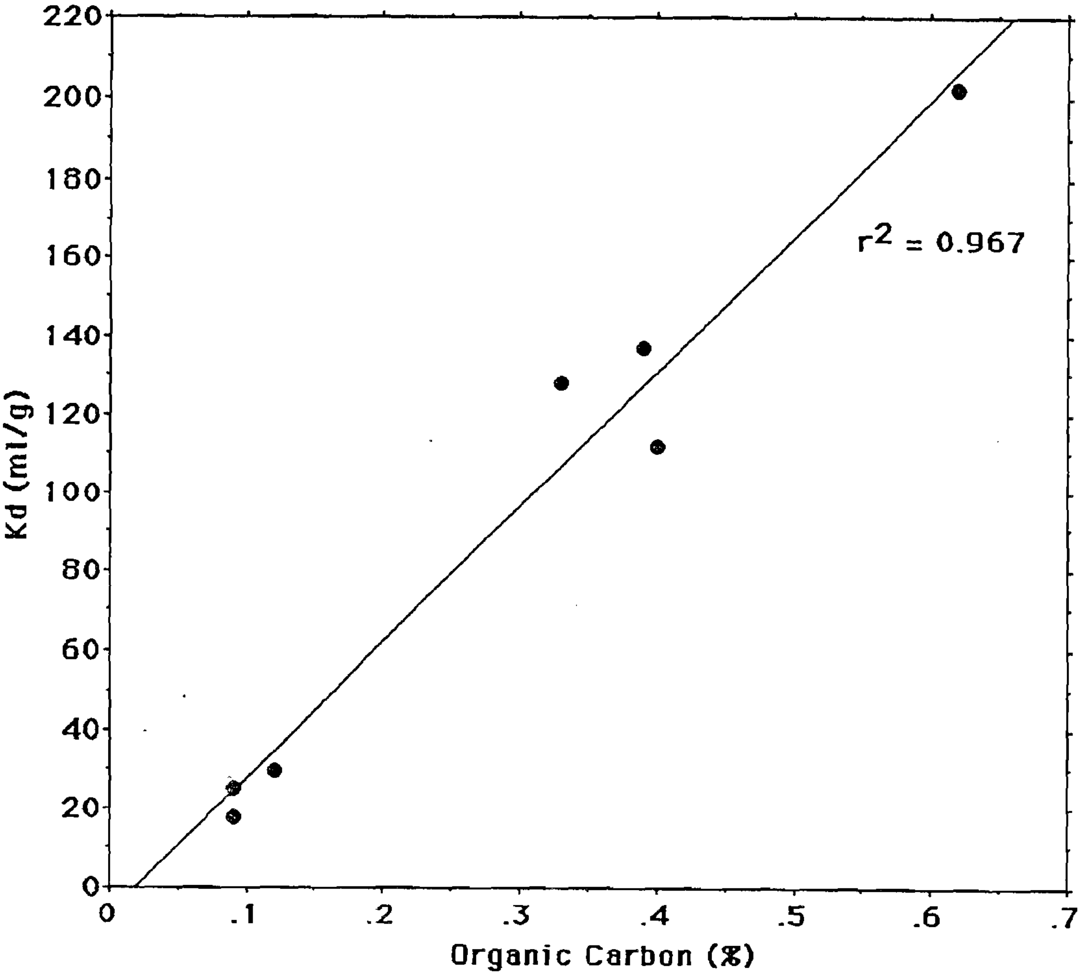

Figure 1. Influence of soil organic carbon on chlordane soil:water partition coefficients (K_d).

Given these results and the fact that soils in the North Hollywood Dump contain significant quantities of organic carbon, little migration was predicted. Elevated levels of chlordane, however, have been found in riverine fish (25 mg/kg) in the Wolf River adjacent to the dump site. It was then hypothesized that dissolved organic carbon (DOC) in the water percolating through the dump might be mobilizing chlordane.

Ground water samples were obtained hydraulically upgradient and downgradient from the dump. Total organic carbon (TOC) analyses indicated upgradient ground water to contain 1.8 mg/l TOC while downgradient ground water contained 34 mg/l TOC. Solubility experiments were performed in order to determine the effect of dissolved organic carbon (humic acid) on the solubility of chlordane; solubility increased linearly with DOC (Fig 2). Since humic acids contain non-polar groups (Stevenson 1982), solubility enhancement has been attributed to the partitioning of the solute into hydrophobic regions of dissolved humic materials (Chiou *et al.* 1986).

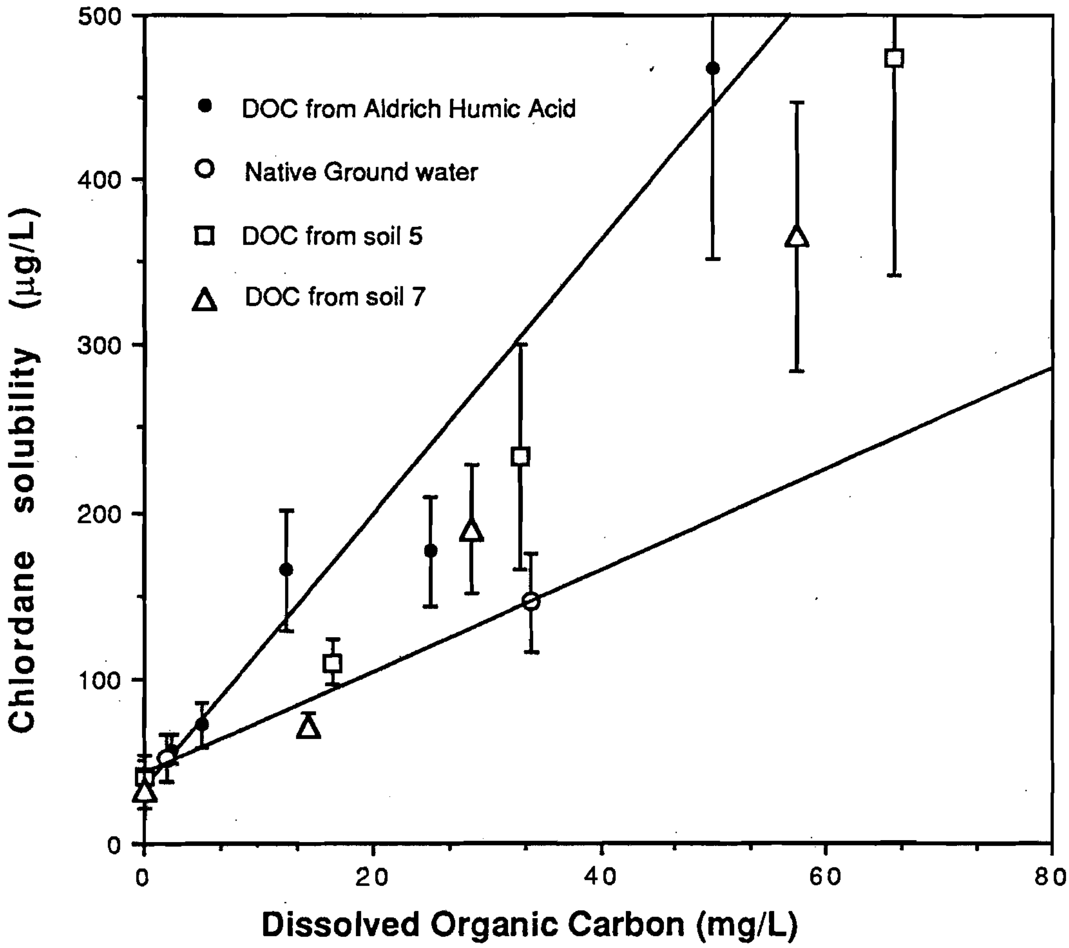

Figure 2. Influence of DOC on chlordane solubility. Upper regression line represents data from Aldrich humic acid. Lower regression line represents data from ground water-extracted humic acid.

Desorption of soil-adsorbed chlordane by DOC was investigated using column studies. Glass columns (6 cm i.d.) were first packed with a plug of glass wool and then uniformly packed with wet sand to a depth of 15 cm. Pore volumes were determined on each column with blue dextran. Carbon-14 labeled chlordane in methanol was loaded onto the top of each column. Following slow evaporation of the solvent, a humic acid solution of 25 mg/l as DOC was made up in synthetic moderately hard water, filtered through a 0.45 μm filter and leached through duplicate columns at a rate of 1 ml/min. Column effluent were sampled twice a day and analyzed for radiolabeled chlordane on a liquid scintillation counter. The experiment was duplicated with 2.5 mg/l DOC.

When leached with 25 mg/l DOC, the centroid of the chlordane breakthrough curve for each column occurred at approximately 50 pore volumes (Fig 3.) Columns with only 2.5 mg/l DOC had not reached the centroid of chlordane elution by 200 pore volumes.

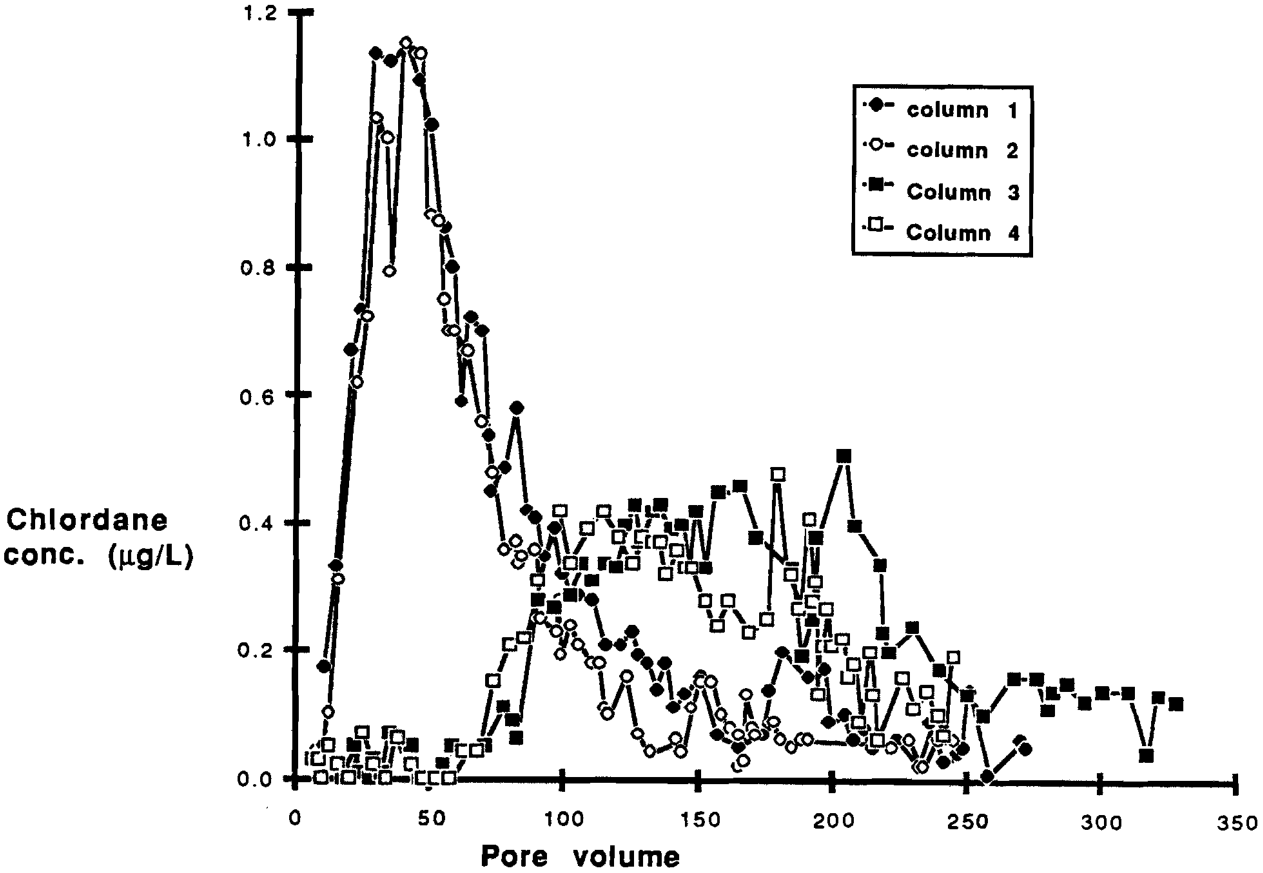

Figure 3. Influence of DOC on chlordane desorption from a soil column. Columns 1 and 2 were leached with 25 mg/l DOC; columns 3 and 4 were leached with 2.5 mg/l DOC.

This dramatic effect of DOC on the mobilization of chlordane may indeed be what is happening in a waste dump situation where decaying wastes may produce significant amounts of DOC. This DOC, in turn, may mobilize strongly adsorbed organic such as chlordane resulting in enhanced migration from the dump into adjacent surface and ground waters.

Future Research Needs

Agricultural nonpoint source pollution results in significant deterioration of aquatic ecosystems. The importance and magnitude of agricultural activities necessitates the addition of chemicals to enhance productivity. Chemical management in agroecosystems is critical for maintaining aquatic ecosystem stability. While bench-scale experiments provide data on chemical solubility, adsorption, and bioavailability, it is often difficult to extrapolate these data to the environment.

It is extremely important that field-scale experiments be designed and implemented in such a manner as to obtain the best and most data for the time and expense incurred. Data are needed that verify mathematical models, enhance our ability to extrapolate from bench-scale experiments, and provide the scientific foundation for good environmental management.

ACKNOWLEDGEMENTS

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CONTRIBUTED PAPERS

SESSION I: ZOOLOGY

Saturday, March 3, 1990

Moderated by:

Steven W. Hamilton
Austin Peay State University

PRELIMINARY REPORT ON REPRODUCTION AND GROWTH OF AMERICAN AND FOWLER'S TOADS (*Bufo americanus* AND *Bufo woodhousei fowleri*) AT LBL AND SURROUNDING AREAS

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ABSTRACT. Museum specimens of American and Fowler's Toads (*Bufo americanus* and *Bufo woodhousei fowleri*) have been examined and measured to determine date and location of collections, sex, breeding condition, body length, and tibio-fibula length. These data are be compared with field data during the 1990 breeding season to determine growth rates, reproductive cycles, and habitat partitioning in these two closely related species at LBL and adjacent surrounding areas. According to most field guides, the American toad occurs as a separate subspecies, the dwarf toad (*Bufo americanus charlesmithi*) west and north of LBL. However, specimens from Lyon County, Kentucky, cannot be assigned to subspecies on the basis of morphological data alone. Preliminary observations indicate that the breeding periods and breeding sites of these two species differ, but do overlap. Hybridization may occurs, and hybrids appear to be fertile. The presence of a few gravid females in autumn indicates that some females may overwinter in a gravid condition. Many specimens have characteristics of both species. Growth rates also overlap, with little discernible difference in size. Both species appear to grow from 15-30 mm per year the first two years, and first breed when they are two years old; most gravid females were at least 59 mm in length, while most sexually mature males were over 50 mm in length. Western Kentucky specimens were slightly smaller. Leg length relative to snout-vent length varied geographically within each species.

[1] Supported by Senior Research Fellowship from The Center for Field Biology, Austin Peay State University.

SUMMER BIRDS USING GIANT CANE (*Arundinaria gigantea*) IN LAND BETWEEN THE LAKES

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ABSTRACT. During Junes of 1988 and 1989 I spent a combined total of 17 days in Land Between The Lakes (LBL) and on adjacent islands studying the birds using giant cane (*Arundinaria gigantea*). Although nine days were spent searching the mainland for stands of giant cane (canebrakes), all extensive canebrakes that I found were either on islands in Lake Barkley, Stewart County, Tennessee, near the southeast corner of LBL, or in similar environments; i.e., low, flat land -- in the adjacent Bear Creek Waterfowl Management Unit (BCWMU). Some island canebrakes covered 0.4-0.8 ha, with plants up to 6.5 m tall.

The 226 observations of individual birds made during the study represented 31 species. The White-eyed Vireo (*Vireo griseus*) was the most frequently recorded species (35 records = 15% of total records), followed closely by the Carolina Wren (*Thryothorus ludovicianus*; 32 records = 14% of total records).

Forty-six nests, representing 7 bird species, were found constructed on giant cane, all either on islands or in the BCWMU. Most nests were found on the periphery of canebrakes where the stands were thinner, with smaller cane poles and denser foliage. Over one-half of the nests were of the Northern Cardinal (*Cardinalis cardinalis*; 25 nests = 54% of total nests). Rarely, were nests attached also to other adjacent plants such as greenbrier (*Smilax*), wild grape (*Vitis*), and small, woody saplings. Forty-four of the nests, representing six species of birds, contained some cane leaves in the nest composition. Only five nests (of three species) contained eggs, and none contained young. Some old nests were within a few meters of a recent nest of the same species (Northern Cardinal and Common Yellowthroat, *Geothlypis trichas*). On islands prone to flooding many old nests contained ant colonies. Some species of birds used the canebrakes for foraging, but apparently not for nesting (Tufted Titmouse, *Parus bicolor*; Louisiana Waterthrush, *Seiurus motacilla*). Others may have nested earlier in the year and were therefore not as territorial or strict in choice of habitat during June when my observations were made (Northern Cardinal; Red-winged Blackbird, *Agelaius phoeniceus*; Carolina Wren). Ground and near-ground nests were typically difficult to detect in the canebrakes and some (e.g., those of the Carolina Wren) may have been overlooked. Small and scattered cane plants were of little avian significance except for limited foraging. But dense, small cane patches, with proportionally much edge, were of great significance to birds, both as nesting and foraging habitat. Canebrakes covering 0.5 ha or more provided much edge habitat and were also highly utilized for both nesting and foraging; but the dense, shaded understory of these giant canebrakes was utilized by few avian species (Carolina Wren). The canopy of the large, dense canebrakes was difficult to evaluate because of its height, but seemed fairly empty of birds. Although giant canebrakes undoubtedly provide substantial protection to birds from many predators, particularly avian, they are also used as hunting grounds by predators such as snakes (e.g., the racer, *Coluber constrictor*). Searches for the "canebrake preferring" Swainson's Warbler, *Limnothlypis swainsonii*, were negative.

INTRODUCTION

This paper reports on data collected in a project designed to investigate the use of giant cane (*Arundinaria gigantea*) by summer birds in Land Between The Lakes (LBL). Land Between The Lakes is a 69,000 ha peninsula of federal, multi-use land between

Kentucky and Barkley lakes in Stewart County, Tennessee, and Trigg and Lyon counties, Kentucky. No previous studies have been reported from LBL on birds using giant cane.

Giant cane is a bamboo plant endemic to the United States. It occurs in the southeastern United States from Texas to Florida, and north to Delaware, Ohio, Indiana, Illinois, and Missouri (Steyermark 1963). The plant has been demonstrated to be a relic of the early Tertiary Coastal Plain flora that was uplifted along with the land during the early Tertiary land formation process (Swayne 1973). Kentucky is at the northern limit of this plant's range. Cane is usually a floodplain species and may form dense stands where conditions are suitable. Such stands form a unique understory habitat, and undoubtedly a number of organisms are dependent upon such a habitat for survival. This unique grass, which is woody, hollow, jointed, and a perennial, apparently does not flower in some years, but spreads instead by rhizomes (Kucera 1961).

One species of bird known to depend upon canebrakes for nesting habitat over much of its range is the rare Swainson's Warbler (scientific names of all bird species are given in Table 1), a southeastern U.S. species often found in lowland, tangled, cane understory (National Geographic Society 1983). With the exception of Meanley's (1971) investigation of Swainson's Warbler, evidently no study has been conducted on the summer avifauna associated with canebrakes. However, Remsen (1986) speculated that the endangered (extinct?) Bachman's Warbler (*Vermivora bachmanii*) may have been a bamboo specialist.

Major canebrakes were not located on the LBL mainland, but extensive cane stands were found on numerous islands in southern Lake Barkley. Few people visit these islands and their biological potential for new discoveries seems substantial. Many of the islands are not on maps, and because of the denseness of the canebrakes, many are difficult to penetrate. If Swainson's Warbler breeds anywhere on LBL, it probably is on these islands. Presently, no summer LBL records exist for Swainson's Warbler; the Bird Checklist for LBL (1984) lists the species as accidental during spring and fall (mainly May records).

Through daily observations during the peak of the breeding season in June, an investigation was conducted of all the birds associated with canebrakes on the mainland and Lake Barkley islands, with a special effort to locate Swainson's Warbler. Species of birds encountered in cane were categorized into two groups:

(1) those nesting in cane, and

(2) those using the cane habitat in other ways (foraging, song perches, etc.).

Finally, a quantitative determination was made of the avifauna using the canebrake habitat.

METHODS AND MATERIALS

Visual and aural observations of birds were recorded in a field notebook. A boat and motor were used for transportation to islands. A cassette tape player and Swainson's Warbler song tape were used in attempts to attract Swainson's Warbler. Field time was usually from dawn to noon, although one evening of observation was also conducted. On cloudy and rainy days when significant avian activity continued past noon, observations were continued until early afternoon (1400-1530 h).

A combined 17 days were spent in the field during Junes of 1988 and 1989 (nine days on the mainland, and eight on islands). Once it became apparent that canebrakes were most extensive on islands, only islands were visited. Some island canebrakes covered 0.4-0.8 ha, with poles up to 6.5 m tall.

Personal experience, field guides, and other references served as basis for confirmation of nest/egg identifications (Bent 1963a, Bent 1963b, Reed 1965, Bent 1968, Harrison 1975). Voucher specimens of nests from this study were deposited in the Museum of Zoology at Austin Peay State University.

Birds were recorded as foraging in cane if they were seen to touch any part of the cane plant, or if they were heard singing or calling from the canebrake. I tried to ensure that individual birds were recorded only once, even if they flew to a different cane patch. Although several canebrakes were visited more than once, an attempt was made to visit as many different canebrakes as possible.

RESULTS AND DISCUSSION

Thirty-one species of birds were observed foraging in giant cane (Table 1). The White-eyed Vireo was recorded foraging most often (35 times, 15% of total observations [226]), followed closely by the Carolina Wren. Meanley (1971), in his study of nesting Swainson's Warblers in the southeastern coastal plains, recorded Carolina Wren, White-eyed Vireo, Prothonotary Warbler, Hooded Warbler (*Wilsonia citrina*), Kentucky Warbler, Northern Cardinal, and Rufous-sided Towhee as being the most common avian associates of cane. I recorded all of these species except Hooded Warbler. A single Worm-eating Warbler observed in a canebrake at the upper end of Hematite Lake was surprising. However, Meanley (1971) also mentions this species as an occasional cane associate.

Table 1. Summary of bird activity observed in giant cane at Land Between The Lakes during June 1988 and June 1989 (based upon total number of times 31 species were recorded touching cane or in a canebrake).

Species	Total observations	Percent of total observations (n=226)
White-eyed Vireo *Vireo griseus*	35	15
Carolina Wren *Thryothorus ludovicianus*	32	14
Northern Cardinal *Cardinalis cardinalis*	27	12
Common Yellowthroat *Geothlypis trichas*	23	10
Indigo Bunting *Passerina cyanea*	16	7

Table 1 (continued):

Species	Total observations	Percent of total observations (n=226)
Louisiana Waterthrush *Seiurus motacilla*	12	5
Tufted Titmouse *Parus bicolor*	10	4
Gray Catbird *Dumetella carolinensis*	9	4
Acadian Flycatcher *Empidonax virescens*	9	4
Prothonotary Warbler *Protonotaria citrea*	7	3
Orchard Oriole *Icterus spurius*	7	3
Carolina Chickadee *Parus carolinensis*	6	3
Red-winged Blackbird *Agelaius phoeniceus*	5	2
Blue Jay *Cyanocitta cristata*	3	1
Yellow-breasted Chat *Icteria virens*	3	1
Kentucky Warbler *Oporonis formosus*	2	<1
Blue-gray Gnatcatcher *Polioptila caerulea*	2	<1
Northern Rough-winged Swallow *Stelgidopteryx serripennis*	2	<1
Ruby-throated Hummingbird *Archilochus colubris*	2	<1
Rufous-sided Towhee *Pipila erythrophthalmus*	2	<1
Parula Warbler *Parula americana*	2	<1
Worm-eating Warbler *Helmitheros vermivorus*	1	<1
Eastern Phoebe *Sayornis phoebe*	1	<1
Green-backed Heron *Butorides striatus*	1	<1
Eastern Wood-Pewee *Contopus virens*	1	<1
Eastern Kingbird *Tyrannus tyrannus*	1	<1
Northern Oriole *Icterus galbula*	1	<1

Table 1 (continued):

Species	Total observations	Percent of total observations (n=226)
Yellow-billed Cuckoo *Coccyzus americanus*	1	<1
Wood Thrush *Hylocichla mustelina*	1	<1
Common Grackle *Quiscalus quiscula*	1	<1
Red-eyed Vireo *Vireo olivaceus*	1	<1
TOTALS	226	100%

Forty-six nests of seven bird species were found constructed on giant cane (Table 2). By far the nest most frequently encountered was that of the Northern Cardinal (25 nests, 54% of total nests found). Meanley (1971) reported Northern Cardinal, Hooded Warbler, and White-eyed Vireo as the closest nesting associates of Swainson's Warbler in canebrakes near Macon, Georgia. I found four White-eyed Vireo nests but no Hooded Warbler nests.

Rarely were nests also attached to other adjacent plants such as greenbrier (*Smilax* sp.), wild grape (*Vitis* sp.), or small woody saplings. Forty-four of the 46 nests discovered (representing six species), contained some cane leaves in the nest construction and composition; only two nests of the Green-backed Heron did not contain cane leaves.

Only five of the 46 nests discovered (representing three species) were active and contained eggs; no nests contained young (Table 2). All other nests were empty and presumably were active earlier in the year or in past years. All empty nests were removed when found so that they could not be recounted. Often an old nest was within several feet of a recent nest of the same species (e.g., Northern Cardinal, Common Yellowthroat); in such cases it is unknown if the same pair of birds was responsible for both nests. Many old nests contained ant colonies, especially in canebrakes on islands prone to flooding.

Discrepancies for some bird species between the number of nests found and their foraging frequency in cane are to be expected; some species simply use cane for foraging and not for nesting (e.g., Tufted Titmouse, Louisiana Waterthrush), while others nested earlier in the year and were not as territorial or specific in habitat requirements during June (e.g., Northern Cardinal, Red-winged Blackbird, Carolina Wren). Carolina Wrens were sometimes observed foraging in cane as family groups with their young of the year, and a young Northern Cardinal out of the nest was observed being fed by an adult female in cane. Nests on or near the ground were difficult to detect (e.g., Carolina Wren), because nest searching was conducted only on standing cane.

Table 2. Summary of 46 bird nests found in giant cane at Land Between The Lakes during June 1988 and June 1989.

Species	Total nests		Percent of total nests found
Northern Cardinal	25		54
Indigo Bunting	6	(2 active-eggs)	13
Red-winged Blackbird	5		11
White-eyed Vireo	4	(1 active-eggs)	9
Common Yellowthroat	3	(2 active-eggs)	7
Green-backed Heron	2		4
Eastern Kingbird	1		2
TOTALS	46		100%

All 46 nests were found on islands in Lake Barkley, Stewart County, Tennessee (counting Bear Creek Waterfowl Management Unit as an island environment) where canebrakes were most extensive. Mainland cane was widely scattered and served mainly as foraging habitat. Most nests were found on the periphery of canebrakes. Meanly (1971) also reported the nest of Swainson's Warbler as rarely being located in the densest part of the canebrake, but usually near the edge where stands were thinner, with smaller cane poles, and denser foliage (due to increased exposure to light at the edge).

CONCLUSIONS

This LBL study revealed the following:

(1) Small, scattered cane plants were of little avian significance except for limited foraging.

(2) Dense, small cane patches with much edge were of great significance to birds, both as nesting and foraging habitat.

(3) Canebrakes of 0.4 ha or more provided much edge habitat and were used by birds for both nesting and foraging; however, the dense, shaded understory of these giant canebrakes was utilized by few avian species (i.e., Carolina Wren). The canopy of such large, dense canebrakes seemed fairly void of birds and nests, but was difficult to evaluate because of height (4.5-6.5 m).

(4) Canebrakes provide considerable protection to birds from most predators, especially avian. However, such canebrakes also provide habitat for some predators; twice large racers (*Coluber constrictor*) were

found in canebrakes (ca. 2 m above ground) coiled tightly around dense cane leaf clumps, apparently waiting to ambush prey.

(5) LBL is at the northern periphery of the breeding range of Swainson's Warbler; searches for this warbler during June were negative, and evidently this species rarely, if ever, breeds in LBL.

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SHREWS OF LBL WITH FIRST RECORDS OF *Sorex (Microsorex) hoyi*: PRELIMINARY RESULTS

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ABSTRACT. Preliminary results from pitfall traps operated at 16 sites on five habitat types on LBL from September 1989 through January 1990 are reported. Habitat types included old field/meadow (4 sites), upland hardwood (6 sites), marsh (1 site), pine woodland (3 sites), and lowland hardwood (2 sites). A total of 130 shrews was taken including *Blarina* spp. (n=57), *Cryptotis parva* (n=50), *Sorex (Microsorex) hoyi* (n=14), and *Sorex longirostris* (n=9). Relative habitat-related frequencies of shrew captures (% of total shrews taken in a habitat / % of total trapping effort that occurred in that habitat) ranged from 2.11 for old field/meadow habitat to 0.28 in lowland hardwoods. Only the old field/meadow and upland hardwood habitat types had all taxa of shrews. *Blarina* spp. was the only taxon that occurred in all five habitat types, while *Sorex* spp. were restricted to the upland areas. The pygmy shrew (*S. hoyi*) was taken on 8 of the 16 trap-sites and is reported for the first time from LBL. Non-target small mammal species taken included the prairie vole (*Microtus ochrogaster*), white-footed mouse (*Peromyscus leucopus*), rice rat (*Oryzomys palustris*), harvest mouse (*Reithrodontomys humulis*), and house mouse (*Mus domesticus*). Trapping will continue on additional sites to investigate ecological and habitat relationships of shrews on LBL and systematic aspects of *Blarina* spp. in LBL and the surrounding region.

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SELECTING CORE AREAS IN LAND BETWEEN THE LAKES FOR A PROPOSED BIOSPHERE RESERVE

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ABSTRACT. In 1986, TVA began exploring the possibility of Land Between The Lakes being designated a biosphere reserve, thus becoming part of an international network of special ecosystems and a participant in UNESCO's Man and the Biosphere Program. An important part of the nomination process was the selection of core areas to be placed in protected status for the LBL biosphere reserve. The U.S. Committee on Biosphere Reserves recommended that there be core areas within LBL containing entire drainages; this being the smallest size unit which most scientists consider to be a self-contained ecosystem.

Lands at LBL are managed to achieve a mosaic of different ages of vegetation to optimize habitat diversity for a variety of wildlife. This requires leaving some lands to progress towards mature forest and manipulating other lands to "drive" conditions back to early succession. To keep within this objective, it was decided the core areas should be 5-10% of the total size of LBL, and that some core areas should be large enough to represent whole watersheds. The remainder and majority of LBL would serve as a buffer zone and would be managed using integrated resource management approaches.

LBL managers decided to involve a team of experts to assist in selecting core areas. Dr. Bill Martin, Director of the Division of Natural Areas at Eastern Kentucky University, chaired a panel of ecologists and watershed experts that met to develop recommendations for core areas in LBL. Panel members represented several federal agencies and regional universities from Illinois, Kentucky, and Tennessee. The panel recommended that 6 to 8 watersheds, half in the Cumberland River and half in the Tennessee River drainages be placed in core status upon LBL becoming a biosphere reserve. Ideally, they should have a dendritic drainage pattern with both perennial and intermittent reaches.

Many biologists recommended LBL managers consider variation in home range sizes of LBL animals if they wished to maintain or enhance species diversity. Habitat diversity would be greatest if the landscape was covered by tracts of many different sizes (1, 10, and 100 ha), ages, and species composition. Based on this and the spatial heterogeneity resulting from LBL's management of forest stands and open lands, LBL managers decided to adopt a core area system consisting of smaller, stand-sized core areas (5-60 ha) and larger, watershed-sized core areas (500 ha).

Core areas will total about 5,725 ha with a few larger areas and numerous smaller tracts:

1. Four major watersheds totaling about 2,125 ha will make up the larger core areas. All four drainages are intermittent and dendritic. Two are located in the north half of LBL and two are in the south half. Two drain into the Cumberland River and two drain into the Tennessee River. Perennial watersheds were not selected because so few occur in LBL. For uniformity, intermittent watersheds, being more common, were selected.

2. Smaller-sized core areas will consist of numerous 5-60 ha patches totaling about 3,600 ha. These will be selected from the network of 27 ecology study areas established and protected since 1972 and from the extensive and more recently established system of old growth management stands. The precise configuration of the smaller core system will be determined upon designation of LBL as an international biosphere reserve.

As a biosphere reserve, LBL should have outstanding research opportunities for scientists involved in basic and applied research. Most biosphere reserves in the U.S. are protected lands (national parks, wilderness areas, etc.), while few focus on resource management as does LBL. None are packaged such as LBL might be with core areas of various sizes surrounded by sizable buffers with the total area administered by a single agency. Additionally, LBL is almost completely surrounded by water, adding another buffering component to the proposed biosphere reserve.

MICROHABITAT FACTORS ASSOCIATED WITH *Peromyscus leucopus* IN LBL

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ABSTRACT. This study examined the microhabitat of white-footed mice, *Peromyscus leucopus*, and the its influence on the species. Live-trapping grids (0.36 ha) were used to sample *P. leucopus* populations in 8 habitat types in LBL during the summers of 1988 and 1989. These included four forest habitat types (undisturbed mature forest and forests approximately 20 years after clearcutting, approximately 10 years after selective harvesting, approximately five years after a wildfire, and five years after a heavy timber harvest) and three field habitat types (four year old field, and fields one year after a controlled burn, and after intensive bushhogging). There were 190 total captures in 15,680 trap nights. Population densities for *P. leucopus* were estimated using the "minimum number known alive" enumeration estimator eight variables describing habitat structure were measured at each capture site. Discriminant function analysis was used to discover any differences in microhabitat characteristics between capture sights and non-capture sites within grids.

THE AQUATIC MACROINVERTEBRATES OF LOST CREEK SPRING, LAND BETWEEN THE LAKES, TENNESSEE

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ABSTRACT. Lost Creek Spring, located in the southwestern corner of TVA's Land Between The Lakes in northwest Middle Tennessee is a temperate, rheocrene-type, calcareous spring with an average temperature of 14.6° C at the primary source. Combining with the effluent of an adjacent rheocrene, it forms a springbrook flowing about 156 m to its confluence with Lost Creek. Mid-channel benthic samples were collected bi-monthly at three "upstream" and three "downstream" sites from November 1988 to September 1989. In addition, two sets of preliminary samples were collected at the upstream sites during September and October 1988. Samples were collected using the English PVC T-joint benthic sampler (380 cm^2). Three "upstream sites" were located at 2, 7, and 22 m from the source and three "downstream sites" were at 119, 129, and 152 m from the source. The objective of this study was to describe the taxonomic composition and relative abundance of benthic macroinvertebrates in this unusual pristine spring.

A total of 90 taxa (including 30 chironomid genera) have been identified from the benthic samples taken in Lost Creek springbrook. Margalef's Taxa Richness, Shannon's Diversity Index, and Pielou's Evenness were all significantly greater ($p<0.05$) for the downstream samples. The average density of macroinvertebrates taken in the samples was much greater in upstream sites (32868/m^2, 16816/m^2, and 30658/m^2) in comparison to downstream sites (13162/m^2, 8342/m^2, and 8439/m^2). The isopod *Lirceus fontinalis* was the dominant taxon in the upstream samples (avg.=55.2%, range=9.5-70.2%); downstream, this species averaged only 4.1% of the sample. Downstream samples were dominated by the amphipod *Gammarus pseudolimnaeus* (avg.=27.8%, range=3.7-50.4%), but this species accounted for only 9.7% of the upstream samples. Twelve non-emergent (non-insect) macroinvertebrate taxa taken in the sampling comprised 86.9% of the average abundance in upstream samples, and accounted for 63.3% of the average abundance in downstream samples.

This study demonstrated a significant increase in taxa diversity about 97 m downstream from the groundwater resurgence. The physicochemical parameters (pH, dissolved oxygen, water temperature, discharge, and chemistry) indicated that one of the main differences between the upstream and downstream sites was the marked difference in discharge during spates. A wet weather creek joined the springbrook above the downstream sites causing large increases in downstream discharge during storm events, shifting the substrate and removing organic matter. However, the upstream sites were not significantly disturbed by spates. The difference in abundance and diversity between upstream and downstream sites suggests that disturbance increases diversity, possibly by limiting the abundance of certain dominant species allowing other well-adapted species to become more important in the community. Stable environments such as found upstream may allow species like *Lirceus fontinalis* to dominate the habitat by excluding or restricting less competitive species.

TAXONOMIC STATUS OF THE EASTERN NEWT, *Notophthalmus viridescens*, IN LAND BETWEEN THE LAKES, KENTUCKY AND TENNESSEE

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ABSTRACT. The subspecific status of eastern newts, *Notophthalmus viridescens*, occurring in Land Between The Lakes (LBL), Kentucky and Tennessee, was evaluated. One hundred fifty adults (69 males, 81 females), collected during the summer of 1989 from five ponds across LBL, were examined and compared to descriptions of recognized subspecies. The following characters were considered: total length, amount of black spotting on body surface, presence or absence of lateral red spots, degree of encirclement of red spots, if present, and degree of demarcation between dorsal and ventral coloration. The mean total length of the sample was 88.9 mm (SD=8.0). Black spotting averaged 13.5 (SD=4.9) spots per 50 mm^2 as counted on the ventral surface of the abdomen. Red lateral spots were present in 96% (144 individuals) of the sample. The degree of encirclement of red spots was 0-25% in 21 individuals, 26-50% in 26 individuals, 51-75% in 21 individuals, and 76-100% in 36 individuals. The dorsal color was sharply demarcated from the ventral color in 44 animals, changed gradually in 43 animals, and the same above and below in 63 animals. These results, especially for the latter three traits, show that LBL newts are intermediate in appearance between *N. v. viridescens* and *N. v. louisianensis* suggesting intergradation as the cause. Further studies comparing LBL samples with samples from well within the ranges of each subspecies are needed to reinforce this conclusion.

IMPORTANCE OF ROOT MATS TO THE AQUATIC MACROINVERTEBRATE COMMUNITY OF BEAR CREEK

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ABSTRACT. Biomass, numbers of individuals, and species composition of the macroinvertebrate communities inhabiting root mats, riffles, gravel/sand bars, and leaf packs were investigated to determine the importance of root mats as headwater-stream microhabitats. Four sites were selected on a second-order reach of Bear Creek located at the southern end of Land Between The Lakes, Stewart County, Tennessee.

Of the total number of individuals captured from riffles and root mats, most were from root mats. However, riffle-dwelling organisms had a greater biomass. These data suggest a relationship between organism size and habitat with invertebrates in root mats being smaller than those in riffles. A total of 72 taxa were collected. Root mats and riffles contained 56 and 59 taxa, respectively. Of these, 13 were exclusive to root mats, 16 to riffles. Most of the individuals inhabiting root mats were dipterans or oligochaetes. Most of the individuals in the riffle community were distributed among five taxa (Diptera, Amphipoda, Trichoptera, Ephemeroptera, Oligochaeta). Our data suggest that root mats are an important habitat for small individuals of numerically predominant faunal groups inhabiting headwater, gravel-bottom streams.

INTRODUCTION

Comparisons of the macroinvertebrate communities inhabiting streams and rivers generally are restricted to riffle and/or pool-dwelling organisms (Armitage *et al.* 1974, Phillippi and Coltharp 1990). However, recent work has broadened the scope of community comparisons by including microhabitats such as tree roots (Jenkins *et al.* 1984, Ormerod 1988, Rutt *et al.* 1989), grass roots (Jenkins *et al.* 1984, Rutt *et al.* 1989), and submerged, wooden substrates or snags (Benke *et al.* 1984). These studies indicate that inclusion of additional microhabitats along with riffles and pools increases estimates of instream biodiversity and that some taxa are either restricted to or characteristic of marginal microhabitats (i.e., tree and grass roots). Abundance of submerged wooden substrates (i.e., conifer logs) also modifies the dominance of certain functional groups (Molles 1982).

Many structural characteristics of macroinvertebrate communities inhabiting marginal submerged roots (i.e., root mats) are unknown or poorly documented. Some basic questions concerning community structure are of particular interest.

1) Are root mat communities similar in composition to one another within a given stream order?
2) Are root mat communities more or less diverse than other microhabitats?

We sought answers to these questions by investigating the macroinvertebrate communities of a relatively undisturbed second-order stream in the Land Between The Lakes.

METHODS

Land Between The Lakes (LBL) is a 68,830 ha 'peninsula' between two reservoirs (Lake Barkley, the impounded Cumberland River, to the east; Kentucky Lake, the impounded Tennessee River, to the west) in western Kentucky and Tennessee. The area is managed by the Tennessee Valley Authority as a national recreation and environmental education area. A second-order reach of Bear Creek in Stewart County, northwest Tennessee, was selected for study (Fig. 1). The stream (713 ha drainage basin) originates on privately owned land south of the LBL boundary and flows northeast into Lake Barkley. A large beaver impoundment exists in the midreach of the creek. The sampling sites were located approximately 1.6 km south of Old Fort Henry Road at LBL road 398. Four sampling sites were designated, two upstream of the beaver impoundment and two downstream. Sites (1 and 2) upstream of the beaver dam were not inundated by the highwater pool of the impoundment. Site 3 was immediately below the beaver dam and Site 4 was approximately 200 m below the dam. Each site consisted of a pool and associated upstream riffle. On several occasions, these upstream riffles were too shallow for sampling, and associated downstream riffles were substituted.

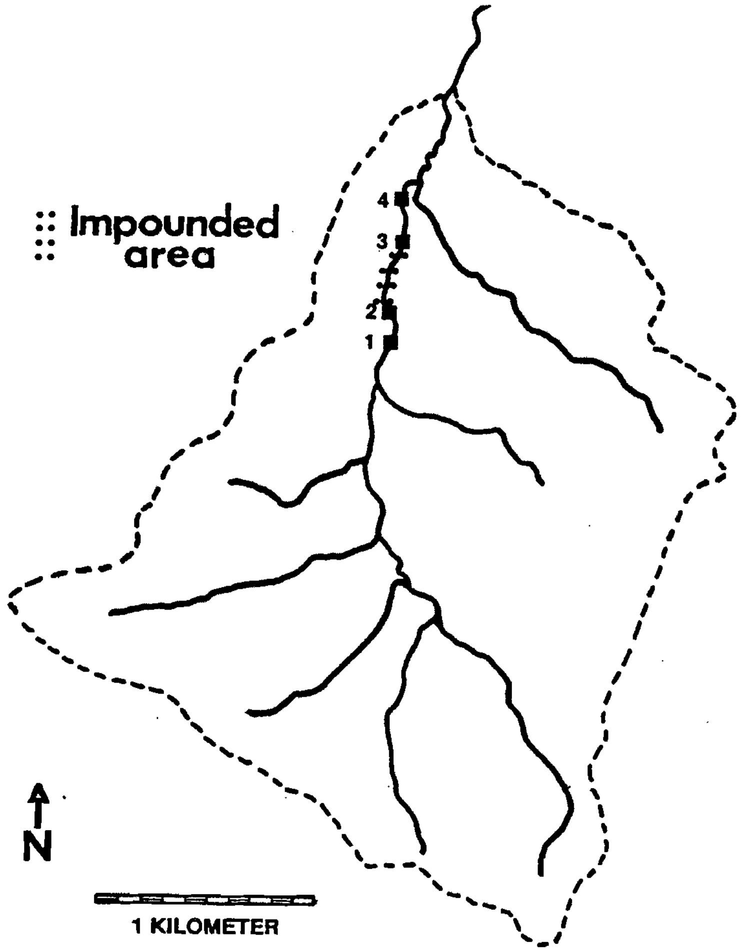

Figure 1. Second-order watershed of Bear Creek, Land Between The Lakes, Stewart County, TN, depicting four sampling sites and their relationships to beaver impoundment.

Four microhabitats were selected for study: riffles, gravel/sand bars, root mats, and leaf packs. Two samples were collected at six-week intervals from each microhabitat at each site during five sampling periods beginning 8 July 1988 and ending 16 December 1988 (N=40). Samples were preserved with a mixture of 95% ethanol (ETOH) and rose bengal stain and stored in plastic bags. Riffles were sampled using a Surber net (0.093 m^2). Riffles were not available at the two upstream sites during July and August (N=32). From the edges of the pools, gravel/sand bars were sampled using a Needham net (N=40). Submerged root mats were gently cut from stream banks and were not available at Site 3 during September (N=38) due to low water levels. In order to determine the surface area of each root mat sample, surface area for 150 root pieces was estimated using the equation for the surface area of a cylinder. The surface area per gram was then estimated for each sample (Richter 1989). Leaf packs were collected by hand from the shallow portions of pools (N=39). Surface area for each leaf pack sample was estimated by cutting ten-1.0 cm^2 squares from each sample, drying these along with the remainder of the sample at approximately 100°F for 24 hours, and weighing the sample and squares. The mean dry weight per gram of the squares was extrapolated to estimate the surface area of the entire sample. In the laboratory samples were sieved using a U.S.A. standard sieve no. 35 (no. 16 for gravel/sand bars). Organisms were picked from the remaining debris, stored in 70% ETOH, and later counted, wet-weighed (gms), and identified generally to the family level or higher.

One-way analyses of variance (ANOVA) were conducted to determine if differences existed in the number of individuals or biomass among the four sites within riffles and within root mats. Significance was declared for $p < 0.05$. In an effort to compare the taxonomic aspects of community structure between root mats and riffles, "common" taxa were considered in selected comparisons as noted. To consider a taxon "common", any of three criteria (modified from Reice 1980) could be met. 1) The total number of individuals was ≥45, 2) the taxon was present in at least 25% of all samples taken, or 3) taxon had 10 or more individuals present in one sample.

RESULTS AND DISCUSSION

Adjusting for an equivalent sample size (N=32) per microhabitat, 29,245 organisms were collected from the four microhabitats (Fig. 2). About one half (47%) of the individuals were from root mats, one third (31.6%) from leaf packs, one fifth (17.8%) from riffles, and the remainder (4%) from gravel/sand bars. In terms of biomass (gms) per sample, a different pattern was shown. Riffles yielded the highest percent biomass (42.7%), and root mats and leaf packs accounted for 23 and 24.6% of biomass, respectively. Gravel/sand bars showed the lowest percent biomass (9.6%).

Organisms inhabiting riffles and root mats accounted for approximately two thirds of the individuals and biomass collected from all microhabitats. In addition, root mats yielded the greatest numbers of individuals and relatively low biomass; in contrast, riffles showed relatively low numbers of individuals and the greatest biomass (Fig. 3).

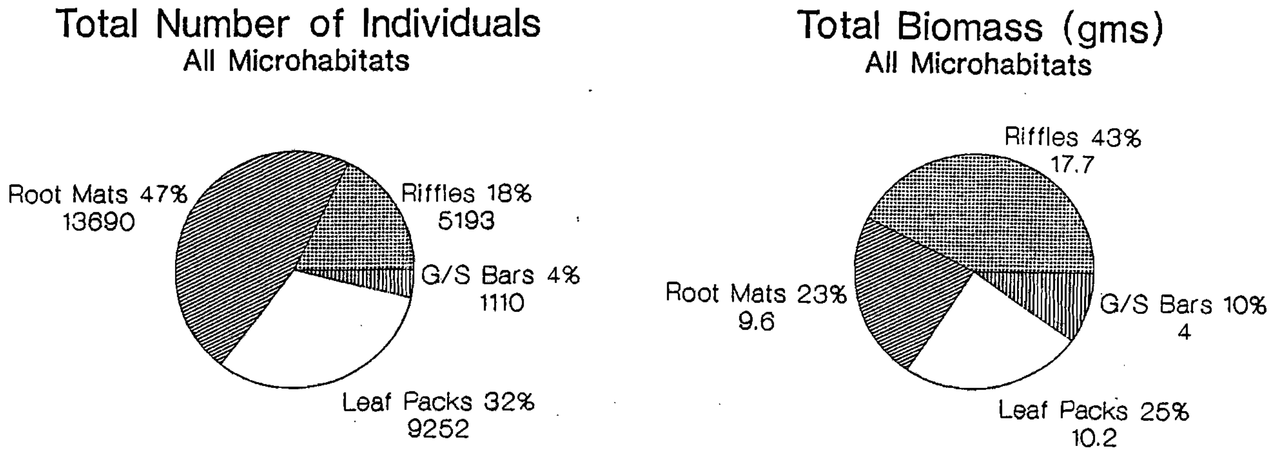

Figure 2. Comparison of total number of individuals and total biomass of macroinvertebrates collected from four microhabitats in Bear Creek. Sample sizes adjusted to N=32.

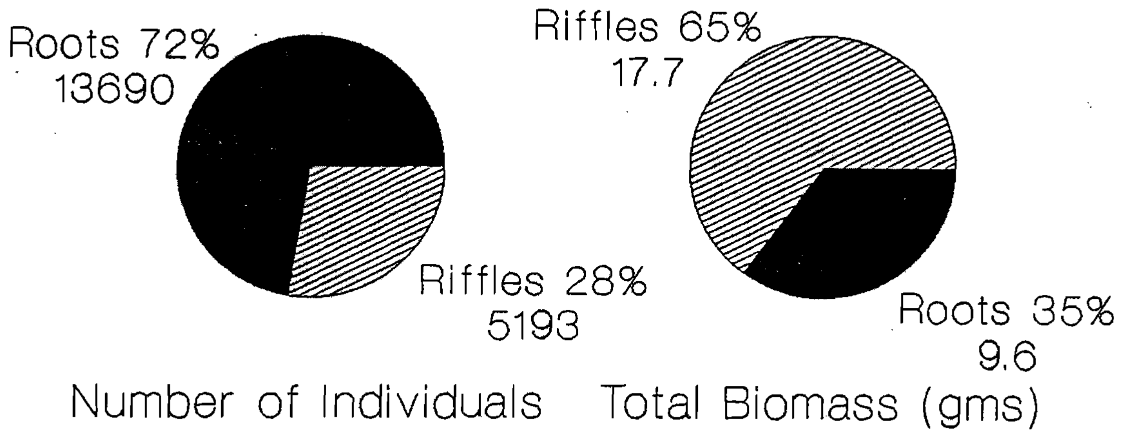

Figure 3. Comparison of total number of individuals and total biomass of macroinvertebrates collected from riffles and root mats in Bear Creek. Sample sizes adjusted to N=32.

These data suggest a relationship between organism size (using weight as a surrogate for size) and habitat. Specifically, invertebrates inhabiting root mats are smaller and more numerous than those in riffles (Fig. 3).

Considering the organisms collected from riffles, approximately 80% of both the total number of individuals and biomass (Figs. 4 and 5) was found at the two sites below the impoundment (Sites 3 and 4). There was a more equitable distribution of biomass and numbers of individuals collected from root mats. An ANOVA revealed that the total number of individuals within each habitat was greatest below the dam (Site 3; $p = 0.0022$ and $p = 0.0212$, for riffles and root mats, respectively). Sustained flow provided by the beaver dam during drought periods is one plausible explanation for the relatively high numbers of individuals at the site. However, biomass was not significantly different among the sites for either microhabitat ($p > 0.30$ for both riffles and root mats).

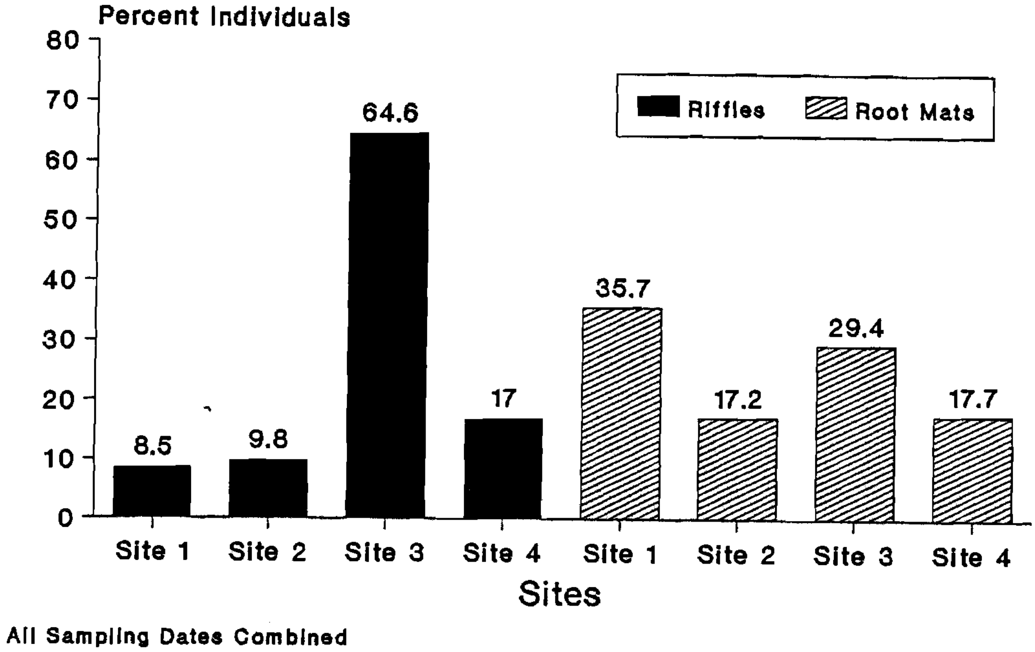

Figure 4. Percentages of total number of macroinvertebrates collected from riffles and root mats in Bear Creek. All sampling dates are combined for each site.

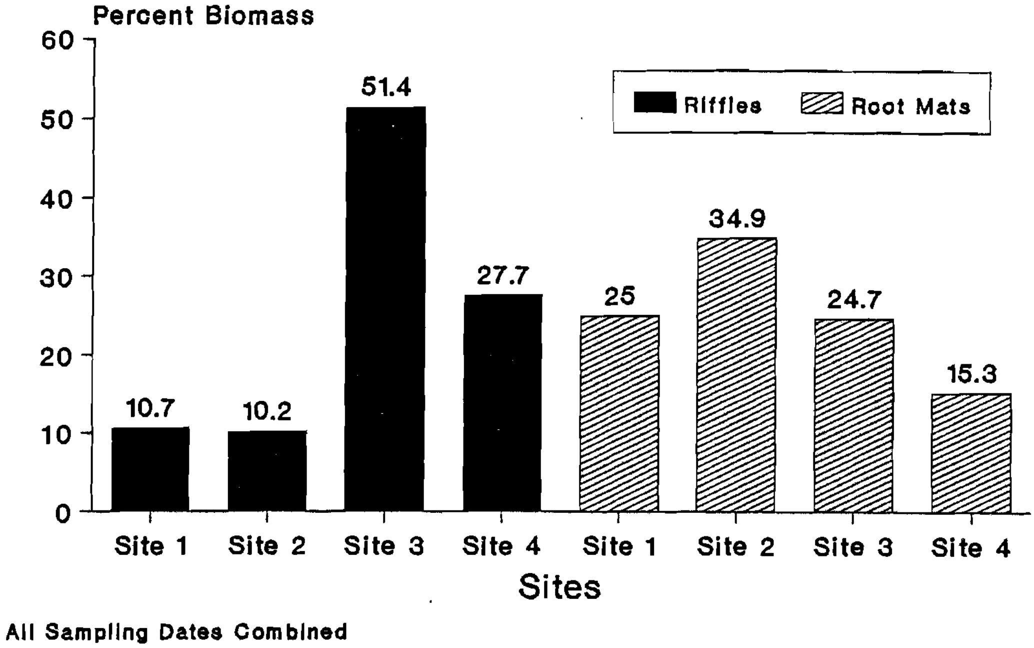

Figure 5. Percentages of total biomass of macroinvertebrates collected from riffles and root mats in Bear Creek. All sampling dates are combined for each site.

Generally, samples from late fall/early winter (November-December) had the fewest numbers of individuals (Fig. 6) and lowest biomass (Fig. 7). The converse relationship was shown in summer samples (July-August). The data suggest seasonal fluctuations in these characteristics are similar between microhabitats.

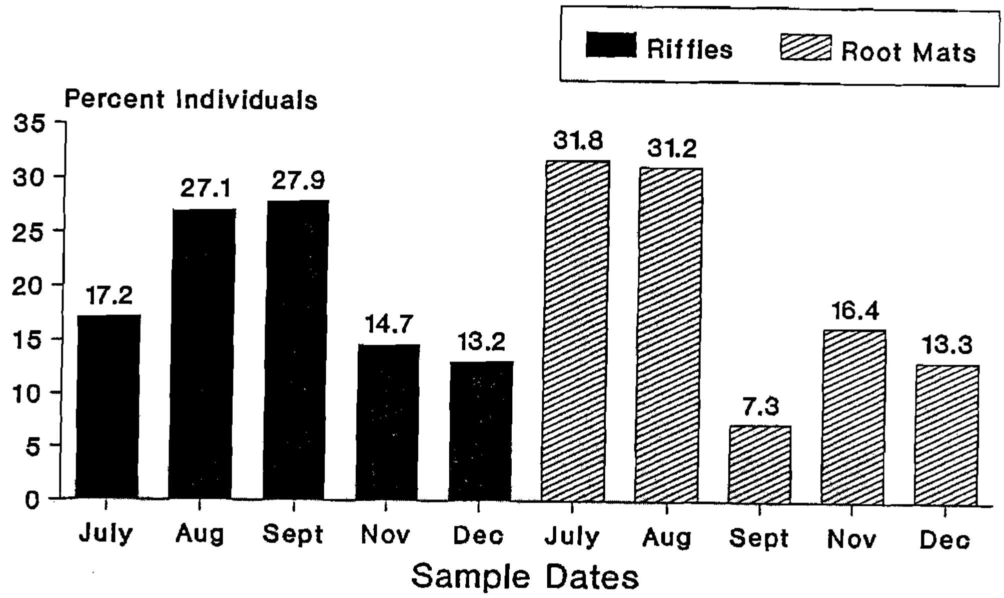

Figure 6. Percentages of total number of macroinvertebrates collected from riffles and root mats in Bear Creek. All sites are combined for each sampling date.

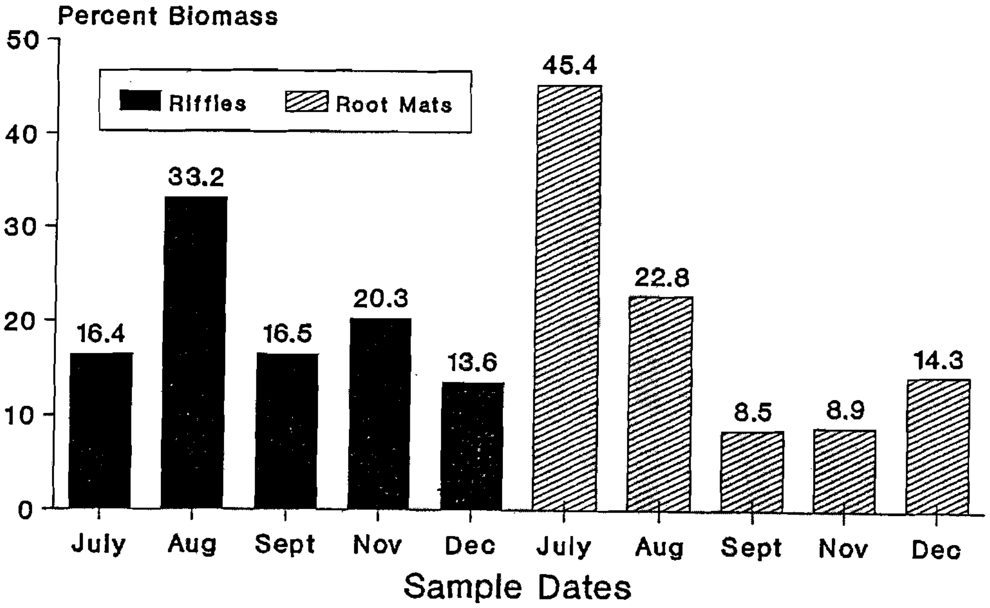

Figure 7. Percentages of total biomass of macroinvertebrates collected from riffles and root mats in Bear Creek. All sites are combined for each sampling date.

A total of 72 taxa (family level and above) were collected from riffle and root mat microhabitats. Root mats and riffles yielded 56 and 59 total taxa, respectively. Thirteen taxa were exclusive to root mats and 16 to riffles. Forty-three taxa were found in both habitats. Following Reice's (1980) definitions, 38 of the 72 total taxa were "common"; 16 of these were found only in riffles and 13 only in root mats. Nine taxa were "common" in both root mats and riffles (Table 1).

Table 1. Unique and shared "common" taxa collected from the riffles and root mats of Bear Creek. "Common" taxa follow definitions of Reice (1980).

Riffles	Root Mats	Shared
Baetidae	Coenagrionidae	Caenidae
Collembola	Corduliidae	Capniidae
Corydalidae	Cyclopoida	Ceratopogonidae
Ephemerellidae	Elmidae	Chironomidae
Gammaridae	*Hyallela azteca*	Gomphidae
Heptageniidae	*Hydra*	Oligochaeta
Hydropsychidae	Hydracarina	Taeniopterygidae
Oligoneuriidae	Hydroptilidae	Unid. Diptera
Perlidae	Leptoceridae	Unid. Ephemeroptera
Perlodidae	Leptophlebiidae	
Philopotamidae	Siphlonuridae	
Rhyacophilidae	Turbellaria	
Sialidae	Unid. Plecoptera	
Simuliidae		
Sphaeriidae		
Tipulidae		

Dipterans were the most abundant (40%) taxon in the riffles (Fig. 8). Abundance in the remaining riffle community was relatively evenly distributed among five groups (i.e., amphipods, trichopterans, ephemeropterans, plecopterans, and oligochaetes). Taxon abundance within the root mat community was less evenly distributed (Fig. 9). Most of the root mat community (87%) was comprised of dipterans (69%) and oligochaetes (18%). Given our level of taxonomic analysis, these data suggest that diversity within root mats is lower than that in riffles.

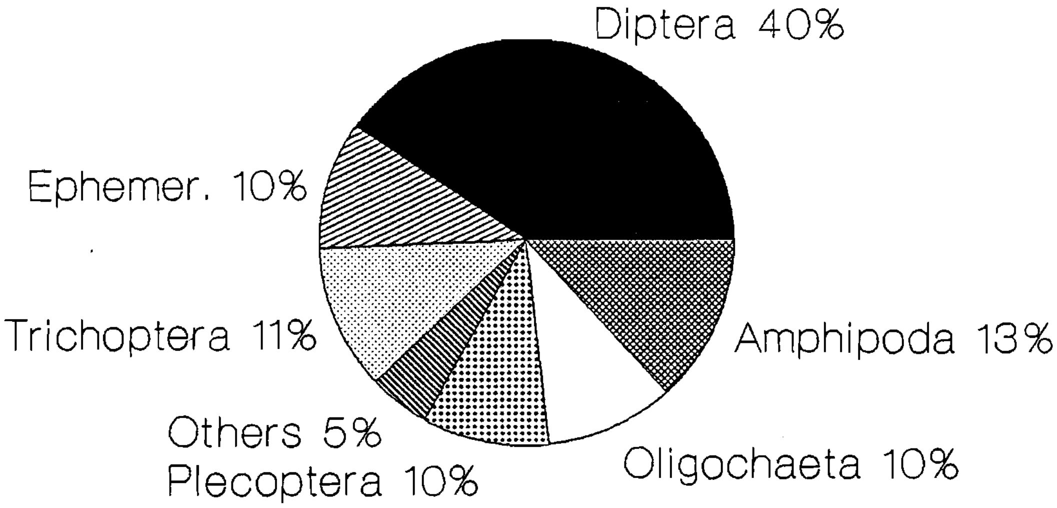

Figure 8. Principle taxonomic groups collected from riffles in Bear Creek.

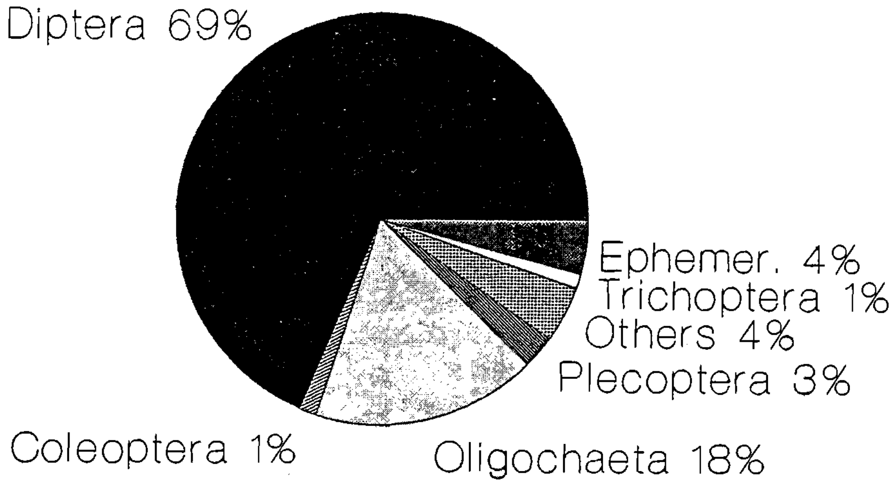

Figure 9. Principle taxonomic groups collected from root mats in Bear Creek.

CONCLUSIONS

Our data indicate that the macroinvertebrate community inhabiting root mats must be examined if accurate estimates of instream biodiversity and community structure are to be obtained, results that are consistent with that of other workers (e.g., Jenkins *et al.* 1984, Rutt *et al.* 1989). Our data also suggest that the macroinvertebrate community of root mats is both quantitatively and qualitatively distinct from the community inhabiting riffles and that root mats harbor smaller individuals and/or perhaps smaller species in larger numbers than do riffles. Since many of the root mat organisms appeared to be earlier immature stages of the species found in the other three habitats, it is possible that the root mats serve as a nursery for aquatic macroinvertebrates. Finally, it appears that root mats yield a similar community composition within a given stream order regardless of longitudinal position.

ACKNOWLEDGEMENTS

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AMPHIBIANS AND REPTILES IN LAND BETWEEN THE LAKES LISTED AS ENDANGERED, THREATENED, OR OTHERWISE OF SPECIAL CONCERN

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ABSTRACT. One salamander (*Ambystoma talpoideum*), three turtles (*Macroclemys temminckii, Chrysemys picta dorsalis* and *Apalone mutica*), one lizard (*Cnemidophorus sexlineatus*), and five snakes (*Lampropeltis triangulum elapsoides, Thamnophis sauritus, Pituophis melanoleucus, Sistrurus miliarius,* and *Nerodia erythrogaster neglecta*) occurring in Land Between The Lakes (LBL) are currently listed by at least one government agency as animals in need of special attention. Their status designations range from "Special Concern" (a state-level category for populations that should be monitored because of limited distribution, potential threats to habitat, special needs, or other circumstances) to "Category 2" (a federal designation for taxa that possibly should be considered for listing as endangered or threatened nationwide, but for which conclusive evidence is unavailable). In this paper, status designations of these 10 listed taxa are reviewed, and their LBL distributions and known habitat requirements discussed. Listed taxa of amphibians and reptiles occurring within 30 kilometers of LBL's boundaries are also identified.

INTRODUCTION

Land Between The Lakes (LBL) is a 69,000 ha peninsula of mostly forested land between the impounded lower reaches of the Tennessee and Cumberland rivers (Kentucky and Barkley lakes, respectively) in southwestern Kentucky and northwestern Tennessee (Fig. 1). It averages about 13 km wide, and extends 61 km from its southern boundary near Dover, Stewart County, Tennessee to its northern boundary (Barkley Canal) just south of Grand Rivers, Lyon County, Kentucky. Designated in 1963 as a national demonstration area for outdoor recreation, environmental education, and resource management, it is under the stewardship of the Tennessee Valley Authority (TVA). Detailed reviews of LBL's geology and history were published by Harris (1988) and Wallace (1988), respectively. Information on its forest communities were provided by Fralish and Crooks (1988). Explanations of the multiple-use approach to its management were presented by Field *et al.* (1986) and Thach *et al.* (1987). Other aspects of the areas character were discussed by Smith (1971).

Sixty-seven species and subspecies of amphibians and reptiles have been reported from Land Between The Lakes, its adjacent waters, or both (Snyder 1972). Another species (*Ambystoma talpoideum*) was discovered during this study. Ten of the resulting 68 taxa appear on one or some combination of state (Tennessee and Kentucky) and federal lists of animals considered as rare, threatened, endangered, or otherwise in need of special attention. The purposes of this paper are to review the status designations of these animals in the bistate area and discuss their known distributions and habitat requirements throughout LBL. Listed taxa of amphibians and reptiles whose known ranges are outside but within 30 kilometers of LBL are also mentioned.

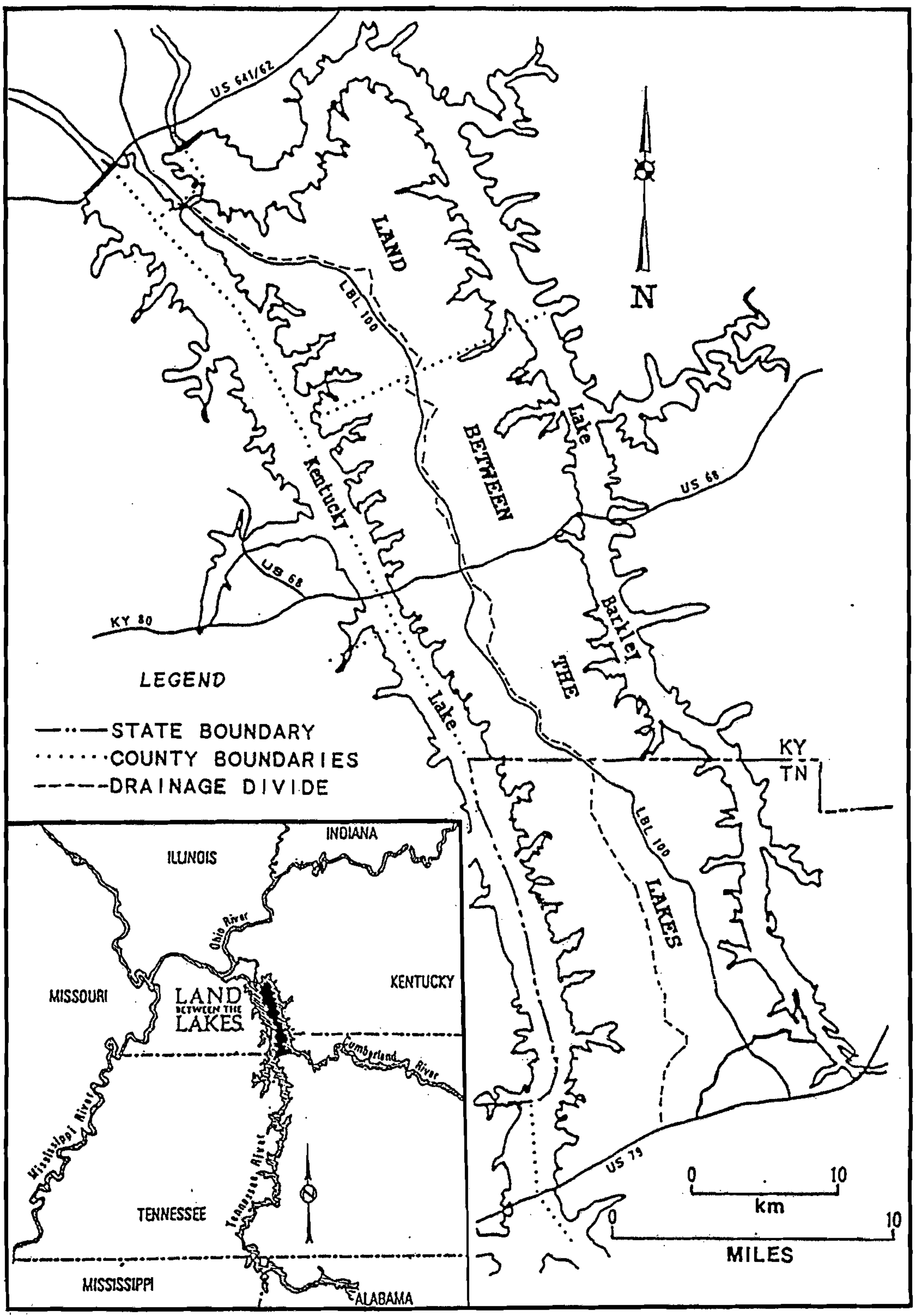

Figure 1. Planimetric maps showing location of Land Between The Lakes in western Kentucky and Tennessee (inset) and its relation to adjacent reservoirs, political boundaries, major roads, and drainage divide.

METHODS

Status designations of listed taxa were obtained from the literature (Eagar and Hatcher 1980, Warren *et al.* 1986, U.S. Fish and Wildlife Service 1985, U.S. Fish and Wildlife Service 1989). Distribution and habitat data were acquired in three ways. First, year-round field work in LBL was conducted from July 1987 through March 1990. Second, surveys of the amphibian and reptile collections in several university collections were carried out. The universities included Austin Peay State University, Murray State University, University of Louisville, University of Kentucky, Morehead State University, and University of Kansas (I visited all of these except the latter; data from the Kansas collection were provided by Joseph T. Collins). Third, sight records submitted by biologists judged capable of identifying listed taxa were compiled and included in the results.

The computer software dBASE III PLUS was used to manage the records accumulated. Detailed locality data are intentionally omitted from this paper to protect the populations being discussed. However, if legitimate needs for this information arise, it can be requested from the Coordinator of Research, Land Between The Lakes, Golden Pond, Kentucky 42231.

RESULTS AND DISCUSSION

Status categories and listed taxa

Five organizations, whose areas of concern include LBL, have published separate or joint lists of animals in need of special attention. These are the Tennessee Wildlife Resources Agency (TWRA), the Ecological Services Division of the Tennessee Department of Conservation (TDC), the Endangered Species Committee of the Kentucky Academy of Science (KAS), the Kentucky Nature Preserves Commission (KNPC), and the United States Fish and Wildlife Service (USFWS). Collectively, these agencies have applied five status categories to selected amphibians and reptiles found in and near LBL. These categories, along with definitions and explanations, follow:

Endangered (E). This category, although recognized by all, is applied by only two monitoring agencies (KAS and KNPC) to any of the herpetofauna in the LBL area. It applies to any "species which is in danger of extirpation and/or extinction throughout all or a significant part of its range in Kentucky" (Warren *et al.* 1986).

Threatened (T). All four state-level monitoring agencies apply this category to selected taxa of LBL's herpetofauna. TWRA and TDC use the definition set forth in Section 70-8-103 of the Tennessee Nongame and Endangered or Threatened Wildlife Species Conservation Act of 1974, which is "... any species or subspecies of wildlife which is likely to become an endangered species within the foreseeable future" (Tennessee Code Commission 1987). KAS and KNPC reserve it for any species "which is likely to become endangered within the foreseeable future throughout all or a significant part of its range in Kentucky" (Warren *et al.* 1986).

Deemed in Need of Management (D). This is a TWRA category reserved for "those species which, although not considered threatened within the state, may not currently exist at or near their optimum carrying capacity. Some of these species may be on the periphery of their range in Tennessee, or may require additional research to determine their actual status" (Eager and Hatcher 1980).

Special Concern (S). This is a category applied to selected LBL herpetofauna by TDC and KAS/KNPC. TDC's definition for it is the same as TWRA's definition for "Deemed in Need of Management" (defined above). KAS/KNPC reserve this category for any "species that should be monitored because (a) it exists in a limited geographic area, (b) it may become threatened or endangered due to modification or destruction of habitat, (c) certain characteristics or requirements make it especially vulnerable to specific pressures, (d) experienced researchers have identified other factors that may jeopardize it, or (e) it is thought to be rare or declining but insufficient information exists for assignment to the threatened or endangered status categories" (Warren *et al.* 1986).

Category 2 (C2). This is a federal-level designation used by USFWS for "taxa for which information now in possession of the Service indicates proposing to list as endangered or threatened is appropriate, but for which substantial data on biological vulnerability and threat(s) are not currently known or on file to support a proposed rule" (U.S. Fish and Wildlife Service 1985).

Table 1 gives the 10 "listed" taxa (one amphibian and nine reptiles) known to occur in LBL, the letter codes of the status assigned each, and totals for the numbers of taxa listed by each monitoring group. At the state level, Kentucky monitors seven taxa of herpetofauna in its portion of LBL, whereas in the Tennessee part the maximum number monitored is six. At the federal level, three taxa (all reptiles) are listed.

LBL distributions and habitat requirements

Overall, 146 records were accumulated for the 10 "listed" taxa occurring in LBL. The number of records ranged from a low of three for *Apalone mutica* (smooth softshell) to a high of 34 for *Cnemidophorus sexlineatus* (six-lined racerunner). Fifty-eight records were from the Tennessee (Stuart County) portion of LBL and 88 were from the Kentucky portion (67 and 21 for Trigg and Lyon counties, respectively). Records for years prior to 1980 (most from the 1960s) totalled 92, and those for years 1980 and after totalled 54.

Figures 2 through 4 show LBL localities for each "listed" taxon, the types of records (vouched by specimen or photograph, or sightings only), and the time frame (pre- or post-1980) of each record. These data, along with habitat information for each taxon, are discussed below.

Table 1. "Listed" taxa of amphibians and reptiles occurring in LBL and codes for their status as assigned by various monitoring groups. Status abbreviations: S = Special Concern, D = Deemed in Need of Management, T = Threatened, C_2 = Category 2. See text for definitions.

	Monitoring Groups			
Taxa	TWRA	TDC	KAS/KNP	USFWS
Apalone mutica Smooth Softshell	-	-	S	-
**Chrysemys picta dorsalis* Southern Painted Turtle	-	-	S	-
**Lampropeltis triangulum elapsoides* Scarlet Kingsnake	-	-	S	-
Thamnophis sauritus Eastern Ribbon Snake	-	-	S	-
Ambystoma talpoideum Mole Salamander	D	S	-	-
Cnemidophorus sexlineatus Six-lined Racerunner	D	S	-	-
Pituophis melanoleucus Pine Snake	T	T	-	C_2
Sistrurus miliarius Pigmy Rattlesnake	T	T	T	-
**Nerodia erythrogaster neglecta* Copperbelly Watersnake	-	S	S	C_2
Macroclemys temminckii Alligator Snapping Turtle	D	S	T	C_2
Number of listed taxa	5	6	7	3

* Pure populations of these taxa apparently do not occur in LBL; instead they seem to be intergrades between the listed taxa and one or more conspecific subspecies.

Apalone mutica - **Smooth Softshell.** A "Special Concern" taxon in Kentucky, *A. mutica* has been documented from only two locations along LBL's shoreline, both near sandy beaches on the eastern shore of Kentucky Lake in Stewart County, Tennessee (Fig. 2A). Specialized trapping techniques, such as those described by Robinson and Murphy (1975), and surveys of turtles caught by the area's commercial fishermen should yield more records along LBL's shorelines.

Chrysemys picta dorsalis - **Southern Painted Turtle.** Also in the "Special Concern" category (Kentucky only), this taxon was shown by Ernst (1970) to intergrade with *C. p. marginata* (midland painted turtle) throughout LBL. My observations support this conclusion, as all of the LBL specimens I examined (six individuals) were intermediate in diagnostic features (plastron pigmentation, color of anterior seams of lateral scutes, and nature of dorsal stripe, if present) that separate these subspecies. Populations are known from the Tennessee and Kentucky portions of both Kentucky and Barkley lakes, and from a pond on the drainage divide near LBL's southern boundary (Figure 2B). Heads of bays where small streams enter seem to be preferred habitat.

Lampropeltis triangulum elapsoides - **Scarlet Kingsnake.** A third "Special Concern" taxon listed only by Kentucky, this snake, like the painted turtle, also occurs in LBL as a subspecies intergrade. This was demonstrated quantitatively by Williams (1988), who examined LBL specimens from all three of its counties. The one Lyon County individual was described as a *L. t. syspila* (red milk snake) x *L. t. elapsoides* intergrade, "possibly with some influence from *L. t. triangulum*" (eastern milk snake. Two specimens from Trigg and Stewart counties were categorized as *L. t. syspila* x *L. t. triangulum* intermediates "with possible influence from *elapsoides*." Specimens obtained from LBL subsequent to those mentioned above also appear to be intergrades, with those from US Highway 68 north appearing intermediate between *L. t. syspila* and *L. t. elapsoides* and those form there south appearing intermediate between *L. t. syspila* and *L. t. triangulum*. Both pre- and post-1980 records from areas throughout LBL were obtained (Figure 2C). Dry, upland forests predominated at the majority of sites.

Thamnophis sauritus - **Eastern Ribbon Snake.** This species, the forth "Special Concern" taxon recognized by Kentucky but not by Tennessee, is known from three locations in LBL (Figure 2D). All of these records came from sites in or near marshy or swampy floodplain habitats along Barkley Lake in northern Trigg County. The paucity of similar habitats on the Kentucky Lake side of LBL may limit its distribution to the Barkley Lake drainage.

Ambystoma talpoideum - **Mole Salamander.** Listed by both Tennessee monitoring groups ("Deemed in Need of Management" by TWRA and as "Special Concern" by TDC) but not by Kentucky, this taxon is known in LBL from a restricted area in northern Trigg and southern Lyon counties (Fig. 3A). Year-round surveys throughout LBL failed to detect the species elsewhere. Fishless upland ponds in both forest and fields were the source of all but two records, both from roads near such ponds. The lack of pre-1980 LBL records may be due to earlier workers bypassing breeding sites during the winter months when easily identifiable adults are present.

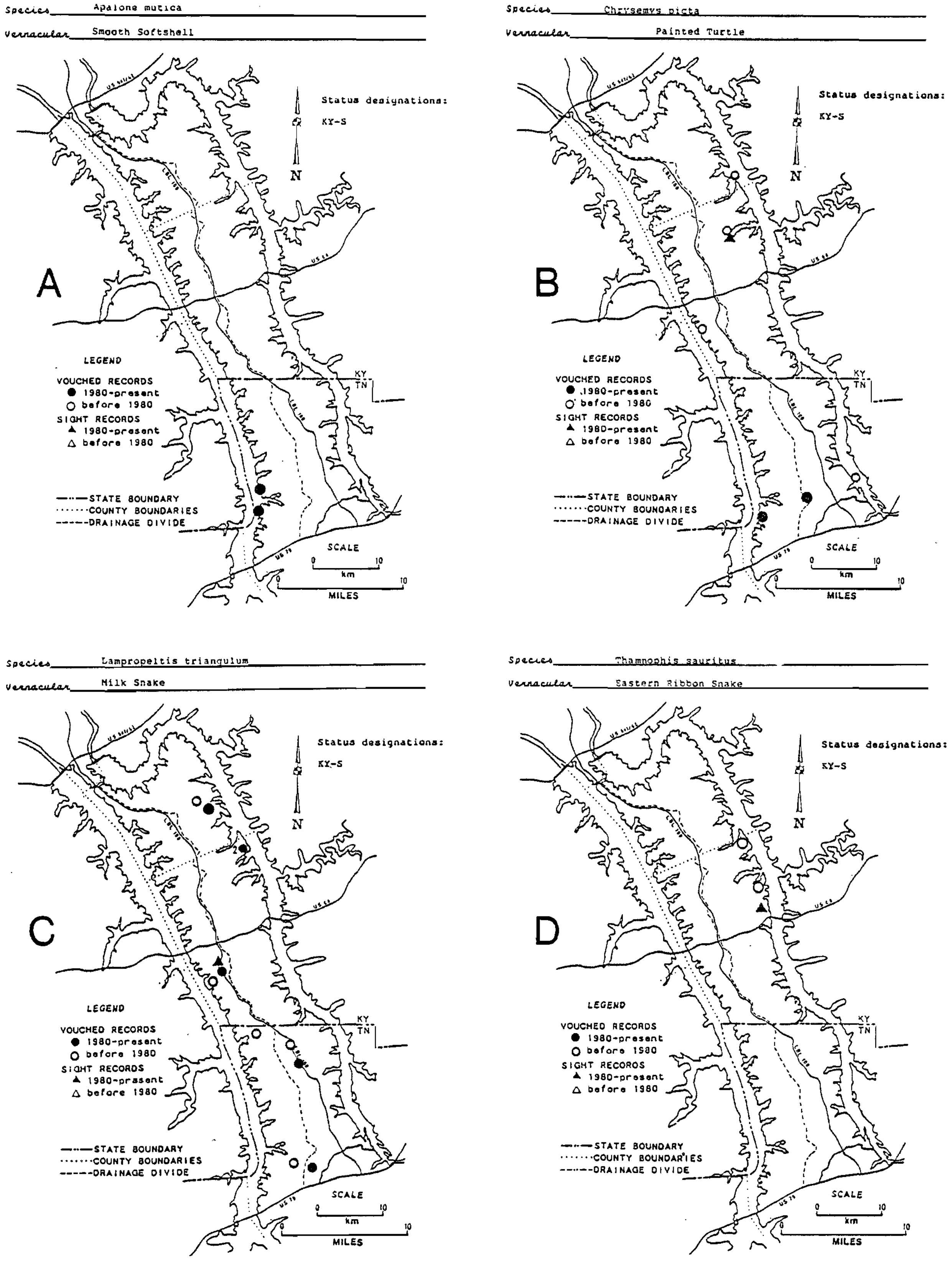

Figure 2. Distributions of (A) *Apalone mutica*, (B) *Chrysemys picta*, (C) *Lampropeltis triangulum*, and (D) *Thamnophis sauritus* in Land Between The Lakes.

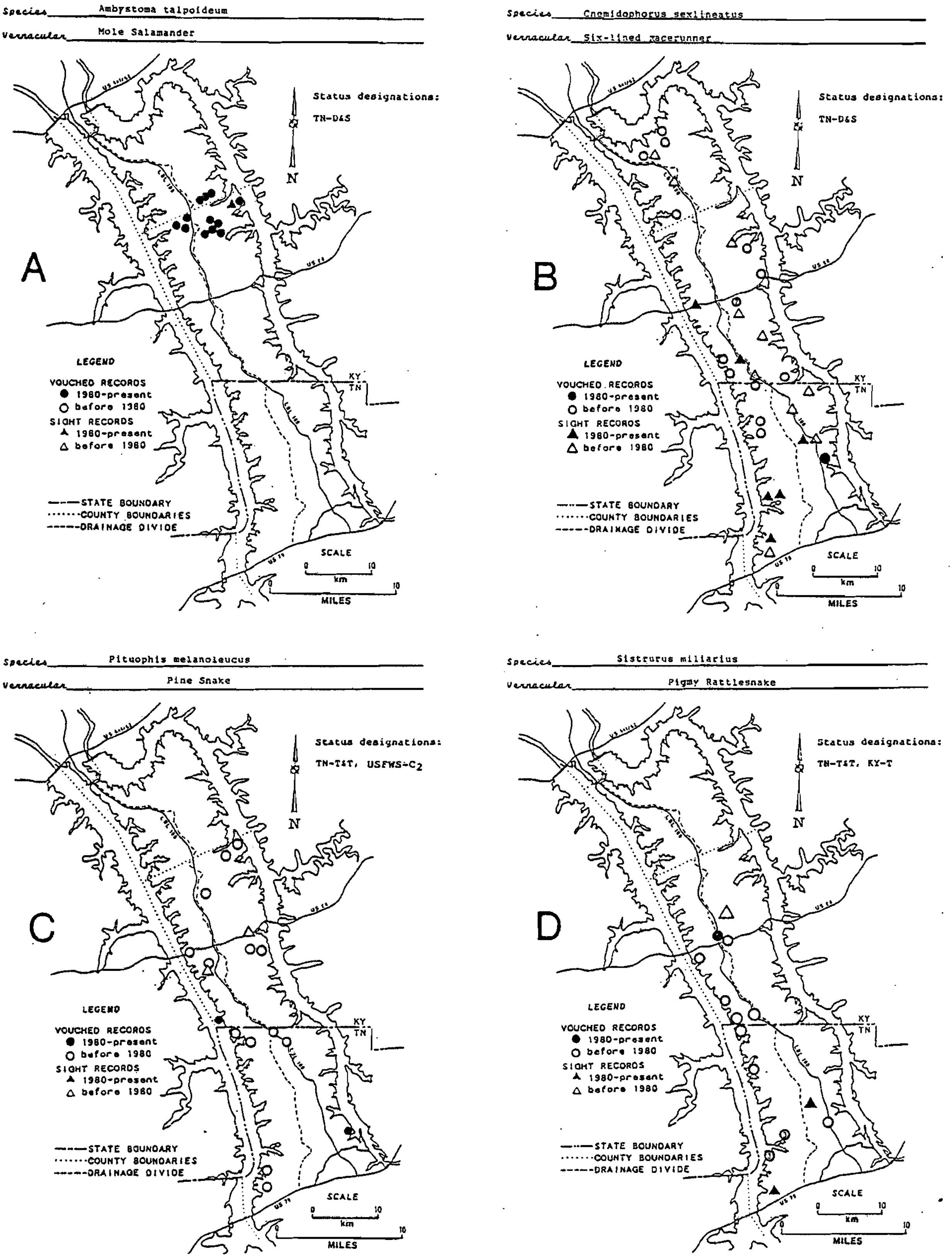

Figure 3. Distributions of (A) *Ambystoma talpoideum*, (B) *Cnemidophorus sexlineatus*, (C) *Pituophis melanoleucus*, and (D) *Sistrurus miliarius* in Land Between The Lakes.

Cnemidophorus sexlineatus **- Six-lined Racerunner.** Carrying the same Tennessee status designation as the mole salamander, this taxon is known from throughout LBL (Figure 3B). However, all LBL records since 1980 are from south of US Highway 68. Dry, sparsely vegetated areas with loosely compacted soils (e.g. abandoned gravel quarries and roadside banks) appear to be preferred habitat.

Pituophis melanoleucus **- Pine Snake.** Listed as "Threatened" in Tennessee and "Category 2" by USFWS, the pine snake is known from most of LBL, excepting Lyon County (Figure 3C). The predominance of records (15 of 17) predate 1980, and all but a few were obtained in floodplain areas where forest and fields intermingled. One specimen was encountered approximately 100 meters offshore in Kentucky Lake.

Sistrurus miliarius **- Pigmy Rattlesnake.** This taxon is considered "Threatened" in both Tennessee (TWRA and TDC) and Kentucky. It was first reported from LBL in Stuart and Trigg counties by Snyder *et al.* (1967). Since then, several specimens have been found, but none from Lyon County (Figure 3D). Reports of the species since 1980, like the earlier ones, are based on specimens found along The Trace (LBL 100) and areas to the west. All individuals encountered were on roads or (as with several pre-1980 records) among rocks and debris along the shoreline of Kentucky Lake. Repeated attempts, since 1987, to find the species in these shoreline situations have failed.

Nerodia erythrogaster neglecta **- Copperbelly Watersnake.** This subspecies of *N. erythrogaster* (plainbelly watersnake) is listed as "Special Concern" in both Tennessee and Kentucky, and is a USFWS "Category 2" status review taxon. Like *C. picta* and *L. triangulum*, *Nerodia erythrogaster* seems to occur as an intergrade in LBL. Specimens appear intermediate between *N. e. neglecta* and *N. e. flavigaster* (yellowbelly water snake). Further work is needed to demonstrate this quantitatively. In LBL, this snake is known from both sides of the drainage divide in Lyon County, but only from Lake Barkley drainages in Trigg and Stewart counties (Figure 4A). The number and distribution of records since 1980 suggest that this subspecies is just as plentiful now (if not more so) as it was during the 1960s. A variety of aquatic habitats, including bays, streams, and upland ponds have yielded specimens.

Macroclemys temminckii **- Alligator Snapping Turtle.** This species is considered "in need of management" (TWRA) and of "Special Concern" (TDC) in Tennessee, "Threatened" in Kentucky, and a possible candidate for listing ("Category 2") by the USFWS. An animal of large lakes and streams, was documented at LBL in three bays on the east side of Kentucky Lake in northwestern Stewart County, Tennessee (Figure 4B). Most of the records from this area came from commercial fishermen who inadvertently caught individuals on trotlines or in trammel nets. A recent record from the Cumberland River just south of Dover, Tennessee opens the possibility of the species occurring in Lake Barkley bays that border LBL's southeast shoreline.

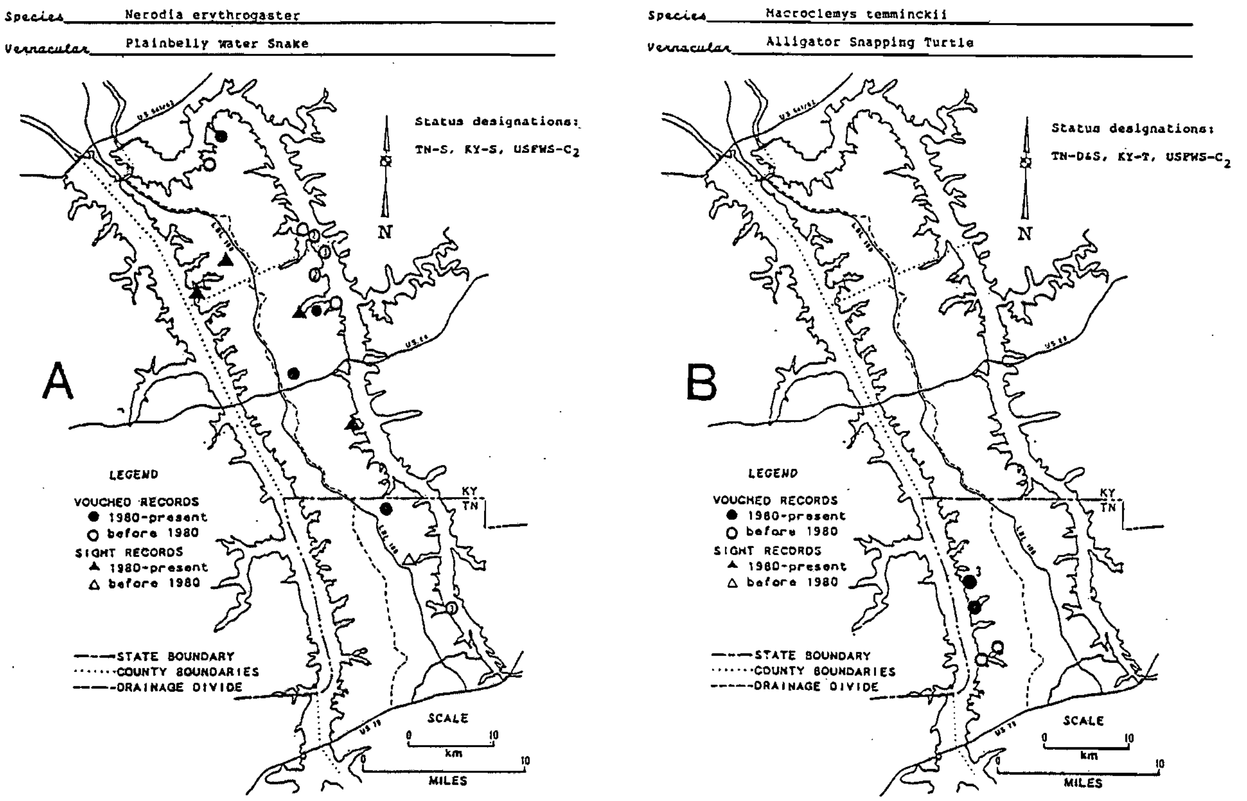

Figure 4. Distributions of (A) *Nerodia erythrogaster* and (B) *Macroclemys temminckii* in Land Between The Lakes.

Other "listed" taxa possibly present in LBL

Nine additional "listed" taxa including six amphibians and three reptiles are known to occur within 30 kilometers of LBL (Table 2). Four of these (*Eurycea longicauda guttolineata, Hyla avivoca*, and *Farancia abacura*) approach LBL from the west (Conant 1975, Moriarty and Evans 1983), and should be sought on the Kentucky Lake side of LBL. Two (*Hemidactylium scutatum* and *Hyla gratiosa*) are known from sites a few kilometers east of LBL (Scott *et al.* 1984, Van Norman and Scott 1987), and would most likely be present in LBL's Barkley Lake drainage. The remaining three (*Cryptobranchus alleganiensis, Hyla avivoca*, and *Ophisaurus attenuatus*) have distributions that flank LBL on at least three sides (Conant 1975, Barbour 1971, Scott *et al.* 1984, Scott and Snyder 1968), and may turn up anywhere in LBL where habitat conditions are compatible.

CONCLUSIONS

The populations of "listed" amphibian and reptilian taxa in LBL appear to be as abundant now (and in some cases more abundant) as during the 1960s prior to development of the government-owned facility. This conclusion is based on the number and distribution of records obtained since 1980 as compared to those recorded earlier. However, monitoring of these taxa should be continued along with management for habitat diversity to help insure that they remain a viable and integral part of LBL's herpetofauna.

Table 2. Status designations assigned by various monitoring groups to "listed" taxa of amphibians and reptiles not known from LBL but that occur within 30 kilometers of its boundaries. Status abbreviations: S = Special Concern, D = Deemed in Need of Management, T = Threatened, C_2 = Category 2. See text for definitions.

	Monitoring Groups			
Taxa	TWRA	TDC	KAS/KNPC	USFWS
Cryptobranchus alleganiensis Hellbender	D	-	-	C_2
Eurycea longicauda guttolineata Three-lined Salamander	-	-	T	-
Hemidactylium scutatum Four-toed Salamander	D	S	-	-
Hyla avivoca Bird-voiced Treefrog	-	-	T	-
Hyla cinerea Green Treefrog	-	-	S	-
Hyla gratiosa Barking Treefrog	D	S	-	-
Eumeces anthracinus pluvialis Southern Coal Skink	-	-	E	-
Farancia abacura Mud Snake	-	-	S	-
Ophisaurus attenuatus Slender Glass Lizard	D	S	S	-
Number of listed taxa	4	3	6	1

ACKNOWLEDGMENTS

Several persons and a number of institutions helped in a variety of ways to make this study possible. Duke Wilder (Murray State University), Burt Monroe (University of Louisville), Wayne Davis (University of Kentucky), Les Meade (Morehead University), and Joseph T. Collins (University of Kansas) provided access to specimens and data in their

museum collections. Matthew Padgett, Eugene Stewart, Kristen Page, Jason Smith, Ellen Twombly, and Janet Ward (all research assistants in The Center for Field Biology at Austin Peay State University) participated in field work and data entry. Charlie Gregg assisted with data acquisition on museum visits. Tom Forsythe, Coordinator of Research Development at LBL, provided many helpful items (e.g. topographic maps, boat, and overnight housing). Donna Davis typed and formatted the manuscript. Support and funding for this project was provided by Austin Peay State University's Center for Field Biology.

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CONTRIBUTED PAPERS

SESSION II: BOTANY

Saturday, March 3, 1990

Moderated by:

Eugene Wofford
The University of Tennessee - Knoxville

SEED DORMANCY/GERMINATION CHARACTERISTICS OF *Lesquerella lescurii* (BRASSICACEAE), A NARROWLY ENDEMIC SPECIES: ECOLOGICAL ASPECTS

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ABSTRACT. **Lesquerella lescurii (Gray) Watson is an obligate winter annual presently known from nine counties in northcentral Tennessee and from Trigg County, Land Between the Lakes, Kentucky. Although the species is narrowly endemic, it has weedy tendencies and thus grows in arable fields and other disturbed habitats. *Lesquerella lescurii* forms a persistent seed bank, and seeds can remain viable in the soil for at least 2.5 years. Seeds are dormant at maturity in May and are dispersed as soon as they ripen. Some of the seeds produced in the current year, as well as some of those in the persistent seed bank, afterripen (come out of dormancy) during late spring and summer; others do not afterripen and thus remain dormant. Seeds require actual or simulated late spring/summer temperatures to afterripen. Germination occurs in early autumn. Fully afterripened seeds germinate over a wide range of daily thermoperiods (15/6-35/20° C) and to much higher percentages in light (14 h daily photoperiod) than in constant darkness. Nondormant seeds that do not germinate in autumn are induced back into dormancy (secondary dormancy) by low temperatures during winter, and those that are dormant do not afterrippen; thus seeds cannot germinate in spring. The seed dormancy and germination characteristics of *L. lescurii* do not differ from those of some geographically widespread weedy species of winter annuals and thus do not help to account for the narrow endemism of this species.**

[3] JMB and CCB are Senior Research Fellows with The Center for Field Biology, Austin Peay State University.

SUGARBERRY (*Celtis laevigata*) AND ITS ASSOCIATES IN THE BOTTOMLAND FORESTS OF THE JACKSON PURCHASE OF KENTUCKY

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ABSTRACT. In the Jackson Purchase of Kentucky, sugarberry (*Celtis laevigata*) is confined mostly to the first and second bottoms of the Mississippi, Ohio, and Tennessee rivers. It may be the forest dominant (Sugarberry forests), a major associate (Green Ash forests), or a minor contributor (Red Maple, Pin Oak, Sweetgum, and Pecan-Shellbark Hickory forests). In those forests, the densities, basal areas, and species associations are influenced by flooding frequency, human disturbances, and microtopography (gradients) of the bottomlands.

INTRODUCTION

Although there have been several floristic surveys in the Jackson Purchase Region of Kentucky (e.g. county floras and floras of selected habitats), quantitative studies characterizing the plant communities there are lacking. Bryant and Martin (1988) used the 1820 General Land Office Survey of the Purchase to piece together the presettlement vegetation. However because of the limitations of that Survey, they were able only to determine species percentages.

The Jackson Purchase is part of the Mississippi Embayment, a Coastal Plain region, and the area of outcrop of the unconsolidated or only semi-consolidated sediments of the Cretaceous and Tertiary (McFarlan 1943). The Mississippi Embayment displays a mosaic of unlike vegetation types including prairie, oak-hickory forests, swamp forest, and mixed mesophytic communities (Braun 1950).

This paper is one part of a study of the plant communities of the Jackson Purchase. Herein I describe and compare the structure and composition of those bottomland hardwood forests in which sugarberry (*Celtis laevigata*) is a component.

Braun (1950) suggested that little difference existed between the forests of the southern part of the Mississippi alluvial plain in Louisiana and Mississippi and those of the northern part in Tennessee, Missouri, Illinois, and Kentucky. On the southern part of that alluvial plain in Louisiana, Thieret (1971) quantitatively described a sugarberry-dominated forest and posed the question of whether similar forests occurred elsewhere on the Mississippi River floodplain. Wharton *et al.* (1982) described the floodplain dominance types in the Southeast (generally to the east and southeast of the Jackson Purchase). They found sugarberry communities to be ecologically or geographically localized, generally in the backswamp or first bottom terraces. In those backswamps and floodplain flats, sugarberry was less common than its associates which included green ash, American elm, and sweet gum (Wharton *et al.* 1982). The Society of American Foresters recognized a sugarberry-American elm green ash type (Eyre 1980) and sugarberry is found in a number of other types. In southern Illinois, Robertson *et al.* (1978) recorded sugarberry as a minor component of the forests communities at Horseshoe Lake.

THE ENVIRONMENT

Sugarberry was found to be a forest component in the Mississippi River floodplain of Fulton and Hickman Counties, near the confluence of the Mississippi and Ohio Rivers in Ballard County; in the first and second bottoms of the Ohio River in Ballard County, and in the Tennessee River floodplain of Marshall County. These sites were nearly flat, although they included slight undulations from a microtopographic view. Relief varied no more than 3-5 m. None of the areas studied was bounded by levees to prevent flooding. Flooding frequently occurs in the winter or early spring with a duration of one to two weeks (Newton and Sims 1987).

Soils have formed from fine-textured alluvium deposited by the floods in the first bottoms. These soils include the Sharkey, Tunica, Newark, Nolin, Open Lake, Patton, Birds, and Robinsonville soil types (Newton and Sims 1987). On the Ohio River floodplain, Wheeling silt loam frequently separates the first bottoms of recent alluvium from the older, higher terraces or second bottoms (Humphrey 1976).

Climate for the Jackson Purchase is temperate with hot, humid summers and occasional cold spells in winter. Rainfall for Fulton County averages 120 cm annually (Newton and Sims 1987) and is typical for much of the Purchase.

METHODS

The woody vegetation of the selected forests was sampled in 0.04 hectare circular plots randomly spaced throughout the forests. All trees ≥10 cm at diameter-breast-height (dbh) were measured within the plots. Data for each forest were analyzed to determine relative density (RD), relative dominance (RDo), and importance value (IV). In one forest, the Upper Bottoms of Fulton County, relative frequency (RF) was also determined. Trees were considered to be canopy (≥30 cm dbh) and subcanopy (≥10 cm dbh <30 cm dbh) following Abrell and Jackson (1977).

Density (trees/ha), basal area (m^2/ha), and species diversity (H') were determined for each forest. Species diversity patterns were calculated using the Shannon-Wiener index: $H' = \Sigma p_i \log_2 p_i$, where p_i is the proportion of each species in the forest (Shannon and Weaver 1949). Stem counts were plotted against their size classes on semilog paper and a regression line was fitted to the plotted data using the methods of Schmelz and Lindsey (1965). The coefficient of determination ($100r^2$), which defines how much variation of the dependent variable (density) is accounted for by the variation of the independent variable (diameter), was used as an index of the degree of past disturbance of the stand structure still detectable at the time of study; a high value indicates little disturbance (Schmelz and Lindsey 1965).

RESULTS

The eight forests with a sugarberry (*Celtis laevigata*) component were confined to the first and second bottoms of the Mississippi, Ohio, and Tennessee rivers. In three of those forests, sugarberry was the domiant, in one (Green Ash-dominated) a major component; and in four (Sweetgum, Pin Oak, Red Maple, and Pecan-Shellbark Hickory) a minor contributor.

The total number of tree species ranged from 8-20 in the stands sampled. The coefficients of similarity among stands ranged from 3.68-61.34% which indicates that these forests are quite dissimilar. The sugarberry forests showed the highest similarities.

The community patterns that emerged on the bottomlands seem best correlated to species diversity (H′) and soils. This suggests that some kind of gradient is operative and species select out along that gradient. Although the topography of these bottomlands appears to be flat, it varies microtopographically, thus influencing soil development (ponding, aeration, etc.) and the influence and duration of flood waters.

The sugarberry-dominated forests varied from 11-16 tree species and H′ was intermediate (2.85-3.03) relative to other stands (Table 1). Basal areas ranged from 21.59-35.64 m^2/ha. The stand with the lowest basal area had the highest density (370.5 trees/ha).

Table 1. A comparision of density (trees/ha), basal area (m^2/ha), diversity (H′), percent canopy trees (%-canopy), percent subcanopy (%-subcanopy), coefficient of determination ($100r^2$), sugarberry importance value (IV) based on 200, and sugarberry density (trees/ha) in eight bottomland forests in the Jackson Purchase of Kentucky.

	trees/ha	m^2/ha	H′	% canopy	% subcanopy	$100r^2$	IV	Sugarberry trees/ha
Upper Bottoms (Fulton County)	269.23	35.64	3.03	52.75	47.25	95	59.95	72.86
Mud Creek (Fulton County)	538.46	21.96	1.98	18.35	81.65	99	23.44	54.33
Lower Bottoms (Hickman County)	429.78	46.40	2.26	52.87	47.13	83	1.25	4.94
Swan Pond (Ballard County)	385.32	33.55	1.93	41.03	58.97	80	5.84	19.77
Ohio River-West (Ballard County)	268.61	29.70	2.92	49.43	50.57	66	52.46	74.08
Ohio River-East (Ballard County)	281.58	39.52	3.50	64.04	35.96	79	11.70	27.17
Ohio River-Beaver (Ballard County)	321.10	37.89	3.34	52.99	47.01	83	2.01	5.49
Tennessee River	370.50	21.59	2.85	25.33	74.67	93	54.15	113.63

The high $100r^2$ (93) may be artifact related to the high numbers of trees in the smaller size classes. This stand shows signs of some past disturbance and recovery is proceeding, especially through the dense growth of smaller trees. Disturbance, probably from flooding or blowdowns, may contribute to the low $100r^2$ (66) in another sugarberry forest. There the density and basal area values are comparable to the sugarberry forest in the Upper Bottoms of Fulton County (Table 1). The Upper Bottoms forest is analyzed in detail (Table 2). Soils include the Sharkey, Newark, and Tunica.

Table 2. The relative frequency (RF), relative density (RD), relative dominance (RDo), and importance value (IV) of tree species in the Upper Bottoms Forest of Fulton County, Kentucky.

	RF	RD	RDo	IV
Celtis laevigata	15.46	27.06	32.01	74.53
Fraxinus pennsylvanica	17.53	20.18	28.61	66.32
Carya illinoensis	17.53	16.97	18.70	53.20
Ulmus americana	9.28	11.93	2.69	23.90
Acer saccharinum	10.31	6.88	2.94	20.13
Liquidambar styraciflua	2.06	1.38	5.43	8.87
Acer negundo	4.12	3.21	1.21	8.54
Crataegus sp.	5.15	2.75	.48	8.38
Quercus palustris	3.09	1.38	.62	6.31
Quercus michauxii	2.06	2.29	1.95	6.30
Gymnocladus dioica	4.12	1.83	.16	6.11
Diospyros virginiana	3.09	1.38	.75	5.22
Carya laciniosa	2.06	.92	1.05	4.03
Carya ovata	2.06	.92	.62	3.60
Quercus lyrata	1.03	.46	1.54	3.03
Foresteria acuminata	1.03	.46	.03	1.52
TOTALS	99.98	100.00	100.01	299.99

There were 19-20 tree species in the two forests with the highest H' (3.34-3.50). Basal areas were high (38-39.5 m^2/ha) and density (281.6-321.1 trees/ha) typical of upland sites (Bryant unpub.). The Wheeling soils predominate under these forests and they are typically found on higher parts of terraces. These sites are subject to flooding only during the highest floods. The mixture of upland and lowland species characterizes these forests. Here sugarberry was a minor component while sugar maple (*Acer saccharum*), basswood (*Tilia americana*), and northern red oak (*Quercus rubra*) made their first appearance.

Those forests with the lowest diversity (1.93-2.26) averaged only 9 tree species per stand. Density was higher in these forests than in others (Table 1), but basal areas were more variable (22-46.4 m^2/ha). Disturbance, due to past logging or prolonged wet soils, seems important here. The forest with the highest density and lowest basal area showed the highest $100r^2$ of 99. Dense growths of green ash (*Fraxinus pennsylvanica*) account for these inconsistencies. The soils on these sites, including the Birds, Patton, Newark-Lindside, Nolin, Open Lake, and Robinsonville and other complexes tend to hold water on their surfaces or remain wetter for longer periods of time than do other soils.

This pattern in species distributions appears to indicate that diversity is related to soils, microtopography, and flooding frequency and duration (prolonged wet soils). In the Jackson Purchase, swamps dominated by one or two species show the lowest diversities and mixed forests on the dissected uplands (loess bluffs) show the highest (Bryant unpub.). The wet bottoms, the sugarberry sites, and the second bottoms fall between these extremes. In general, the importance of oaks and some hickories increases from the first to the second bottoms.

Bottomland forests are no longer extensive in the Jackson Purchase, primarily because of the clearing for agriculture. The remaining forests show the signs of disturbance and encroachment. Perhaps the finest example of a sugarberry-dominated bottomland forest is the Upper Bottoms Forest in Fulton County. The dominants include sugarberry, green ash, pecan (*Carya illinoensis*), and American elm (*Ulmus americana*) (Table 2). The coefficient of similarity between this forest and Thieret's (1971) Louisiana forest is >51%.

The $100r^2$ for the Upper Bottoms Forest is 95 and this forest appears to be stable based on the size class distributions for all tree species. However size class distributions for sugarberry, pecan, and green ash are roughly bell-shaped (Fig.1). American elm shows the inverted-J curve (Fig.1B), but its confinement to only three size classes may be a product of mortality from Dutch elm disease. The bell-curve indicates slow recruitment but may be typical of some long-lived tree species. Blowdowns open the forest canopy, but more work is needed to determine their importance here.

Ground cover was dense with catbriers (*Smilax* sp.) and cane (*Arundinaria gigantea*). Vines were prolific and covered the trunks of many trees. These vines were mostly poison ivy (*Rhus radicans*) and trumpet vine (*Campsis radicans*). Seedlings and saplings were of the same species as the canopy and subcanopy trees but more work is needed to determine the tree replacement patterns in this forest.

DISCUSSION

The vegetation of most riparian ecosystems is dominated by diverse trees that are adapted to a wide variety of environmental conditions on the floodplains (Mitsch and Gooselink 1986). The vegetation adapts to moisture or anaerobic gradients (Wharton *et al.* 1982) from the wettest to the driest parts of the floodplain, but because of the microtopography, this is not a smooth change from zone to zone (Mitsch and Gooselink 1986).

The sugarberry-green ash-American elm forest type has been recognized (Eyre 1980). It appears to be more prominent along the Mississippi River than in the floodplains of other rivers of the Southeast where it is ecologically or geographically localized (Wharton *et al.* 1982). This forest community occupies the backswamp or first terrace flats of the first bottom terraces (Wharton *et al.* 1982). That is also the situation for sugarberry in the Jackson Purchase with its importance decreasing both to the wetter and drier sites. To the drier end, oaks and hickories show increases in importance and to the wetter end, green ash and red maple (*Acer rubrum*) are more prominent.

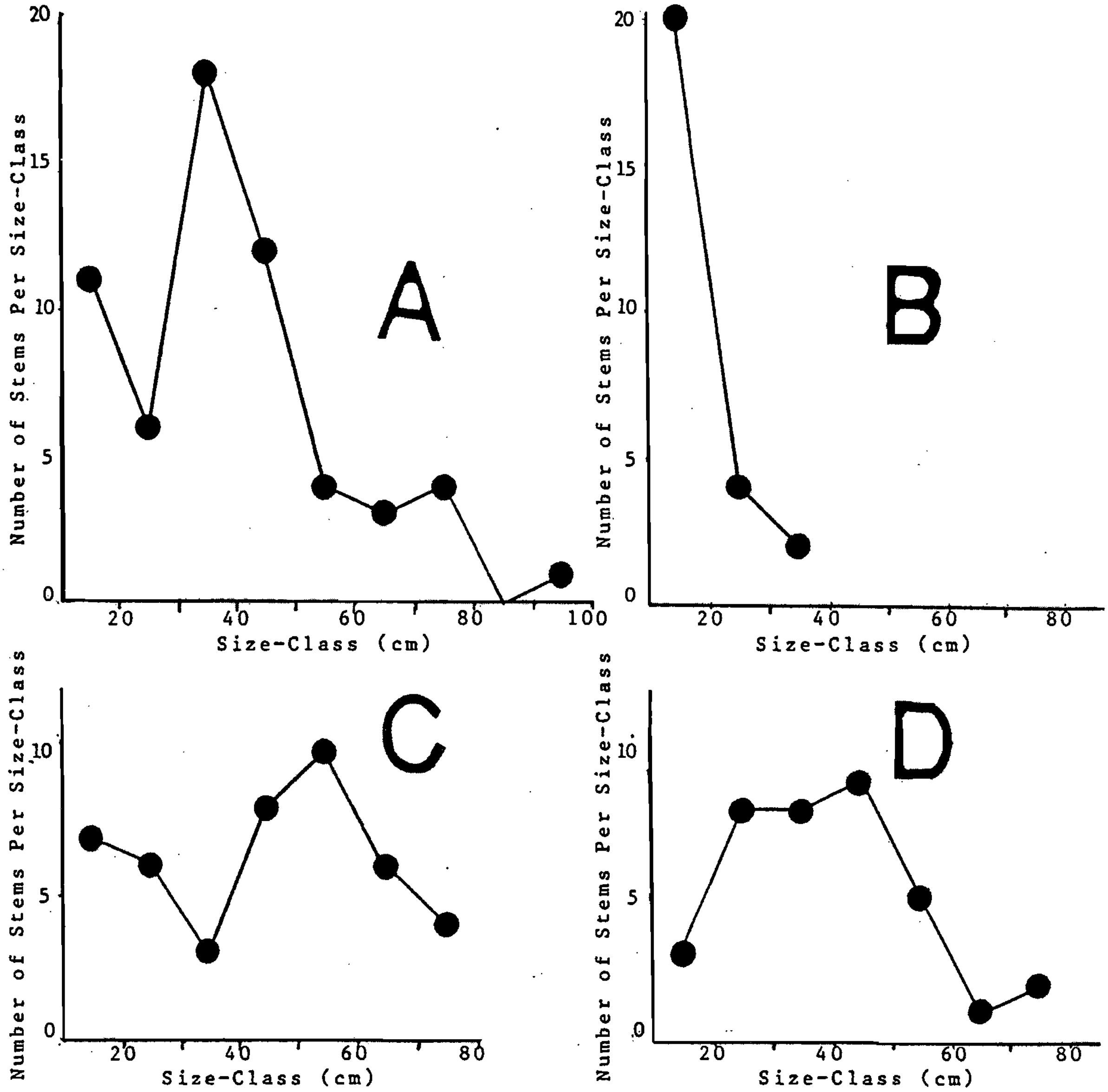

Figure 1. Size-class distribution of the four leading trees, A. Sugarberry, B. American elm, C. Green ash, and D. Pecan, in the Upper Bottoms of Fulton County, Kentucky. Numbers are plotted against the mid-points of the diameters in 10 cm intervals.

The relationship of soils and tree species associations has been well-documented (Fowells 1965). Although floodplains may appear to be flat, microtopographic differences are significant in regulating species distributions. The floodplain level does not rise uniformly from the river and as a consequence, areas at successively higher levels in the floodplains are flooded less frequently than those at lower levels (Mitsch and Gooselink 1986). Robertson *et al.* (1978) concluded that the tree species at Horseshoe Lake respond in an individualistic manner to components in the environment. That undoubtedly is the case here and explains the distributions and species associations in the Jackson Purchase bottomlands. Braun (1950) listed 19 principal tree species that tend to be mingled in the broad alluvial valleys of the Southeast. Fifteen of those species were present in the bottomland forest types reported here. She also noted that these species may be segregated into more or less distinct communities related to period and depth of submergence.

The most common natural disturbances in bottomland ecosystems are associated with floods (Wharton *et al.* 1982). Some hardwood species that grow in bottomlands are not water tolerant during the growing season, but during the dormant season all typical bottomland species can survive extended flooding (Johnson and Shropshire 1983). Thus, the time of flooding and the duration of flooding are important determinants in species population patterns.

Mixed stands were essentially even-aged before cutting practices and natural mortality modified stand structure and composition (Johnson and Shropshire 1983). The size class distributions of sugarberry, green ash, and pecan are somewhat indicative of even-age for the Upper Bottoms Forest in Fulton County. That forest has been largely undisturbed by past or recent cutting practices. Such an age-class pattern is not nearly so well-defined in most of the other forests.

Johnson and Shropshire (1983) report that mixed bottomland hardwoods, including the sugarberry-green ash-American elm type, seldom exceed 34.4 m^2/ha basal area and most are between 25.3-29.8 m^2/ha. Robertson *et al.* (1978) found the old-growth stand at Horseshoe Lake to have a basal area of 36.8 m^2/ha with the secondary stand having 31.2 m^2/ha. The basal areas recorded for the Jackson Purchase forests are quite comparable. Wharton *et al.* (1982) reported that the diversity of the bottomland hardwood canopy increases with the complexity of the floodplain topography. Robertson *et al.* (1978) showed diversity to increase from 2.19 on the wet sites to 2.84 on the transitional sites and to 3.05 on the mesic sites at Horseshoe Lake. This pattern is nearly identical to that observed in this study.

Thieret's (1971) question concerning the occurrence of similar sugarberry forests elsewhere on the Mississippi River floodplain is answered. In the Jackson Purchase of Kentucky these forests occupy the first bottom terraces, are on Sharkey soils for the most part, and are transitional relative to the forests on the wetter and drier sites. The importance of pecan in the Jackson Purchase forests and of the oak-hickory element in general, relative to the lower Mississippi floodplain, are distinguishing differences. Continued and more detailed studies of the bottomland hardwood forests of the Jackson Purchase are needed to better understand and manage this disappearing community type.

ACKNOWLEDGMENTS

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EFFECTS OF PRESCRIBED FIRE ON OAK FOREST UNDERSTORY

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ABSTRACT. We examined data collected from 1965-1989 on the understory of a prescribed-burn upland oak forest at the University of Tennessee Highland Rim Forestry Station near Tullahoma. Treatments were annual, periodic (once in five years), and no burn. Each treatment was replicated three times.

Species richness declined dramatically under the no-burn regime. Tree seedling establishment was inhibited and sprout size decreased in the annual and periodic burns; here the understory aspect was quite open. Tree sprout cover in the periodic burns followed the incidence of fire being lower in the September following each spring burn. Graminoid cover, chiefly little bluestream (*Schizachyrium scoparium*), decreased to zero in the no-burn treatment and was variable in other treatments, decreasing irregularly from 1973-1975 to 1988 and establishing a new high in 1989. Composite, legume, and other forb cover declined to zero under the no-burn treatment. Composite cover in periodic plots oscillated around fire years when cover was generally highest. Legume cover peaked in four of five fire years and other forb cover generally increased in the year after a fire.

COMMUNITY SITE RELATIONSHIPS AT LAND BETWEEN THE LAKES, KENTUCKY AND TENNESSEE

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ABSTRACT

The objective of the study was to examine composition and productivity of non-successional (climax) stands as a function of soil and topographic characteristics. Disturbance has affected much of the LBL forest by opening sites and allowing the invasion of pioneer species. The first step in studying community-environment relationships is to examine the pattern of compositionally stable stands. COMPAH analysis, an agglomerative clustering technique, of the data from 71 compositionally stable stands designated seven major community types. Analysis of environmental data indicates that community composition is largely related to soil moisture, aspect, elevation, and distance to opposing slope.

Communities of xeric sites are dominated by *Quercus marilandica*, *Q. prinus*, and *Q. stellata*. Mean site index (*Q. alba*) is 32, 45.3, and 46.6 ft, respectively. The *Q. marilandica* community occurs on extremely exposed, high elevation (mean = 166 m), southwest facing slopes and ridges. The mean available water capacity (AWC) is 7.9 cm. Associated species include *Carya glabra*, *Q. prinus*, *Q. stellata*, and *Q. velutina*. The *Q. prinus* community is established mainly on south to west facing slopes and ridges with medium to high exposure, and high elevations (mean = 168 m). The mean AWC is 11.2 cm and soils usually have a very high rock content (25% to 70%). *Quercus alba*, *Q. stellata*, and *Q. velutina* are components of this community. The *Q. stellata* community is located on highly exposed southwest slopes and ridges at high elevations (mean = 161 m). The mean AWC is 10.9 and soils usually are silty and have a fragipan. A variety of other species including *C. glabra*, *Q. alba*, *Q. coccinea*, *Q. marilandica*, and *Q. prinus* are found in this community.

The *Q. alba* and *Q. velutina* communities are located in the center (or xeric-mesic) portion of the moisture gradient. Here *Q. alba* site index is 53.3 and 44.4, respectively. The *Q. alba* community is on southeast to northwest slopes (Az = 135° to 315°) of lower elevations (mean = 144.8 m). Distance to the opposing slope (DIST) decreases (mean = 475.1 m) and the mean AWC slightly increases (mean = 13.5 cm) from the previous communities. Other species of this community are *Q. coccinea*, *Q. prinus*, *Q. stellata*, and *Q. velutina*. The *Q. velutina* community is located on highly exposed north to southeast slopes (Az = 0° to 130°) of high elevations (mean = 159 m) with a mean soil AWC is 13 cm. Associated species are *Acer saccharum*, *C. glabra*, *Nyssa sylvatica*, *Oxydendrum arboreum*, *Q. alba*, and *Q. coccinea*.

The more mesic *Fagus grandifolia* community occupies less exposed (DIST = 270.9 m) northern facing slopes of lower elevations (mean = 130 m). The mean AWC increases to 14.7 cm and site index increases to 60. Soils are usually derived from limestone. *Acer saccharum*, *Carya ovata*, *Q. alba*, and *Q. rubra* also are common species.

The Mixed Mesophytic community has a low elevation (mean = 117 m) and little exposure (mean DIST = 60 m). Mean AWC of these stream terrace sites is 21.5 cm. Species include *A. saccharum*, *Liquidambar styraciflua*, and *Liriodendron tulipifera*.

FOREST SUCCESSION PATTERNS AT LAND BETWEEN THE LAKES, KENTUCKY AND TENNESSEE

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ABSTRACT. A study of forest succession was conducted at Land Between The Lakes (LBL), Kentucky and Tennessee. The vegetation forms a mosaic which is the result of site factors and past influences from which, in some cases, the vegetation has not recovered. Major factors affecting vegetation at LBL include disturbance from farming, fire, and timber harvesting for lumber and charcoal for iron furnaces.

Percent similarity using species importance values between overstory and understory strata, was used to determine the compositional stability of 138 stands. Successional change was identified in 58 stands with major changes occurring in a large number of *Quercus alba* dominated stands and in all stands dominated by *Pinus echinata*.

Mean percent similarity (41.6) for the *P. echinata* stands indicates a substantial difference between overstory and understory composition. The *P. echinata* community presently occupies ridges and upper slopes in the Devil's Backbone area of LBL. Fires regularly swept through the area until the early 1960s when TVA assumed management. Aspects range from southeast to south to west, and elevations from 162 to 189 meters. Typically, similar sites at LBL are dominated by stable communities of *Q. prinus*, *Q. stellata*, and in some cases *Q. alba* and *Q. marilandica*. It appears that under the present conditions (i.e. no major disturbance) these *P. echinata* stands will be replaced in the future by xerophytic oak species.

The *Q. alba* community is the most common and widespread forest community at LBL. Both compositionally stable and successional *Q. alba* stands occur. Available water capacity, elevation, slope position, and distance to opposing slope, along with aspect, interrelate to influence the degree and rate of succession in these communities. Successional *Q. alba* stands generally occur on sites with a high available water capacity or low elevation, and a northwest to northeast to southeast aspect. Comparable sites at LBL support stable communities dominated by *Acer saccharum* and/or *Fagus grandifolia*. The understory of successional *Q. alba* stands usually contained a moderate to high density of *A. saccharum*, *F. grandifolia*, and other mesophytic species and a low density of *Q. alba* seedlings and saplings.

Past disturbance at LBL has influenced community distribution by allowing some species to invade sites from which they were previously excluded by competition. Thus, the *P. echinata* community and many *Q. alba* communities are occupying sites that would support stable communities dominated by species relatively more mesophytic and shade tolerant. In the absence of periodic disturbance *P. echinata* communities will convert to *Q. prinus* and other dry site oaks, and *Q. alba* communities will convert to *A. saccharum* and *F. grandifolia*.

A COMPARISON STUDY OF TWO PLANT COMMUNITIES ALONG THE SOUTH FORK-FORKED DEER RIVER

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ABSTRACT. A study was conducted to determine whether major renovation work completed in 1978 on a lower portion of the South Fork-Forked Deer River in Western Tennessee has had any effect over a twelve year period on the composition of adjoining wetland plant communities. Vegetation quadrats were established in plant communities adjacent to portions of the river where major renovation and no renovation work was conducted. The two bottomland hardwood communities exhibited a high degree of composition similarity with a coefficient of community of 95.3% and Simpson's Species Diversity of 8.13 and 8.02, respectively.

INTRODUCTION

The Forked Deer River watershed is a major component of the Obion-Forked Deer River Basin (OFDRB) representing approximately 12,325 km^2 and 11% of the land surface of Tennessee. In addition, the Basin contains approximately 35% of the state's bottomland hardwoods (OFDRB, 1983). Many of the major streams in the OFDRB of west Tennessee were channelized from 1912 to the early 1930's. There was little or no channel maintenance during the subsequent years, and trees along the river banks grew and fell into the river. In addition, the watershed lands were increasingly used for row crop agriculture. The accelerated erosion brought about deposition of soil material and organic debris from fallen trees resulting in the formation of debris dams blocking the free flow of the channels. The impeded water would back up into bottomland hardwoods, cultivated fields, and roadways. The winter waters stopped flowing back into the river in early spring, and would stand in the fields and bottomlands well into and sometimes through the growing season.

In the late 1960's the U.S. Army Corps of Engineers began a major renovation program in the Forked Deer River Basin in which rivers were straightened and large amounts of natural vegetation were removed from along the banks. This work should not be confused with efforts of the Obion-Forked Deer River Basin Authority that was formed in 1972 to see that the streams flowed more freely by using less drastic means to remove debris dams, connecting tributaries to the main channels, and maintaining sufficient water levels in old river cutoffs for functional fish and wildlife habitat. The Authority was also assigned the task of constructing flood and sediment control structures to help retard the excessive runoff and resulting erosion brought about by increasing farming and urbanization pressures (OFDRB 1979, OFDRB 1983).

This study was conducted to determine whether the major renovation work completed in 1978 on the South Fork-Forked Deer River had any apparent effect on the vegetation composition of adjoining wetlands. The renovation work was stopped at the downstream side of the State Highway 54 bridge north of Brownsville. Upstream from the bridge the river received no renovation work, and so the associated wetlands served as a control. All studies were made on the south side of the river because the land to the north is in cultivation.

The soil type at both study sites is a Rosebloom Silt Loam that supports bottomland hardwoods and incurs seasonal flooding during the wet periods of winter and early spring. The sites are typical of a natural green-tree type reservoir in which winter flood waters are allowed to flow freely in and out of the bottomlands (Broadfoot and Williston 1973). The soil is deep, somewhat acidic, and poorly drained with <1 percent slope. A few days of flooding usually occurs during the non-growing season, thus not being detrimental to tree establishment and growth (Schlaegel 1984).

METHODS

Sixty 10m x 10m vegetation study quadrates were established and evaluated in each community starting 600 meters upstream and downstream from the bridge to insure there would be no possible impact from bridge construction or maintenance activities. The quadrats were placed 10 meters apart perpendicular to the river in a series of six lines parallel to the river (Curtis and Cottam 1962, Oosting 1956, Miller 1985). The nomenclature of plants follows that of Gleason and Cronquist (1963).

The coefficient of community similarity was calculated by the formula (Oosting,1956):

$$S_{jk}=\frac{2W}{a+b}*100$$

W = species occurring in both communities in which the lowest of each pair of frequency percentages is summed and doubled to represent the degree that the two communities share the measured characteristic (frequency)

a+b = sum of all species percentages in communities j and k

Species diversity was determined using Simpson's species diversity index (also variously termed dominance diversity and effective or functional species; Simpson 1949):

$$D=\frac{N(N-1)}{\sum_{i=1}^{s} n_i(n_i-1)}$$

N = the total number of individuals of all species

n_i = the total number of individuals of the ith species

s = the total number of taxa

RESULTS AND DISCUSSION

A master list of all 193 vascular plants recorded in the quadrats for both communities has been compiled (Table 1). The coefficient of similarity for the two riparian communities is 95.3% while the species diversity is 8.13 along the renovated portion and 8.02 in the upstream community. There was no evidence that renovation of the river has had any effect on the adjoining wetland habitat during the past twelve years in regard to plant species composition or diversity, nor has there been any apparent loss of wetland in the area of renovation work other than along the levee proper. The non-renovated river upstream from the bridge contains numerous fallen trees that are collecting sediment and debris from collapsing river banks. Downstream from the bridge where the river is free flowing, the banks are heavily vegetated and stable.

The relatively high degree of community similarity and the high species diversity in each community cannot be attributed to the physical configuration of the adjacent river but rather to the similar soil types in each community and to the annual flooding regime in which the flood waters leave the plant communities prior to each growing season.

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APPENDIX

Master list of vascular plants found in both wetland communities.

Abutilon theophrasti
Acalypha virginica
Acer negundo
Acer rubrum
Acer saccharinum
Acer saccharum
Aesculus pavia
Agropyron sp.
Agrostis hyemalis
Albizia julibrissin
Allium canadense
Allium cernum
Alnus serulata
Amaranthus hybridus
Ambrosia artemisiifolia
Ambrosia trifida
Amelanchier arborea
Ampelopsis arborea
Ampelopsis cordata
Andropogon virginicus
Aralia spinosa
Arisaema dracontium
Arisaema triphyllum
Arundinaria gigantea
Asarum canadense
Asclepias incarnata
Asclepias tuberosa
Asimina triloba
Aster dumosus
Aster pilosus
Aster simplex
Aster vimineus
Azolla caroliniana
Betula nigra
Bidens discoidea
Bidens frondosa
Boehmeria cylindrica
Botrychium virginianum
Callicarpa americana
Campsis radicans
Caronilla varia
Carya cordiformis
Carya illinoensis
Carya ovata
Cassia fasciculata
Celtis laevigata
Celtis occidentalis
Cercis canadensis
Chenopodium album
Cirsium discolor
Claytonia caroliniana
Claytonia virginica
Clematis virginiana
Cornus florida
Cornus stolonifera
Cyperus dactylon
Cyperus erythrorhizos
Cyperus pseudovegetus
Cyperus strigosus
Daucus carota
Digitaria sanguinalis
Diospyros virginiana
Echinochloa muricata
Echinochloa occidentalis
Elaeagnus angustifolia
Eleusine indica
Elymus virginicus
Eragrostis hirsuta
Eragrostis hynoides
Eragrostis refracta
Erigeron canadensis
Erigeron strigosus
Euonymous americanus
Euonymous atropurpureus
Eupatorium coelestinum
Eupatorium rugosum
Euphorbia preslii
Fagus grandifolia
Foresteria ligustrina
Frageria virginiana
Fraxinus pennsylvanicus
Gleditsia aquatica
Gleditsia triacanthos
Glyceria striata
Helianthus annuus
Helianthus petiolaris
Heterotheca latifolia
Hibiscus militaris
Hydrangea arborescens
Ilex decidua
Ilex opaca
Impatiens carpensis
Ipomoea hederacea
Ipomoea lacunosa
Iris cristata
Juglans nigra
Juniperus virginiana
Lactuca floridana

Lamium amplexicaule
Lamium maculatum
Lamium purpureum
Leersia oryzoides
Lepidium virginicum
Lespedeza cuneata
Lilium superbum
Lilium tigrinum
Lindera benzoin
Liquidambar styraciflua
Liriodendron tulipifera
Lonicera japonica
Maclura pomifera
Menispermum canadensis
Monarda didyma
Monarda fistulosa
Morus rubra
Narcissus sp.
Nyssa aquatica
Oenothera biennis
Onoclea sensibilis
Ostrya virginiana
Ozalis stricta
Panicum agrostoides
Panicum lanuginosum
Parthenocissus quinquefolia
Passiflora incarnata
Paulownia tomentosa
Phaseolus bracteata
Phlox divaricata
Phytolacca americana
Pilea pumila
Plantago lanceolata
Platanus occidentalis
Pluchea camphorata
Podophyllum peltatum
Polygonum densiflorum
Polygonum lapathifolium
Polygonum longistylum
Polygonum scandens
Polystichum acrostichoides
Populus deltoides
Populus heterophylla
Prunus serotina
Quercus falcata
  var. *pagodeafolia*
Quercus michauxii
Quercus nigra
Quercus palustris
Quercus phellos
Quercus stellata
Rhus glabra
Rhus radicans
Robinia pseudocacia
Rosa palustris
Rubus argutus
Rumex altissimus
Sagittaria latifolia
Salix nigra
Sambucus canadensis
Sassafras albidum
Setaria geniculata
Sisyrinchium angustifolium
Smilacina racemosa
Smilax bona-nox
Smilax hispida
Solidago canadensis
Sorghum halepense
Staphylea trifolia
Stellaria media
Taraxacum officinale
Taxodium distichum
Tridens flavus
Trifolium arvense
Trifolium pratense
Trifolium procumbens
Trifolium repens
Trillium recurvatum
Typha latifolia
Ulmus alata
Ulmus rubra
Urtica dioica
Verbascum blattaria
Verbascum thaspus
Vernonia altissima
Veronica agrestis
Veronica arvensis
Veronica peregrina
Viola missouriensis
Viola papilionacea
Vitis aestivalis
Vitis cinerea
Vitis rotundifolia
Wisteria frutescens
Xanthium strumarium

THE FERNS AND FERN ALLIES OF LAND BETWEEN THE LAKES

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ABSTRACT. A floristic study was made of the pteridophytes (ferns and fern allies) of Land Between The Lakes, a 68,800-ha, mostly wooded and dissected upland between the lower and impounded Cumberland and Tennessee rivers. The site has been in public ownership since 1964 and managed by the Tennessee Valley Authority as a National Demonstration Area for conservation, education, and recreation. Based on our studies of the literature, a survey of holdings in regional herbaria, and extensive field work in 1987-1989, the pteridophyte flora consists of 31 taxa, including four fern allies and 27 ferns (26 species and one *forma*). An annotated checklist is given, distributions and habitat preferenda within the three-county area of LBL are discussed, and some taxonomic problems noted.

INTRODUCTION

Land Between The Lakes (LBL) is a 68,800 ha tract between the impounded lower Tennessee River (Kentucky Lake) and the impounded lower Cumberland River (Barkley Lake). Parts of Lyon and Trigg counties, south-Central Kentucky, and Stewart County, northwestern Middle Tennessee, are included. The peninsula has been managed by the Tennessee Valley Authority (TVA) since 1964 as a National Demonstration Area for conservation, education, and recreation.

The Austin Peay State University Center for Field Biology is researching various biotic features of the area and preparing databases on the flora and fauna. This paper contributes to those efforts and gives results of our studies on the pteridophyte flora. The objectives were to prepare a list of the LBL ferns and fern allies based on literature, herbarium, and field studies, and to give their LBL distribution and habitat preferenda. A brief description of the area will provide insight into habitat types available for pteridophyte occupancy and give background material for checklist annotations.

THE AREA

History and Present Conditions. Complete historical accounts prepared by Smith (1971), Henry (1976), and Wallace (1988) show that prior to 1964, LBL was an area of small farms, communities, and towns with a population of about 5000. The landscape had a legacy of disturbance, including farming, lumbering, Civil War activities, iron mining and related charcoal production, grazing, fires, erosion, and numerous other anthropogenic influences. There were no railroads, recent industries, or cities. Kentucky Dam, built on the Tennessee River by TVA in 1944, inundated much of the rich, alluvial bottomlands on the west side, and Barkley Dam, closed on the Cumberland River by the U.S. Army Corps of Engineers in 1966, likewise flooded many lowlands on the east side.

Plans for LBL were developed in the 1950s, concurrent with those for construction of Barkley Dam and a canal connecting the two reservoirs. Federal purchase and management was proposed for the included land area because it would be surrounded on three sides by water, virtually isolated, and especially because considerable acreage was already federally held in reservoir easements and a wildlife management area. The Tennessee Valley Authority was granted stewardship in 1964 with the mandate to develop a National Demonstration Area for conservation, education, and recreation.

Today most of the former homes, stores, barns, churches, and other buildings have been removed. Yet farm ponds, orchards, fences and fencerows, roadways, exotic species, old fields, and numerous other, often subtle, evidences of habitation remain. About 250 cemeteries in various degrees of upkeep are scattered throughout LBL and a few such historical features as old iron furnaces are maintained. Many fields are planted in grain each year for wildlife, and others are maintained open by clipping. In addition, some bottomlands are leased to area farmers, mostly for soybeans, corn, and/or hay. With the exception of one forest designated as a National Natural Landmark and several others protected as TVA Ecological Study sites, timber is harvested on a planned rotation throughout LBL.

Developments since 1964 include a working 1850s-model farmstead, a demonstration farm, environmental education centers, erosion control projects, visitor's center, campgrounds, picnic areas, live-in group camps, American bison range with a herd of about 50 animals, hiking trails, a wranglers camp with barns, campgrounds and riding trails, off-road vehicle trails, and numerous other related facilities. Other changes include building of subimpoundments and development of wet-soil areas for wildlife. As might be expected, hunting (deer, turkey, small game) and fishing are major activities. Total visitation is approaching three million per year.

Physical Features. LBL is approximately 65 km long, 13-19 km wide, and with more than 500 km of shoreline. It is within the Western Highland Rim Subsection, Highland Rim Section, Interior Low Plateaus Physiographic Province, and adjoins the Mississippi Embayment of the Coastal Plain Province on the west. The Central (Nashville) Basin Section is to the east, the Southern Highland Rim Subsection to the south, and the Pennyroyal Plain Subsection to the north (Fenneman 1938).

The topography is that of a maturely dissected plateau with narrow ridges, steep slopes, and deep ravines. Headwaters of numerous tributaries of the two rivers (reservoirs) butt against each other to form a narrow drainage divide that extends the length of LBL. Portions of the present north-south highway, called the "Trace" in reference to historical usage, follow this divide. Elevations range from 110 to 210 m. Slopes, of various aspects, are 0-10% in bottomlands to 50% and more above streams and ravines, and some bluffs are perpendicular. Few interior streams are permanent and many former springs were inundated by the impoundments.

The bedrock is predominantly cherty limestones of Mississippian age. Surface exposures are uncommon except along the lakes and major streams and there are few karst features such as caves and sinkholes. Tuscaloosa white chert gravels of Cretaceous age occur over much of the uplands, often overlain by McNairy Sand, also of Cretaceous age. In addition, brown gravels (Tertiary-Quaternary) often overlie the Cretaceous, and silty loess (Pleistocene) veneers the uplands (Harris 1988).

Soils have generally developed in thin loess over gravel and chert beds and are low in fertility, droughty, and inferior for agriculture; without proper management, erosion is excessive. Harris (1988), describes three mapping units, Brandon-Lax complex of uplands, Baxter-Hammond complex of slopes, and Brandon-Saffel complex on slopes where Tuscaloosa gravels are present. Bottomland soils were formed by alluvial sediments, but most of the lower valleys and bottomlands are now under water.

Climatic data, summarized by Carpenter and Chester (1987) from Dickerson (1960) and U.S. Dept. Commerce (1931-1987), show that the LBL climate is warm-temperate with long warm summers and short mild winters. The growing season is about 191 days and extends from mid-April to mid- or late-October. Average precipitation is well distributed throughout the year and averages 126.8 cm. The average temperature is 14.5°C; January is the coldest month (average 2.6°C) and July the warmest (average 25.4°C).

Vegetational Features. The vegetation of LBL is that of Braun's (1950) Western Mesophytic Forest Region of the Eastern Deciduous Forest Formation. This is an ecotonal region between more xeric types westward (Oak-Hickory Region) and more mesic types eastward (Mixed Mesophytic Region). There is no single climax type; instead a mosaic of types occurs, with local conditions (climate, soils, topography) determining specific vegetational conditions.

The dissected topography and influences of the adjacent great riverine systems have resulted in a number of habitat types in LBL. This, in turn, accentuates the transitional character of the vegetation and flora by providing habitats for elements from contiguous physiographic and vegetational regions. Carpenter and Chester (1988) and Chester and Ellis (1989) provided an overview of habitat-community types of LBL and the region. The following broad types occur in LBL: (1) wetlands, (2) dissected uplands, and (3) cultural communities.

The major wetlands are adjacent to the reservoirs and strongly influenced by their fluctuating water levels. Several inundation and vegetation types described in the regional wetland classification system of Carter and Burbank (1978) occur. Included are open water, seasonally dewatered flats, shrub swamps, bottomland forests (remnants only), wet meadows, and emergent marshes. Reintroduced beaver have been especially significant in creating ponds, wet meadows, and marshes along many streams.

Most of the LBL landscape is that of an extensively dissected upland, resulting in xeric ridges, slopes of various degrees and aspects, narrow ravines, and streambanks. The area is about 80% forested and almost all communities are oak (*Quercus*) dominated; hickories (*Carya*), maples (*Acer*), and elms (*Ulmus*) are usually present as are numerous other hardwoods (see Carpenter and Chester 1988, Fralish and Crooks 1988, 1989). Gymnosperms include red cedar (*Juniperus virginiana*), which is scattered throughout in successional situations, a few mixed hardwoods-pine forests (*Pinus echinata* and *P. virginiana*) on dry uplands and bluffs, and bald cypress (*Taxodium distichum*) along the Tennessee River. Some xeric bluffs (mostly west-facing along the Tennessee River) and mesic-seepage bluffs (mostly on north-facing slopes above streams in southern LBL) provide habitats for some indicative species.

Cultural communities are those resulting from anthropogenic influences and include lawns, cemeteries, meadows, successional fields, fencerows, orchards, roadsides, cut-over forests, and various others. Also included are monoculture forests of from one to several hectares in even-age stands of white, loblolly and Virginia pine, and bald cypress. These cultural communities contribute little to pteridophyte diversity in LBL, even though several species commonly grow in one or more of them.

PREVIOUS LITERATURE ON LBL FERNS AND FERN ALLIES

Excellent summaries of regional and Kentucky and Tennessee pteridophyte floras are available and a review of literature prior to publication of those works would be redundant. Lyle (1980) studied pteridophytes of the Northwest Highland Rim of both states. Her extensive collections included numerous LBL representatives. In Kentucky the most recent synopsis is that of Cranfill (1980), who prepared an account, with distribution maps, of all taxa known from the State; several LBL records were cited.

The classical work of Shaver (1954) is the most comprehensive account of Tennessee ferns, although fern allies were not included. Numerous records were cited from Stewart County, but not a single specimen was collected from the LBL portion (based on specimen citations in the work). Wofford and Evans (1979) prepared an atlas of Tennessee ferns and fern allies, based primarily on specimens in the University of Tennessee and Vanderbilt University Herbaria. Several county records were added for Stewart County. Evans (1989) summarized the recent literature applicable to fern taxonomy and included information on the distribution of several hybrid and rare taxa in the State; no Stewart County records were added.

Several reports have concerned LBL directly. Phillips (1968) prepared a report for TVA on the ferns (fern allies excluded) of LBL in which he listed 18 species and two subspecific taxa. That report was not published and hence not generally circulated, but Phillips later (1974) prepared a photographic guide for most of those species. Carpenter and Chester (1987, 1988) studied the Bear Creek Natural Area in southern LBL and published floristic lists, including ferns and fern allies. Their report added three species to the Phillips list (*Athyrium pycnocarpon, Botrychium dissectum, Cystopteris bulbifera)* and provided the first report of a fern ally from LBL (*Equisetum arvense).* Other reports of LBL ferns include *Azolla caroliniana* by Chester and Souza (1986), and *Asplenium ruta-muraria* by Chester and Richardson (1988).

Other literature consulted during the study include works by Beitel (1979), Carlson and Wagner (1982), Hauke (1983), Key (1982), and Lellinger (1985).

METHODS

This account of LBL ferns and fern allies is based on observations and study by the junior author (EWC) since 1967 and a concentrated field and herbarium study by the senior authors (SMN and MLM) during 1987-1989. Data were obtained from three sources.

Literature Studies. Summaries of pteridophyte floras of Tennessee and Kentucky were consulted and pertinent data extracted. The Phillips (1968) report, prepared from data collected in the early 1960s, was especially helpful in determining changes in distribution and frequency for some species.

Herbarium Studies. The major collections of LBL ferns, including the vouchers of Phillips (1968), Lyle (1980), and our own are in the Herbarium of Austin Peay State University. However, most of the herbaria in Tennessee and Kentucky were visited and curators consulted about LBL specimens. The collections of Mr. Raymond Athey of Paducah, an ardent student of the Kentucky flora, were especially important (Athey collections were studied at Memphis State University, Vanderbilt University, and in his private holdings at Paducah).

The following herbaria were visited by EWC over the past several years:
Athey Herbarium, Paducah, KY
Eastern Kentucky University, Richmond, KY
Memphis State University, Memphis, TN
Middle Tennessee State University, Murfreesboro, TN
Murray State University, Murray, KY
Tennessee Technological University, Cookeville, TN
Tennessee Valley Authority, Muscle Shoals, AL
University of Kentucky, Lexington, KY
University of Tennessee-Knoxville, TN
University of Tennessee-Martin, TN
Vanderbilt University, Nashville, TN
Western Kentucky University, Bowling Green, KY

Field Work. Numerous trips were made to likely fern habitats in LBL during 1987, 1988, and 1989. Sites were determined by perusing U.S.Geological Survey topographic quadrangle maps, by interviewing knowledgeable persons, from our own personal knowledge of the area, and from trial and error visits to likely sites. Collections were prepared according to standard procedure and accessioned into the Austin Peay State University Herbarium (APSC). Identifications were made from Shaver (1954), Cranfill (1980), and Lellinger (1985). In addition, Dr. R. Dale Thomas (Northeast Louisiana University) identified several specimens of *Ophioglossum*, and Dr. Murray Evans (University of Tennessee-Knoxville) identified some of our *Asplenium* material. Nomenclature generally follows that of Cranfill (1980).

RESULTS

Floristic Summary

As now known, the LBL pteridophyte flora consists of 31 taxa (30 species and one *forma*). Seven of these taxa are first reported here for LBL; in addition, seven new records are reported for LBL portions of Lyon County and five for Trigg County (taxa, LBL county distributions, county records, and first reports are given in Appendix). Taxa are distributed as follows:

Fern Allies. Four species of fern allies, belonging to three genera and three families, were found (Appendix and checklist). All four species occur in Stewart County; three fern allies (*Equisetum arvense, Lycopodium digitatum,* and *Selaginella apoda*) are known from Trigg County, while only one *(Lycopodium digitatum)* is known from Lyon.

True Ferns. Twenty-seven taxa, including 16 genera and eight families, were found (Appendix and checklist). Five of the families, including 12 genera and 15 species, occur in all LBL counties. Seven families, including 12 genera and 19 species, occur in Lyon County and all eight families, with 15 genera and 20 species, were found in Trigg County. Seven families, including 15 genera and 24 species, occur in Stewart County.

DISCUSSION

As noted previously, Phillips (1968) reported 18 species and two subspecific taxa of ferns and no fern allies from LBL in a report submitted to the Tennessee Valley Authority. Since that time, six taxa have been added to the known LBL pteridophyte flora. *Azolla caroliniana* was reported from Stewart and Trigg counties by Chester and Souza (1986). *Athyrium pycnocarpon, Botrychium dissectum, Cystopteris bulbifera,* and *Equisetum arvense* were reported from the Bear Creek Natural Area (Stewart Co.) by Carpenter and Chester (1987, 1988), and *Asplenium ruta-muraria* from Lyon County by Chester and Richardson in 1988.

We herein report four ferns and three fern allies as new for LBL. The ferns are *Athyrium thelypterioides, Botrychium dissectum* forma *dissectum, Ophioglossum engelmannii,* and *Thelypteris palustris.* The fern allies are *Equisetum hyemale, Lycopodium digitatum,* and *Selaginella apoda.*

Land Between The Lakes is a deeply dissected upland between parallel valleys of the Cumberland and Tennessee Rivers.. The bedrock is cherty limestone of Mississippian age and the topography is homogenous. With the exception of some lakeshore and streamside bluffs, outcrops on some slopes, and such cultural excavations as the old quarries on the south shore of Hematite Lake, adjacent to and southeast of Woodlands Nature Center, and in Hillman Ferry Campground, surface exposures of bedrock are uncommon (Harris 1988). Soils are generally shallow and often badly eroded. Springs are infrequent and surface streams, though numerous, usually cease flow during summer. Southwesterly winds prevail in the typically hot dry summers and frost heaving is prevalent in winter. These edaphic and abiotic factors militate against both variety and luxuriance of pteridophytes. Despite their failure to pullulate in drought years, several species do persist and even thrive in the more mesic woodlands and in the microhabitats provided by verdant north-facing outcroppings.

Of the 16 species common to the three counties, most have documented distributions throughout Kentucky and Tennessee and display tolerance for a relatively broad range of growing conditions. As expected, most are typical woodland species, such as *Asplenium platyneuron* and *Polystichum acrostichoides*, which occur in about the same frequency and abundance as observed by Phillips (1968) more than 20 years ago. In at least three cases, changes from anthropogenic influences have resulted in frequency and population increases. Most notable is *Onoclea sensibilis*, reported as rare by Phillips. Wetlands resulting from fluctuating water levels have provided extensive habitat and an abundance of this species. Likewise, wildlife management pools in bottomlands, especially in the Bear Creek area, have provided ideal habitat for *Azolla caroliniana* (not reported by Phillips). *Ophioglossum pycnostichum*, reported as very rare by Phillips, has become abundant in many ravines, perhaps due to removal of livestock.

Concerning infrequently encountered taxa, such epipetric calciphiles as *Asplenium resiliens, Asplenium ruta-muraria, Cystopteris bulbifera,* and *Pellaea atropurpurea* are limited by the dearth of mesic outcroppings in LBL. Although present, these species do not attain their growth potential, as they do along the Kentucky River cliffs of the Inner Bluegrass where fronds of *Cystopteris bulbifera* may be up to a meter long (Cranfill 1980). Formation of extensive wetlands by increased beaver populations has provided appropriate habitat for *Thelypteris palustris* in Stewart County. Trigg County populations of this species, associated with *Osmunda regalis* in deep shade along the shores of Hematite Lake, are taller, less robust, and produce fewer fertile fronds than meadow populations in Stewart County.

An elusive species is *Ophioglossum engelmannii*, which was collected on limestone in Trigg County during the middle 1970s by Mr. R. Athey (personal communication), though the voucher could not be located. The site has succeeded from an open, glade-like area to heavy thickets and this species may no longer occur in LBL.

The distribution of such species as *Athyrium pycnocarpon* and *A. thelypterioides* present more perplexing problems. Years of field research have produced only one or two plants of each species. The limiting factor is not immediately evident, but is probably related to lack of habitat or to such former land-use factors as pasturing or lumbering. According to Cranfill (1980), *A. pycnocarpon* is becoming rarer in the western portions of its range. He also notes that *A. thelypterioides* appears to be the most ecologically exacting species of the genus, requiring mesic north or east facing slopes and circumneutral soils along sandy streambanks. However, he attributes its absence in Central Kentucky to insufficient collecting, not to inadequate habitat.

Distribution of the LBL fern allies has not been examined before and more work will be required before a fully satisfactory record is obtained. It appears that the scarcity of sandy sites greatly restricts the occurrence of *Equisetum*. Although several new populations of *Lycopodium digitatum* recently have been found, this species is generally rare in LBL. *Selanginella apoda*, being remarkably inconspicuous, almost certainly is more widely distributed than collections indicates.

Several genera presented taxonomic problems and our list of LBL pteridophytes will probably be altered as results of biosystematic and other studies underway elsewhere (see Evans 1989) become available. Most notable problems are (1) the variability expressed by *Athyrium asplenioides*, (2) the *Botrychium biternatum-dissectum* complex, (3) the varieties of *Pteridium aquilinum*, and (4) the designation of LBL *Azolla* as *A. caroliniana* vs. *A. mexicana*. Also, somewhat anomalous specimens of *Ophioglossum pycnostichum* with longer, almost acuminate fronds were sometimes found; morphological-genetical variation in this genus has been documented by Cranfill (1980).

ANNOTATED CHECKLIST

The fern allies and true ferns are separated as major categories in the following list. Under each category the families, genera, and species are listed alphabetically. Taxa new to LBL are indicated by an asterisk (*). Synonomy, where appropriate, is given. The annotation for each species includes the following: distribution in Kentucky and Tennessee (taken from Cranfill [1980], Shaver [1954], and Wofford and Evans [1975]), general distribution (LBL county distributions are given in Appendix), habitat(s) in which the taxon is(are) most often encountered in LBL, and previous LBL reports or other appropriate material.

1. Fern Allies

Equisetaceae, Horsetail Family

***Equisetum arvense* L.**, Field Horsetail. Generally distributed in northern portions of TN and in the Knobs and Cumberland Plateau of KY; less frequent in the Jackson Purchase of both states. Rare in LBL, although usually abundant when found; most often on sandy streambanks and in adjacent meadows, rarely on lakeshores.

***_Equisetum hyemale_ L.**, Scouring-Rush. Scattered throughout KY and TN; rare along sandy streambanks in southern LBL.

Lycopodiaceae, Club-Moss Family

***_Lycopodium digitatum_ A. Braun** [*L. flabelliforme* (Fern.) Blanch.] Ground Cedar, Running-Pine. Scattered in the West Tennessee uplands and on the Western Highland Rim, but more general eastward in TN; concentrated in the Bluegrass and Cumberland Plateau of KY, but found in all provinces. Infrequent in LBL, but populations are sometimes extensive and usually associated with disturbed, mixed forests in acidic soils.

Selaginellaceae, Spike-Moss Family

***_Selaginella apoda_ (L.) Spring,** Meadow Spike-Moss. Scattered throughout KY but primarily east of the Tennessee River in TN; widely scattered along streambanks, on seepage bluffs, and in moist to soggy acidic meadows in LBL.

2. True Ferns

Adiantaceae, Maidenhair Family

***Adiantum pedatum* L.,** Common Maidenhair. Throughout KY and TN; in mesic woodlands throughout LBL, often in large stands in ravines and on lower slopes.

***Cheilanthes lanosa* (Michx.) Eaton,** Hairy Lip Fern. Along the Dripping Springs Escarpment in KY and east of the Tennessee River in TN; infrequent on dry limestone bluffs in LBL.

***Pellaea atropurpurea* (L). Link,** Purple Cliffbrake. Concentrated in the Mississippian Plateau and Bluegrass regions of KY and east of the Tennessee River in TN; infrequent on xeric limestone bluffs and outcrops in LBL.

Aspleniaceae, Spleenwort Family

***Asplenium platyneuron* (L.) Oakes,** Ebony Spleenwort. Throughout KY and TN; throughout LBL in woods, thickets, and old fields.

***Asplenium resiliens* Kunze,** Black-Stemmed Spleenwort. Primarily in middle and eastern portions of KY and TN; on moist limestone bluffs, thus habitat restricted in LBL.

***Asplenium rhizophyllum* L.** [*Camptosorus rhizophyllus* (L.) Link], Walking Fern. Primarily in middle and eastern portions of KY and TN; infrequent on mesic limestone bluffs and outcrops in LBL woodlands.

***Asplenium ruta-muraria* L.,** Wall-Rue Spleenwort. Scattered throughout Middle and East Tennessee; along the Pottsville Escarpment and within the Inner Bluegrass regions of KY. Rare in LBL (known from one Lyon County site) in crevices of shaded limestones bluffs.

***Athyrium asplenioides* (Michx.) Eaton** [*A. filix-femina* subsp. *asplenioides* (Michx.) Hulten], Southern Lady Fern. Throughout TN and KY; frequent in non-calcareous soils of moist to swampy woodlands throughout LBL.

***Athyrium pycnocarpon* (Sprengel) Tidest.,** Glade Fern. Widely scattered throughout eastern portions of KY and TN with fewer reports westward; rare in LBL and known only from one Stewart County site.

***Athyrium thelypterioides* (Michx.) Desv.**, Silvery Glade Fern. Concentrated in eastern portions of KY and TN with sporadic reports westward; rare in southern LBL streambank forests where it is known only from two Stewart County sites.

***Cystopteris bulbifera* (L.) Bernh.**, Bulblet Bladder Fern. Concentrated in the Bluegrass and Knobs regions of KY and east of the Tennessee River in TN; rare on moist limestone bluffs in southern LBL.

***Cystopteris protrusa* (Weatherby) Blasdell** [*C. fragilis* (L.) Bernh. var. *protrusa* Weath.], Southern Fragile Fern. Concentrated in middle and eastern portions of KY and TN, scattered in western portions; abundant throughout LBL in mesic to dry woodlands.

***Onoclea sensiblis* L.**, Sensitive Fern. Throughout KY and TN; frequent in many wet fields, woods, and thickets of LBL.

***Polystichum acrostichoides* (Michx.) Schott**, Christmas Fern. Throughout KY and TN; abundant in many LBL woods, especially in ravines and on mesic slopes and shaded gulley banks.

***Woodsia obtusa* (Sprengel) Torrey**, Common Woodsia. Throughout TN and west of the Cumberland Plateau in KY; common along shaded slopes and streambanks throughout LBL.

Azollaceae, Water-Fern Family

***Azolla caroliniana* Willd.**, Mosquito Fern. Most often in the KY and TN counties bordering the Mississippi River; known from a few LBL swamps and lowland pools.

Dennstaedtiaceae, Bracken Family

***Pteridium aquilinum* (L.) Kuhn** (including the vars. *latiusculum* [Desv.] Underw. ex Heller and *pseudocaudatum* [Clute] Heller), Bracken Fern. Scattered throughout, but primarily in the Knobs and Cumberland Plateau of KY; throughout TN. Along dry sunny roadsides, shaded knolls and uplands throughout LBL. Both varieties may occur in LBL (Cranfill 1980), but differences remain elusive to us.

Ophioglossaceae, Adder's-Tongue Family

***Botrychium biternatum* (Sav.) Underwood** (*B. tenuifolium* Underw., *B. dissectum* Spreng. var. *tenuifolium* [Underw.] Fern.), Southern Grape Fern. Scattered throughout TN; also throughout KY, but primarily in the Knobs and Breaks regions. Frequent in LBL, mostly in low woodlands.

***Botrychium dissectum* Sprengel forma *obliquum* Fernald** (*B. obliquum* Muhl. ex Willd., *B. dissectum* Spreng. var. *obliquum* [Muhl.] Clute), Common Grape Fern. Widely distributed over KY, but concentrated in the Bluegrass Region; scattered over TN. Frequent in LBL, often with the preceding species.

****Botrychium dissectum Sprengel* forma *dissectum***, Dissected Common Grape Fern. Distribution for KY and TN not given separately in references cited, but apparently quite rare in both states. Very rare in LBL and known only from a few alluvial woods southward; the forms occur together with various intermediates.

***Botrychium virginianum* (L.) Swartz**, Rattlesnake Fern. Throughout TN and KY; abundant throughout LBL in moist woods with deep humus, mostly in ravines and on slopes.

****Ophioglossum engelmannii* Prantl**, Limestone Adder's-Tongue. Mostly in the Central Basin and southern Cumberland Plateau of TN; concentrated along the Dripping Springs Escarpment in KY. Very rare, reported without voucher from one Trigg County site in LBL.

***Ophioglossum pycnostichum* (Fern.) Love & Love** [*O. vulgatum* L. var. *pycnostichum* Fern.], Southeastern Adder's-Tongue. Scattered in West and Central KY and throughout TN with the exception of the Eastern Highland Rim and Cumberland Plateau; infrequent in low woods and thickets throughout LBL.

Osmundaceae, Royal Fern Family

***Osmunda regalis* L.**, Royal Fern. Throughout both states, but concentrated along the Pottsville Escarpment in KY; rare in swampy woods of LBL.

Polypodiaceae, Polypody Family

***Polypodium polypodioides* (L.) Watt.**, Resurrection Fern. Throughout TN and most of KY except eastward; infrequent in LBL, mostly on trees, but sometimes on rocks.

Thelypteridaceae, Marsh-Fern Family

***Thelypteris hexagonoptera* (Michx.) Weatherby** [*Phegopteris hexagonoptera* (Michx.) Fee; *Dryopteris hexagonoptera* (Michx.) Christ.], Broad Beech Fern. Throughout KY, TN and LBL, where it is mostly in mesic to dry woods.

****Thelypteris palustris* (L.) Schott**, Marsh-Fern. Widely scattered throughout KY and TN; rare in wet meadows and low woods in LBL.

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APPENDIX. Distribution of Ferns and Fern Allies in LBL by Counties.

Families	Species[1]	Lyon[2]	Trigg[2]	Stewart[2]
	FERN ALLIES			
Equisetaceae				
	Equisetum arvense	-	x**	x
	*Equisetum hyemale**	-	-	x
Lycopodiaceae				
	*Lycopodium digitatum**	x	x	x
Selaginellaceae				
	*Selaginella apoda**	-	x	x
	FERNS			
Adiantaceae				
	Adiantum pedatum	x	x	x
	Cheilanthes lanosa	x**	x	x
	Pellaea atropurpurea	x**	-	x
Aspleniaceae				
	Asplenium platyneuron	x	x	x
	Asplenium resiliens	x	-	x
	Asplenium rhizophyllum	x	x**	x
	Asplenium ruta-muraria	x	-	-
	Athyrium asplenioides	x	x	x
	Athyrium pycnocarpon	-	-	x
	*Athyrium thelypterioides**	-	-	x
	Cystopteris bulbifera	-	-	x
	Cystopteris protrusa	x**	x	x
	Onoclea sensibilis	x	x	x
	Polystichum acrostichoides	x**	x	x
	Woodsia obtusa	x	x	x
Azollaceae				
	Azolla caroliniana	-	x	x
Dennstaedtiaceae				
	Pteridium aquilinum	x	x	x
Ophioglossaceae				
	Botrychium biternatum	x**	x**	x
	B. dissectum forma *dissectum**	-	-	x
	B. dissectum forma *obliquum*	x**	x**	x
	Botrychium virginianum	x	x	x
	*Ophioglossum engelmannii**	-	x	-
	Ophioglossum pycnostichum	x**	x**	x

Appendix continued.

Osmundaceae				
	Osmunda regalis	x	x	-
Polypodiaceae				
	Polypodium polypodioides	-	x	x
Thelypteridaceae				
	Thelypteris hexagonoptera	x	x	x
	*Thelypteris palustris**	-	x	x

1. * = first reported for LBL here.
2. ** = a county record for LBL for a previously reported species.

BEST MANAGEMENT PRACTICES USED WITH TIMBER HARVEST IN PICKETT STATE FOREST, TENNESSEE

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ABSTRACT. Best management practices (BMPs) developed for silviculture minimize impacts on the environment; however, little research has been conducted to determine the usefulness of BMPs in Tennessee. The Pickett State Forest study was designed to determine the effectiveness of conservation measures prescribed by the Tennessee Department of Conservation, Division of Forestry.

An intensive study of water quality and aquatic biota was conducted in order to evaluate potential environmental impacts following logging activities which incorporated BMPs. Water chemistry (nutrients, solids, total organic and inorganic carbon, and heavy metals), benthic macroinvertebrates (diversity, density, and taxa richness), and fish production were studied at sites above, adjacent to, and below logged areas. The study was initiated 15 months prior to logging and continued for 8 months after timber harvest.

All aspects of the study indicated that timber harvesting did not noticeably affected the water quality or biota of streams in Pickett State Forest. Variations in the parameters studied prior to logging continued to follow the same trends during and after logging. With the exception of seasonal changes in total phosphorus, suspended solids, and total organic carbon, chemical analysis suggests low concentrations of all water quality constituents studied. Fluctuations in benthic macroinvertebrate and fish populations were apparently due only to seasonal effects and other natural phenomena.

Although our study indicates that BMPs are effective in protecting water quality and associated biota, other practices utilized in silviculture such as removal of overhead riparian canopy, stream crossings, placement of logging roads near water courses, site burning, and replanting should be evaluated, especially in terms of chronic effects.

THE FAGACEAE AND JUGLANDACEAE OF LAND BETWEEN THE LAKES: A REVIEW

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ABSTRACT. Members of two vascular plant families, Fagaceae and Juglandaceae, dominate almost all forest communities of Land Between The Lakes, Kentucky and Tennessee. This report lists the LBL taxa of these families, including 19 native and one exotic species of *Quercus* (oaks), nine of *Carya* (hickories), two of *Juglans* (walnuts), one of *Castanea* (American chestnut), and one of *Fagus* (American beech). Their LBL distributions and habitat preferenda are discussed and taxonomic complexities noted. Floristic-geographic affinities also were determined and the results show that the 33 taxa include one introduction, 13 intraneous, and 19 extraneous elements. The high percentage of extraneous taxa is not unexpected since LBL is within a vegetational ecotone (Western Mesophytic Forest Region) and is at the interface of two major physiographic regions (Interior Low Plateaus and Coastal Plain).

INTRODUCTION

Land Between The Lakes (LBL) is a 68,800-ha National Recreation Area in northwestern Middle Tennessee (Stewart County) and southwestern Central Kentucky (Lyon and Trigg counties). In public ownership and managed by the Tennessee Valley Authority since 1964, the area is essentially a peninsula. The western boundary is Kentucky Lake (the impounded lower Tennessee River), the eastern boundary is Barkley Lake (the impounded lower Cumberland River), and a man-made canal connecting the two reservoirs forms the boundary to the north. The southern boundary essentially follows U.S. Highway 79. About 13-19 km wide and 65 km long with more than 500 km of shoreline, the area is 80% forested and managed for various demonstration and public use activities.

The recorded history of LBL has been summarized by Smith (1971), Henry (1976), and Wallace (1988). Prior to 1964, the area was mostly agricultural with small communities and a low population (about 5000 people). A significant mining industry (iron) flourished during the 1800s and lumbering has been important since settlement. TVA management has been toward conservation, education, and recreation, including development of environmental education centers, a demonstration farm, an 1850s working farmstead, ORV areas, campgrounds, and various other components. Hiking, hunting, fishing, and camping are major activities. Timber is harvested on a planned basis. Many old fields are maintained by clipping or are in wildlife plantings while some bottomlands are leased to area farmers. Such remnants of habitation as farm ponds, fences, cemeteries, orchards, ore pits, and exotic species abound.

Harris (1988) admirably described the physical features of the area, noting that the peninsula is located at the northwestern corner of the Highland Rim Section of the Interior Low Plateaus Physiographic Province with elevations ranging from about 110-210 m. Strongly dissected by many tributaries of the two large rivers, the topography is generally that of long narrow ridges, deep ravines, and steep slopes. Few interior streams are permanent. The present upland soils, derived from Mississippian cherty limestones and Cretaceous gravels and loess, tend to be droughty. Many bottomlands were inundated as a result of the high dams (Kentucky Dam in 1944 and Barkley Dam in 1966).

The area vegetation is that of Braun's (1950) Western Mesophytic Forest Region, a transitional type from the more xeric Oak-Hickory Region to the west and the more mesic Mixed Mesophytic Region to the east. No single climax type occurs; instead, a mosaic of types is primarily determined by local climatic and edaphic factors and topography. In LBL, dissection has led to several habitat types ranging from low swamps to high ridges and slopes of various aspects. In addition, proximity to the Coastal Plain Province and its flora to the west, the Middle Tennessee limestone flora to the east, prairie remnants northward including the Big Barrens of Kentucky, and various other elements which have migrated in via the two major drainages (such as a small but significant Appalachian element), partially accounts for the diversity of species and communities. However, most of the vegetation has been disturbed since settlement (late 1700s) by iron-ore mining, the Civil War, lumbering, farming, and various other anthropogenic activities.

The composition and structure of LBL forest communities are under investigation by Fralish and associates (e.g., Fralish and Crooks 1988, 1989). These studies, and our own later cited, show that almost all forest communities are oak dominated with a strong hickory component.

This paper presents the results of our research that proposed to (1) review the LBL taxa of Fagaceae (beech family) and Juglandaceae (walnut family), noting taxonomic complexities, (2) determine the LBL distribution and habitat preferenda of the taxa, and (3) determine floristic-geographic affinities of the taxa to acertain if these major and representative components of the LBL flora indicate the transitional (physiographic and vegetational) nature of the area. Morphological descriptions and illustrations of the taxa may be found in Chester *et al.* (1987).

METHODS

The taxa lists and associated materials are a compilation of data and insights resulting from our studies of the area flora since the early 1960s (EWC) and the early 1970s (JS and RJJ). In addition, one of us (RJJ) has studied extensively the red and black oaks of the entire eastern United States. While data from other papers are used and cited, the following studies specifically involving LBL and one or more of us provided the majority of the data: Carpenter and Chester (1987, 1988), Chester *et al.* (1976, 1987), Ellis *et al.* (1971), Jensen (1972, 1979, 1988a, 1988b, 1989), Jensen *et al.* (1973), Scott *et al.* (1980), Schibig (1972), and Schibig and Chester (1988). The results of extensive sampling of forest communities of LBL and the surrounding area (Jensen 1972, Schibig 1972, summarized in Appendix 1) were especially useful in determining habitat/community preferenda and associates.

To determine floristic-geographic affinities, distribution maps of Little (1971, 1977) and an adaptation of Cain's methods for determining intraneous and extraneous elements (Cain 1930, 1944) were used.

RESULTS AND DISCUSSION

Taxa List

The LBL Fagaceae and Juglandaceae consist of five genera, 33 species, and four subspecific taxa and are here enumerated (see Chester *et al.* [1987] for keys to taxa). Several hybrid complexes in the genus *Quercus* also are noted.

Fagaceae (Beech Family)

In most Northwest Highland Rim forests, one or more members of the beech family either dominate or contribute significantly. While American beech is mostly limited to some ravines, bottomlands, and mesic slopes, one to several species of oaks are found in almost all forest types, including those of lowland swamps, bottomlands, streambanks, upland flats and swamps, slopes of various aspects, bluffs, and xeric ridges.

***Castanea dentata* (Marsh.) Borkh.** The American chestnut once may have been a dominant member of forest communities on many dry and well-drained sites. We have no quantitative data on its former role or status, but some residents of the early 1900s describe forests with plentiful chestnut trees. Only a few sprouts remain today as a result of the chestnut blight that decimated this species in the first half of the twentieth century.

***Fagus grandifolia* Ehrh.** American beech is found almost exclusively on moist slopes and in ravines and bottomlands where it may dominate (Appendix 1). Fralish and Crooks (1988) reported American beech as an important component in *Acer saccharum* communities in the Kentucky portion of LBL. In the Tennessee portion of LBL, a *Fagus grandifolia-Acer saccharum* community is associated with Baxter-Bodine soils (Fralish and Crooks 1989). According to Jensen (1972) and Schibig (1972), species commonly associated with American beech are *Acer saccharum, Carya glabra, C. ovata, Cornus florida, Juglans nigra, Liriodendron tulipifera, Nyssa sylvatica, Quercus alba, Q. rubra*, and *Ulmus rubra.*

***Quercus acutissima* Carruthers.** Sawtooth oak is an introduced species native to eastern Asia. In LBL, it is known only from a few localities, including a grove planted in Barnes Hollow south of Silver Trail, and at scattered sites along the Trace, especially in Trigg County.

***Quercus alba* L.** White oak occurs in a variety of habitats throughout LBL (Appendix 1). It is infrequent on poorly-drained soils but grows on almost all well-drained sites. Fralish and Crooks (1988) observed that white oak occupies the majority of the most productive sites in the Kentucky portion of LBL and later (Fralish and Crooks 1989) reported communities dominated by white oak as the "most common and prominent in the landscape" of the Tennessee portion of LBL. The latter communities are associated with both Brandon/Lax and Baxter/Bodine soils. Major associates of white oak reported by Fralish and Crooks (1988, 1989) are essentially the same as those reported by Jensen (1972) and Schibig (1972) and include *Acer saccharum, Carya glabra, C. ovalis, C. ovata, C. tomentosa, Cornus florida, Fagus grandifolia, Liriodendron tulipifera, Nyssa sylvatica, Quercus falcata, Q. prinus, Q. stellata,* and *Q. velutina.*

Quercus bicolor **Willd.** Swamp white oak is a very rare in LBL and known by us from only a few sites. All known occurrences are in low woods near the reservoirs. Dominants in these woods include *Acer rubrum, A. saccharum, Carya ovata, Liquidambar styraciflua, Nyssa sylvatica, Quercus pagoda,* and *Ulmus rubra* (Chester and Schibig, in prep.). While Jensen (1972) and Schibig (1972) did not encounter this oak in their sampling, Fralish and Crooks (1988) did and reported it as a very minor component of communities dominated by *Quercus alba.*

Quercus coccinea **Muenchh.** Scarlet oak is most common on xeric slopes and ridges and rarely found on mesic sites such as north-facing slopes and in ravines (Appendix 1). It is fairly common along Mulberry Flat Road and along the ridge roads above Ginger Bay. Jensen (1972) and Schibig (1972) listed *Carya glabra, C. tomentosa, Nyssa sylvatica, Oxydendrum arboreum, Quercus alba, Q. marilandica, Q. prinus, Q. stellata,* and *Q. velutina* as common associates of scarlet oak. Fralish and Crooks (1988, 1989) found scarlet oak to achieve greatest importance in communities dominated by *Quercus stellata.*

Scarlet oak is morphologically variable in LBL and some of this variability may be the result of hybridization with *Quercus velutina* (Jensen 1988a, 1988b). In addition to the typical form, trees having acorns with broad, distinctly warty cups, classified as *Q. coccinea* var. *tuberculata* Sarg., occasionally are encountered.

Quercus falcata **Michx.** Although southern red oak may be found in moderately moist habitats and occasionally on poorly-drained upland sites, it is most common on dry slopes and ridges (Appendix 1), e.g., along Mulberry Flat Road and Blue Springs Road. Fralish and Crooks (1988) found southern red oak to be an important component of communities dominated by *Quercus stellata* and later (Fralish and Crooks 1989) reported it as a minor component of a variety of community types, all associated with Brandon/Lax or Baxter/Bodine soils. According to Jensen (1972) and Schibig (1972), primary associates of southern red oak are *Carya glabra, C. ovalis, C. tomentosa, Quercus alba, Q. stellata,* and *Q. velutina.*

Several forms and varieties of *Q. falcata* have been recognized, the most common of which is cherrybark oak, here treated as a species, *Q. pagoda. Quercus falcata* var. *triloba* (Michx.) Nutt. has three-lobed leaves that may resemble those of blackjack oak. However, because leaves having this form may also be found on trees bearing typical leaves, its taxonomic status is questionable (Jensen 1989).

Quercus imbricaria **Michx.** Shingle oak generally grows on moderately mesic sites, such as moist slopes, but also may be found on open hillsides and along streambanks, fencerows, and roadsides (Appendix 1). It is fairly common at Cravens Bay Lake Access and at Wrangler's Camp. Common associates of shingle oak are *Acer rubrum, Carya cordiformis, C. ovata, Liriodendron tulipifera, Nyssa sylvatica, Prunus serotina, Quercus rubra,* and *Ulmus rubra* (Jensen 1972, Schibig 1972). Putative hybrids having shingle oak as one parent have been found in several localities. Trees apparently representing hybridization between *Quercus imbricaria* and *Q. rubra (Q.* X *runcinata* [A. DC.] Engelm.) are known from Wrangler's Camp while a tree appearing to be a hybrid between *Quercus imbricaria* and *Q. falcata* (*Q.* X *anceps* Palmer) has been found at Cravens Bay Lake Access.

Quercus lyrata **Walt.** Overcup oak is not common in LBL. It is occasionally found along streambanks, along the reservoir margins, or in marshy or wet bottoms, such as around Duncan Bay. Jensen (1972) and Schibig (1972) encountered this species only on Upland Flats (Appendix 1), a habitat type not found in LBL, and reported its major associates as *Acer negundo, A. rubrum, A. saccharinum, Nyssa sylvatica, Platanus occidentalis, Populus deltoides, Quercus palustris, Q. phellos,* and *Salix nigra.*

Quercus macrocarpa **Michx.** Bur oak is very rare and known by us only from southern LBL. We have found it a few times on streambanks and in poorly-drained bottomlands near Lake Barkley. Although it was reported as a minor component of streambank communities by Jensen (1972) and Schibig (1972) (Appendix 1), it was not found in communities sampled in LBL. Fralish and Crooks (1988, 1989) also failed to encounter bur oak in their sampling. Despite the lack of sampling data, our observations indicate that bur oak has the same associates as overcup oak.

Quercus marilandica **Muenchh.** Blackjack oak is found almost exclusively on very dry ridges and adjacent dry slopes (Appendix 1), although it occurs occasionally as secondary growth on open hillsides. While Fralish and Crooks (1988) found blackjack oak to dominate on several dry sites and as a major component in *Quercus stellata* communities of northern LBL, their later study (Fralish and Crooks 1989) reported it as a minor component of this same community type in southern LBL. Jensen (1972) and Schibig (1972) reported major associates of blackjack oak to be *Carya glabra, C. tomentosa, Oxydendrum arboreum, Quercus alba, Q. coccinea, Q. prinus, Q. stellata,* and *Q. velutina.* Jensen (1988a) found evidence of hybridization between *Quercus marilandica* and *Q. velutina* (Q. X *bushii* Sarg.) on dry slope communities immediately above Ginger Bay.

Quercus michauxii **Nutt.** Generally rare but sometimes locally abundant in LBL, swamp chestnut oak is found occasionally in mesic habitats such as lower slopes, streambanks, and swampy areas (Appendix 1), e.g., around Hematite Lake, along the creek between Hematite Lake Dam and Honker Lake, and in bottomland hardwoods near lower Bear Creek (Carpenter and Chester 1988). Jensen (1972), Schibig (1972), and Carpenter and Chester (1988) reported common associates to be *Acer negundo, A. saccharinum, Betula nigra, Carya cordiformis, C. laciniosa, Platanus occidentalis, Populus deltoides, Salix nigra,* and *Ulmus rubra.*

***Quercus muehlenbergii* Engelm.** Chinkapin oak is not common in LBL, but it is sometimes encountered on moderately moist slopes and in ravines with limestone outcrops or bluffs, e.g., along the north side of Hematite Lake. As noted in Appendix 1, this oak is a minor component of slope and ravine communities and, in the Northwest Highland Rim, achieves its greatest importance in Limestone Bluff communities where it is commonly associated with *Acer saccharum, Carya ovata, Fraxinus americana, Juniperus virginiana, Ostrya virginiana*, and *Ulmus alata* (Jensen 1972, Schibig 1972). Fralish and Crooks (1988, 1989) reported chinkapin oak as a minor component of *Acer saccharum* and *Fagus grandifolia* communities.

A shrubby form of *Q. muehlenbergii*, differentiated by smaller leaves with only 3 to 7 pairs of teeth, is often treated as a separate species, *Q. prinoides* Willd. (dwarf chinkapin oak). The latter has not been encountered in LBL, although it might be expected based on its reported range.

***Quercus nigra* L.** Water oak was known from a single LBL site along the Tennessee River at Hughes Bay where one small tree, now apparently dead, was last observed in 1971. This oak is known from several localities just to the west and north of LBL and reasonably might be expected to occur elsewhere in LBL, especially along Kentucky Lake.

***Quercus pagoda* Raf.** A common species in LBL, cherrybark oak typically is found in moderately mesic habitats, from moist slopes to poorly-drained bottomlands (Appendix 1; Carpenter and Chester 1988). Excellent specimens occur at Neville Bay Lake Access, Cravens Bay Lake Access, and the Youth Station. Fralish and Crooks (1988) reported cherrybark oak as a minor component of their *Acer saccharum* community but did not encounter it in their later study (Fralish and Crooks 1989). Jensen (1972) and Schibig (1972) listed *Celtis occidentalis, Fagus grandifolia, Liquidambar styraciflua, Nyssa sylvatica, Prunus serotina,* and *Ulmus rubra* as common associates.

Cherrybark oak often has been treated as a variety of *Quercus falcata*. However, morphological and ecological distinctions between the two are considered sufficient to warrant recognition as a species (Jensen 1988b, 1989).

***Quercus palustris* Muenchh.** Not a common tree in LBL, pin oak is most often found on moist lowlands or on poorly-drained uplands (Appendix 1). Good specimens occur at Silo Overlook and at Brandon Spring Group Camp. Yard plantings also persist, as along the south side of Highway 68 east of the Field Archery Range. Our sampling (Jensen 1972, Schibig 1972) showed the same distribution and associates as reported for *Quercus lyrata.*

***Quercus phellos* L.** Willow oak occurs occasionally along streambanks or on poorly-drained uplands (Appendix 1). Several large trees are known from the area where Road 232 approaches Kentucky Reservoir near the former site of Ft. Henry. Jensen (1972) and Schibig (1972) reported the chief associates of willow oak as *Acer rubrum, Liquidambar styraciflua, Nyssa sylvatica, Quercus lyrata, Q. palustris, Q. velutina,* and *Ulmus rubra.*

***Quercus prinus* L.** Chestnut oak often dominates forests on the very driest ridges and slopes (Appendix 1; Carpenter and Chester 1988). Primary associates reported by Jensen (1972) and Schibig (1972) are *Carya glabra, C. tomentosa, Nyssa sylvatica, Oxydendrum arboreum, Quercus alba, Q. coccinea, Q. stellata, Q. marilandica,* and *Q. velutina.* Fralish and Crooks (1988, 1989) listed similar associates and described compositionally unstable chestnut oak sites in which *Acer saccharum* was a co-dominant.

***Quercus rubra* L.** Northern red oak is found in a wide range of habitats (Appendix 1) but is relatively uncommon in LBL. While it may be found on river bluffs or occasionally on dry slopes and ridges, it is more often found on moist slopes and in ravines, such as along Road 131 in Racetrack Hollow and along Tharpe Road in Jackson Hollow. Jensen (1972) and Schibig (1972) found it to be most important in North-Facing Slope and Limestone Bluff communities. Fralish and Crooks (1988) reported it as a dominant in at least one of their *Acer saccharum* communities in northern LBL. However, it was not found in *Acer saccharum* communities in southern LBL (Fralish and Crooks 1989); instead, it was a minor component of communities on Baxter/Bodine soils dominated by *Quercus alba, Q. velutina,* or *Fagus grandifolia.* Carpenter and Chester (1988) listed northern red oak as one of the dominants on mesic slopes and in ravines of the Bear Creek Natural Area. Associates of northern red oak reported by Jensen (1972) and Schibig (1972) include *Acer saccharum, Carya ovalis, C. ovata, Fagus grandifolia, Fraxinus americana, Liriodendron tulipifera, Nyssa sylvatica, Quercus alba, Q. muehlenbergii,* and *Q. velutina.*

Variability in fruit characteristics has led to recognition of two varieties by some. If the nuts are small and have a cup covering 1/3 of the nut, the tree may be assigned to *Q. rubra* var. *borealis* (Michx. f.) Farw. Trees with large nuts covered only about 1/4 by the cup may be classified as *Q. rubra* var. *rubra.* It is our experience that both varieties occur in LBL, but no attempt has been made to treat them separately.

***Quercus shumardii* Buckl.** Shumard oak grows most often near streambanks or on mesic slopes and in bottoms (Appendix 1; Carpenter and Chester 1988). Several large trees grow along the trail around Hematite Lake. Jensen (1972) and Schibig (1972) reported the chief associates of Shumard oak to be *Acer negundo, A. saccharinum, Carya cordiformis, C. laciniosa, Celtis laevigata, C. occidentalis, Platanus occidentalis, Populus deltoides, Salix nigra,* and *Ulmus rubra.* Fralish and Crooks (1988) reported Shumard oak to be a minor component of communities dominated by *Acer saccharum.*

Several varieties of this oak have been recognized. Both the typical var. *shumardii,* characterized by acorn cups that are rather flat when viewed from the side and covering about 1/4 of the nut, and the smaller fruited var. *schneckii* (Britt.) Sarg., in which the cup is more rounded and covers about 1/3 of the nut, occur in LBL.

***Quercus stellata* Wang.** Post oak is found almost exclusively on very dry ridges and slopes where it is often a dominant species (Appendix 1). It is common along Mulberry Flat and Jenny Ridge roads and on the dry ridges above Ginger Bay. Fralish and Crooks (1988, 1989) reported post oak communities to be more common in the Kentucky portion of LBL. These communities have *Carya glabra, Quercus alba, Q. coccinea, Q. falcata,* and *Q.*

marilandica as primary associates. Post oak communities in the Tennessee portion of LBL are found on Brandon/Lax soils with *Quercus alba, Q. coccinea,* and *Q. prinus* as chief associates. Jensen (1972) and Schibig (1972) also included *Carya tomentosa* and *Oxydendrum arboreum* as common associates of post oak.

***Quercus velutina* Lam.** Black oak is most often encountered on mesic to dry slopes and ridges and occasionally is an important component on poorly-drained upland sites (Appendix 1). While it is not as common as *Quercus alba,* the two are often found together. Fralish and Crooks (1989) reported *Quercus alba* as the second most important species in black oak communities associated with Baxter/Bodine soils. In addition, black oak is commonly associated with *Carya glabra, C. tomentosa, Quercus coccinea, Q. falcata, Q. marilandica,* and *Oxydendrum arboreum.*

Juglandaceae (Walnut Family)

Collectively, the Juglandaceae of the LBL area are most important in dry slope, ravine, moist slope, and xeric ridge forests (Appendix 1). Specifically, the walnuts (*Juglans nigra* and *J. cinerea*) are most important in ravine and streambank forests; the hickories (*Carya* spp.) are distributed as stated for the family.

***Carya carolinae-septentrionalis* (Ashe) Engl. and Graebn.** Southern shagbark hickory is not always considered distinct from shagbark hickory and sometimes is referred to as *C. ovata* var. *australis* (Ashe) Little (Little 1969, 1979; Duncan and Duncan 1988). We are following Radford *et al.* (1964) and recognizing *C. carolinae-septentrionalis* as a species. It is rare throughout the Northwest Highland Rim and thus we are unable to confidently state its habitat affinities in the area; it did not appear in our sampling (Jensen 1972, Schibig 1972, summarized in Appendix 1). However, Hardin (1952) noted that it grows on various sites including limestone hills, river bottoms, and in other low woodlands. Mature specimens grow along the southern banks of the bay at the former Pleasure Island Resort, Kentucky Reservoir, Stewart County.

***Carya cordiformis* K. Koch.** Bitternut hickory is frequently encountered on the more mesic sites of the area. It reaches greatest importance on streambanks, in ravines, and on moist slopes, but is virtually absent from dry slopes and ridges (Appendix 1). Data from Jensen (1972) and Schibig (1972) show the primary associates to be *Acer negundo, A. saccharinum, Fagus grandifolia, Liriodendron tulipifera,* and *Ulmus rubra*. Fralish and Crooks (1989) suggest the association of *Carya cordiformis* with Baxter/Bodine soils and communities dominated by *Fagus grandifolia* and *Quercus alba*. Also, we have found bitternut to be important in a remnant bottomland forest of the Cross Creeks National Wildlife Refuge, Stewart County. This community was on a Cumberland River floodplain with soils of the Arrington-Lindside-Beason association (Chester and Schibig, in prep.)

***Carya glabra* (Mill.) Sweet.** Pignut hickory is frequently found on the most xeric sites of the area, such as ridges and slopes, but it is infrequently encountered otherwise (Appendix 1). According to Jensen (1972) and Schibig (1972), major associates are *Acer saccharum, Carya tomentosa, Quercus alba, Q. prinus, Q. stellata,* and *Q. velutina*. Schibig and Chester (1988) found *Carya glabra* to be the most important hickory species in the shortleaf pine-mixed hardwoods community of LBL. Prominent associates there are *Oxydendrum arboreum, Quercus alba, Q. coccinea, Q. prinus, Q. stellata,* and *Q. velutina*. Fralish and Crooks (1989) found *Carya glabra* on several soil types and in several communities, but their data show it to be most strongly associated with Baxter/Bodine soils and the *Quercus velutina* community on ridgetops and south slopes.

***Carya illinoensis* (Wang.) K. Koch.** Pecan is rare in the LBL area and we know of only a few native individuals. A tree in the Bear Creek Waterfowl Management Area (southern LBL) has a diameter of nearly five feet and is one of the largest LBL trees of any species. A few planted trees remain on former homesites. Although no sampling data is available for *Carya illinoensis* in LBL, our observations are that native specimens are restricted to lakeshores or bottomlands of both reservoirs, where the major associates include *Acer rubrum, Betula nigra, Fraxinus pennsylvanica, Liquidambar styraciflua, Platanus occidentalis,* and *Ulmus* spp.

***Carya laciniosa* (Michx. f.) Loud.** Shellbark hickory is infrequent in LBL and the surrounding area. It typically grows in ravine, streambank, and bottomland forests, but because of rarity, importance values are comparatively low (Appendix 1). Large, old trees are sometimes found, as in the floodplain of Bear Creek near the South Information Station and on Cumberland River alluvium within the nearby Cross Creeks Wildlife Refuge. Associates of *Carya laciniosa* are *Acer negundo, A. saccharinum, Fagus grandifolia, Liriodendron tulipifera, Platanus occidentalis,* and *Ulmus rubra* (Jensen 1972, Schibig 1972). In LBL, *Carya laciniosa* is most often found on stream-terrace (Greenville and Lobelville) and in bottomland and terrace soils (Arrington-Lindside-Beason).

***Carya ovalis* (Wang.) Sarg.** The taxonomic status of red hickory is uncertain. Gleason (1952) and Gleason and Cronquist (1963) maintained the species but noted its variability and suspected it to be a hybrid between *Carya ovata* and *C. glabra*. Fernald (1950) also recognized it as a variable species with several varieties. Manning (1950) argued that *C. ovalis* and *C. glabra* are separate species because pure forms of each are very different morphologically. He also noted that they were probably recently evolved and that hybrids are common. Little (1969) named the taxon *C. glabra* var. *odorata* (Marsh.) Little (also see Little 1979), while Radford *et al.* (1964) retained *C. ovalis* as a species. More recently Duncan and Duncan (1988) rejected recognition at any level, and Wofford (1989) maintained the var. *odorata.* Most *C. ovalis* specimens observed by us are readily distinguished from *C. glabra* when fruits and bark are available. In addition to the typical variety (*C. ovalis* var. *ovalis*), we have recorded the var. *obcordata* (Muhl.) Sarg. from LBL, but it is much more scarce than var. *ovalis.*

From the data (Appendix 1) and our general observations, *Carya ovalis* is an important species in well-drained ravine and slope forests. Jensen (1972) and Schibig (1972) recorded *Acer saccharum, Fagus grandifolia, Liriodendron tulipifera, Quercus alba, Q. stellata,* and *Q. velutina* as important associates. Fralish and Crooks (1989) link *Carya ovalis* mostly with Baxter/Bodine and Greenville/Lobelville soils. In their study, its greatest importance was in the *Acer saccharum* community.

***Carya ovata* (Mill.) K. Koch.** Shagbark hickory is a variable species and the variation may be great enough to include specimens we have assigned to *Carya carolinae-septentrionalis* (see discussion under that species). Yet we believe that the species are distinct and note the morphological differences elsewhere (see Chester *et al.* 1987).

In LBL and the surrounding area, *C. ovata* is an abundant species in many habitats (Appendix 1). It is most important on mesic slopes and in ravines and was the only hickory sampled in limestone bluff forests where it was the seventh most important species. *Carya ovata* has many associates because it occurs in diverse habitats (Appendix 1), but in limestone bluff forests the chief associates are *Fraxinus americana, Juniperus virginiana, Quercus muehlenbergii, Q. rubra,* and *Ulmus alata* (Jensen 1972, Schibig 1972). Fralish and Crooks (1989) link *Carya ovata* to Baxter/Bodine soils and to the *Fagus grandifolia* community. We (Chester and Schibig in prep.) found it to be a major component of area bottomland forests on Arrington-Lindside-Beason soils.

***Carya pallida* (Ashe) Engl. and Graebn.** Sand hickory is rare in the LBL area and we have little sampling data for it. It was found in the shortleaf pine-mixed hardwoods community (Schibig and Chester 1988) but was of minor importance. It is restricted to the driest ridges and slopes and seems to be more abundant northward in LBL. *Carya pallida* is often associated with *Oxydendrum arboreum, Pinus echinata, Quercus coccinea, Q. marilandica,* and *Q. prinus,* and appears to do well on the droughty, nutrient-poor Brandon and Lax soils of higher elevations (Fralish and Crooks 1989).

***Carya tomentosa* Nutt.** Mockernut hickory is an important component of most dry ridge and slope forests (Appendix 1), but is an insignificant component of the shortleaf pine-mixed hardwoods forest on the xeric ridges and slopes of Devil's Backbone, Stewart County (Schibig and Chester 1988). Chief associates include *Carya glabra, Quercus alba, Q. prinus, Q. stellata,* and *Q. velutina* (Jensen 1972, Schibig 1972). Fralish and Crooks (1989) place *Carya tomentosa* with several community-soil types; its greatest importance was in the *Quercus prinus* community (Baxter/Bodine soils), the *Q. alba* community (Brandon/Lax soils), and the *Acer saccharum* community (Greenville/Lobelville soils).

***Juglans cinerea* L.** White walnut is rare in the area, but was sampled in ravine and streambank forests where it is of minor importance (Appendix 1). Also, it has been observed (not sampled) in moist slope forests. Its rareness may be due to short longevity (rarely exceeding 75 years) and low nut production. *Juglans cinerea* is usually found with *Acer negundo, Fagus grandifolia, Juglans nigra, Liriodendron tulipifera, Platanus occidentalis,* and *Ulmus rubra* (Jensen 1972, Schibig 1972) and occurs most often on streambank soils (Greenville and Lobelville).

***Juglans nigra* L.** Black walnut is found mostly in the same habitats and with the same associates as *J. cinerea,* but is typically more abundant (note the significantly higher importance values for *J. nigra* in ravine and streambank forests, Appendix 1). Mature specimens (planted) are found around many of the old LBL homesites. Fralish and Crooks (1989) found *J. nigra* on Greenville and Lobelville soils associated with the *Acer saccharum* community.

Floristic-Geographic Relationships

The system of Cain (1930, 1944) has been used widely (e.g., Jones 1983) to show floristic-geographic affinities of floras or parts of floras. As noted by Cain (1944):

> Species in a certain territory can be classified as **intraneous** or **extraneous** according as their occurrence in that territory is well within the area of the form or near the periphery of its area, respectively. . . . . It is an easy and suggestive procedure in the preliminary study of the floristics of a territory to divide the plants into intraneous and extraneous groups, and further to subdivide them on the basis of extent and direction of area.

The distribution of each species was examined (Little 1971, 1977) and intraneous and extraneous elements categorized according to the following definitions:

Introduced: A non-native element.

Intraneous: LBL is within the distribution of the species by at least 100 miles.

Extraneous: LBL is near the periphery of the distribution; the distance from LBL to the limit of the species range is no greater than 100 miles.

Extraneous elements were further classified as eastern, northern, or southern, depending upon the direction from LBL that the major segment of the range extends. The classification for each species is given in Table 1 and discussed below. A statistical summary is given below in Table 2.

Introduced Element

The introduced element is an insignificant part of the Fagaceae and Juglandaceae of LBL. Sawtooth oak (*Quercus acutissima)* has been planted in a few sites for wildlife food, but expansion and naturalization has not been observed even though acorns are produced.

Intraneous Elements

Thirty-nine percent of the subject taxa are intraneous. Of these, a greater percentage of hickories (56%) than oaks (35%) is intraneous. Intraneous taxa include *Carya cordiformis, C. glabra, C. ovalis, C. ovata, C. tomentosa, Juglans nigra, Quercus alba, Q. marilandica, Q. muehlenbergii, Q. rubra, Q. shumardii, Q. stellata,* and *Q. velutina.* Most intraneous elements are generally distributed over eastern United States. However, *Quercus marilandica, Q. shumardii,* and *Q. stellata* are more southerly-ranging species.

Table 1. LBL Taxa of Fagaceae and Juglandaceae and Their Floristic- Geographic Affinities.

			Extraneous		
Taxa	Introduced	Intraneous	Eastern	Northern	Southern
FAGACEAE					
Castanea dentata			x		
Fagus grandifolia			x		
Quercus acutissima	x				
Q. alba		x			
Q. bicolor				x	
Q. coccinea			x		
Q. falcata					x
Q. imbricaria				x	
Q. lyrata					x
Q. macrocarpa				x	
Q. marilandica		x			
Q. michauxii					x
Q. muehlenbergii		x			
Q. nigra					x
Q. pagoda					x
Q. palustris				x	
Q. phellos					x
Q. prinus			x		
Q. rubra		x			
Q. shumardii		x			
Q. stellata		x			
Q. velutina		x			
JUGLANDACEAE					
Carya carolinae-septentrionalis					x
C. cordiformis		x			
C. glabra		x			
C. illinoensis					x
C. laciniosa				x	
C. ovalis		x			
C. ovata		x			
C. pallida					x
C. tomentosa		x			
Juglans cinerea				x	
J. nigra		x			
Totals (33)	1	13	4	6	9
Percents	3.0	39.4	12.1	18.2	27.3

Extraneous Elements

Nearly 58% of the taxa are extraneous, including American beech, American chestnut, 12 of 20 oaks, 4 of 9 hickories, and 1 of 2 walnuts. Further classification of extraneous elements shows that the LBL representatives of the oak and walnut families represent considerable geographic diversity.

(1) **Eastern Extraneous Elements.** Four taxa (12.1 %), including *Castanea dentata, Fagus grandifolia, Quercus coccinea,* and *Q. prinus* have clearly defined eastern (of LBL) distributions.

(2) **Northern Extraneous Elements.** Six taxa (18.2%), including *Carya laciniosa, Juglans cinerea, Quercus bicolor, Q. imbricaria, Q. macrocarpa,* and *Q. palustris* have distributions lying predominantly to the north of LBL; one of these (*Q. macrocarpa*) is actually more northwestward.

(3) **Southern Extraneous Elements.** The influence of the adjacent Coastal Plain floras on those of LBL is shown by the large southern element (9 taxa, 27.3%), made up of *Carya carolinae-septentrionalis, C. illinoensis, C. pallida, Quercus falcata, Q. lyrata, Q. michauxii, Q. nigra, Q. pagoda,* and *Q. phellos*. Seven of these species range throughout the south while one (*C. carolinae-septentrionalis*) is primarily Atlantic Coastal Plain in distribution and another (*C. illinoensis*) is primarily Gulf Coastal Plain and Mississippi Valley in distribution.

Table 2. Statistical Summary of the LBL Fagaceae and Juglandaceae and Their Floristic-Geographical Affinities.

Family-Genus	Taxa	Exotics*	Intraneous*	Extraneous*
FAGACEAE				
Castanea	1	0	0	1(100)
Fagus	1	0	0	1(100)
Quercus	20	1(5.0)	7(35.0)	12(60.0)
Subtotal	22	1(4.5)	7(31.8)	14(63.6)
JUGLANDACEAE				
Carya	9	0	5(55.6)	4(44.4)
Juglans	2	0	1(50.0)	1(50.0)
Subtotal	11	0	6(54.5)	5(45.5)
Totals	33	1(3.0)	13(39.4)	19(57.6)

*Number of species with percents in parenthesis.

SUMMARY

Land Between The Lakes, due to strongly dissected topography and the adjacent riverine systems, exhibits a number of habitats ranging from dry ridges, slopes of various aspects, and deep ravines, to streambanks and bottomlands. The mostly-hardwood, long-disturbed forests are oak dominated (8 white oaks and 11 red and black oaks) with a strong hickory component (9 species); American beech is limited to some mesic slopes, bottomlands, and ravines, American chestnut persists as sprouts in some slope and ridge forests, white walnut is quite rare in streambank forests, and black walnut is scattered throughout in various habitats. Hybridization between several species of *Quercus* is evident in numerous situations. The 33 species of the Fagaceae and Juglandaceae include one introduction, 13 intraneous, and 19 extraneous elements. The southern (mostly Coastal Plain) extraneous element is most evident. The significant extraneous element (ca. 58%) clearly indicates the ecotonal-transitional nature of this segment of the LBL flora. Further analyses will be required to determine if this characteristic is true for the entire LBL vascular flora.

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APPENDIX 1. Importance Values (IV)* for the LBL taxa of Fagaceae and Juglandaceae** in seven habitats (topographic areas)***.

	Habitats and Importance Values						
Taxa	LB	XR	SF	NFS	R	UF	SB
FAGACEAE							
Fagus grandifolia			2.0	56.0	23.8	2.4	
Quercus alba	1.7	50.1	81.3	24.8	13.8	3.6	
Q. coccinea		19.3	1.6				
Q. falcata	1.3		10.5	3.2		1.8	
Q. imbricaria				1.3	1.3		1.4
Q. lyrata						1.8	
Q. macrocarpa							1.2
Q. marilandica		20.6	1.3				
Q. michauxii				1.5			1.5
Q. muehlenbergii	29.1		4.9	3.4	2.7		
Q. pagoda				9.3	2.1	1.2	
Q. palustris						3.2	
Q. phellos						7.8	
Q. prinus		77.3					
Q. rubra	13.6	1.8	3.8	12.1	6.3		2.3
Q. shumardii	3.2		1.5		5.2		4.8
Q. stellata		40.3	30.3	1.2			
Q. velutina		13.3	59.4	23.2		13.3	
Quercus spp. (all)	48.9	222.7	194.6	80.0	31.4	32.7	11.2
Subtotals (Family)	48.9	222.7	196.6	136.0	55.2	35.1	11.2
Percent of Total IV	16.3	74.2	65.5	45.3	18.4	11.7	3.7
JUGLANDACEAE							
Carya cordiformis				7.2	9.8		13.7
C. glabra		28.8	11.0	7.1		7.4	
C. laciniosa			1.3		8.5		2.4
C. ovalis			12.7	17.3	9.5		
C. ovata	9.0	1.9	7.6	3.0	6.5	2.5	
C. tomentosa		10.2	20.2	6.7	1.6		
Carya spp. (all)	9.0	40.9	52.8	41.3	35.9	9.9	16.1
Juglans cinerea					1.9		1.4
J. nigra			1.3	2.9	13.9		8.9
Juglans spp. (all)	0.0	0.0	1.3	2.9	15.8	0.0	10.3
Subtotals (Family)	9.0	40.9	54.1	44.2	51.7	9.9	26.4
Percent of Total IV	3.0	13.6	18.0	14.7	17.2	3.3	8.8

Appendix 1 continued.

Totals for Fagaceae and Juglandaceae	57.9	263.6	250.7	180.2	106.9	45.0	37.6
Percent of Total IV	19.3	87.9	83.6	60.1	35.6	15.0	12.5
Totals for Other Taxa	242.1	36.4	49.3	119.8	193.1	255.0	262.4
Percent of Total IV	80.7	12.1	16.4	39.9	64.4	85.0	87.5

* Importance Value (IV) = sum of relative density, relative frequency, and relative basal area; data from Jensen (1972) and Schibig (1972)

** Taxa not encountered in sampling and hence not included in Appendix 1 include: *Castanea dentata, Quercus acutissima, Q. bicolor, Q. nigra, Carya carolinae-septentrionalis, C. illinoensis,* and *C. pallida*

*** LB = Limestone Bluffs, XR = Xeric Ridges, SFS = South-facing Slopes, NFS = North-facing Slopes, R = Ravines, UF = Upland Flats, SB = Streambanks

LEAF CUTICULAR AND GROSS MORPHOLOGICAL MODIFICATIONS IN *Phytolacca americana* L. (PHYTOLACCACEAE) IN RELATION TO ENVIRONMENTAL POLLUTION

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ABSTRACT. Eleven populations of *Phytolacca americana* L. (pokeweed) were studied to determine the relationship between environmental pollution and variation in leaf morphology and leaf cuticular pattern. Statistical analysis of the data from plant populations of polluted habitats revealed a decrease in leaf length, leaf width, and number and size of berries. Furthermore, these populations had a decrease in stomatal frequency values and epidermal cell wall undulations. Subsidiary cell complex of "paracytic" type remained the same in all eleven plant populations.

INTRODUCTION

Various plant taxa have been studied to determine the effects of environmental pollution on particular plant organs. Chamberlain (1934), in his pioneer studies, found that gases of a large city were detrimental to coniferous flora, especially their needles. Scheffer and Hedgcock (1955) studied the effects of smelters pollutants, mainly sulfur dioxide on the forest trees of the Northwest. They found that sulfur dioxide brought about a characteristic mottling of leaves and that conifers were more affected than deciduous plants. Fluoride and sulfur dioxide were observed to destroy spongy mesophyll and lower epidermis first, followed by chloroplast distortion and palisade damage (Solberg and Adams 1956). The upper epidermis was affected last. Oxidant type pollution was found to have damaging effects on the floral productivity of geraniums and carnations (Feder 1970). In a steel producing town, Port Talbot in Wales, Pyatt (1970) noted that the lichen flora decreased in species richness with increasing proximity to the pollution source. Furthermore, the thallus size of the lichens decreased. Mathis and Tomlinson (1972) reported similar results while studying effects of air pollution on the lichen flora of Nashville, Tennessee.

Cuticular and morphological features have been of much use in taxonomic, ecological, and paleobotanical studies (Dunn *et al.* 1965, Au 1969, Gates and Vogelmann 1969). However, their usefulness in studying environmental pollution is relatively recent and needs further investigation. Preliminary studies (Sharma 1975, Sharma 1985, Sharma and Butler 1973, Sharma and Mann 1984) on a wide variety of plant taxa indicate the reliability of cuticular dynamics as indicators of environmental pollution.

To understand further the utilization of this relatively new technique of interpreting relationships between cuticular features and environmental pollution, pokeweed, *Phytolacca americana* L., was selected because of its common occurrence in the southern United States, where this investigation was conducted (Fig. 1). Pokeweed is an herbaceous dicotyledonous plant. It grows in a wide variety of habitats including waste ground, along roadsides and borders of cultivated areas. The root is known to have medicinal properties in the treatment of skin diseases. The berries are eaten by birds and the purple juice of the berries is used for coloring purposed (Steyermark 1981). It is known to possess mitogens, compounds that can be absorbed through skin abrasions, causing serious blood aberrations (Lewis and Elvin-Lewis 1976).

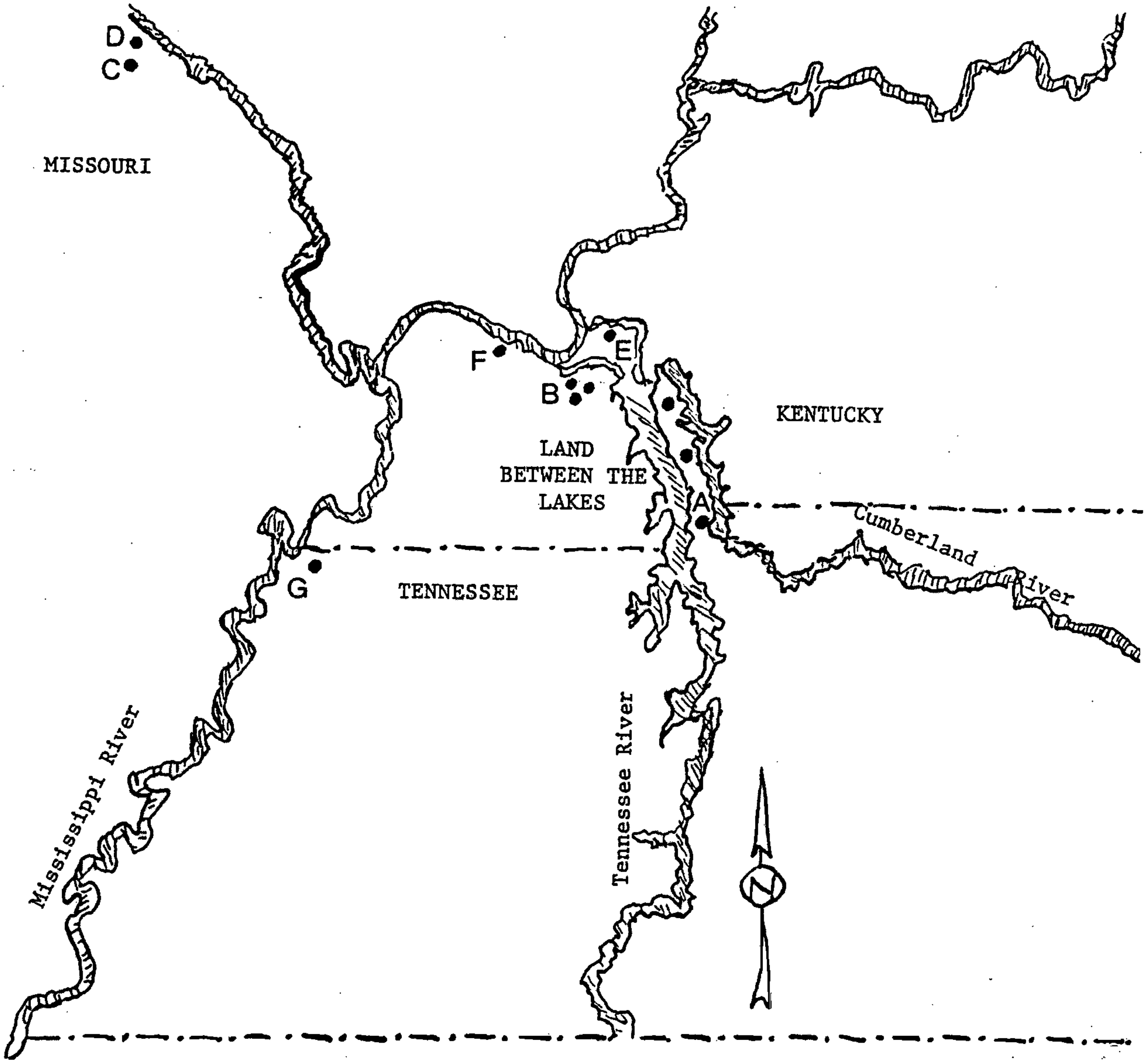

Figure 1. Map showing locations of plant populations.

MATERIALS AND METHODS

Study Sites

Seven population groups (A-G) comprising a total of 11 populations of *P. americana* L. representing varied levels of environmental pollution were selected from similar microhabitats in the mid-southern parts of the United States (Table 1, Fig. 1). Populations

1, 2 and 3 were collected in the relatively unpolluted, uninhabited areas of Land Between the Lakes (LBL) in western Kentucky and Tennessee. This 68,800 ha area represents a fairly unpolluted, rural habitat with no resident industry. However, there is some indigenous pollution because of vehicular traffic, especially during the summer months. LBL populations of pokeweed provide an environment in sharp contrast to the metropolitan area of St. Louis, Missouri or the industrial complex of Culvert City, Kentucky. Populations 4, 5, and 6 were collected in the Culvert City area. Culvert City is a small town in northern Marshall County of western Kentucky. In contrast to nearby LBL, Culver City has a vast complex of industrial units (petroleum, smelters, plastics, etc.) emitting a wide variety of pollutants and, therefore, represents a highly contaminated habitat. Population 9 from nearby Smithland, Kentucky was also affected by the air pollution generated by the industrial complex of Culvert City. Populations 7 and 8 represented two widely separated habitats in St. Louis, Missouri, one of the larger industrial cities in the United States. While population 7 was growing in a wooded area in the outskirts of St. Louis, population 8 was collected from the heavily polluted downtown area. Population 10 from Paducah, Kentucky, 35 km north of LBL, was growing in an area exposed to air, water, and soil pollution generated by automobiles, a power plant, and other nearby industrial units. Population 11, characterized by the absence of industry and excessive vehicular traffic was collected from the rural and relatively unpolluted environment of Reelfoot Lake in west Tennessee.

Table 1. Distribution and habitat features of *Phytolacca americana* L. populations

Population Group	Populations	Locality	Relative Degree of Pollution *	Source of Pollution
A	1,2,3	Land Between the Lakes	+	None
B	4,5,6	Culvert City, KY	+++++	Industry
C	7	St. Louis - outskirts	+	Vehicular traffic
D	8	St. Louis - downtown	+++++	Industry, Vehicular traffic
E	9	Smithland, KY	++++	Industry
F	10	Paducah, KY	+++	Vehicular traffic, Industry
G	11	Reelfoot Lake, TN	+	None

* +++++, highest level; +, lowest level

Field and Laboratory Methods

Each sample consisted of ten leaves collected at random from the lower portions of stems of five plants growing in the area. The leaf samples were collected in late summer to ensure their maturity at the time of sampling. Macroscopic data were tabulated including leaf length, leaf width, and petiole length from the 10 leaves from all five samples. Berry diameter and number of berries in inflorescence were recorded from each of the five sampled plants. Macroscopic leaf damage such as chlorosis, necrosis, and other anomalies were noted in addition to berries damage. Mean values and standard deviation of the vegetative data are shown below (Table 2).

Table 2. Vegatative characteristics* of *Phytolacca americana* L. population groups

Group and Population	Leaf Length (cm)	Leaf Width (cm)	Petiole Length (cm)	Berries in Inflorescence	Berry Diameter (mm)
Group A					
1	11.4 ± 0.7	4.1 ± 0.4	1.2 ± 0.1	36.9 ± 4.1	7.2 ± 0.6
2	11.2 ± 0.7	4.4 ± 0.2	1.2 ± 0.1	38.6 ± 3.3	7.0 ± 0.6
3	10.9 ± 0.3	3.9 ± 0.2	1.2 ± 0.1	40.2 ± 3.5	8.0 ± 0.8
Group B					
4	7.2 ± 0.8	2.2 ± 0.4	1.2 ± 0.1	34.0 ± 2.4	2.3 ± 0.4
5	7.3 ± 0.4	2.0 ± 0.4	1.2 ± 0.1	34.2 ± 2.6	2.8 ± 0.6
6	7.4 ± 0.4	2.1 ± 0.3	1.2 ± 0.7	38.7 ± 5.2	3.0 ± 0.6
Group C					
7	14.2 ± 0.3	4.9 ± 0.1	1.9 ± 0.1	29.9 ± 2.6	4.2 ± 0.7
Group D					
8	8.0 ± 0.3	2.5 ± 0.1	1.6 ± 0.1	13.7 ± 2.1	4.4 ± 0.5
Group E					
9	7.3 ± 0.4	2.2 ± 0.4	1.3 ± 0.1	36.4 ± 1.8	2.9 ± 0.7
Group F					
10	10.6 ± 0.7	3.8 ± 0.2	1.8 ± 0.2	23.3 ± 4.4	4.7 ± 0.6
Group G					
11	10.6 ± 0.3	3.9 ± 0.2	1.3 ± 0.8	41.0 ± 4.5	7.4 ± 0.5

* The values represent means of 10 measurements ± one standard deviation.

Cuticular impressions of upper and lower leaf surfaces were prepared by applying Duco® cement to washed and dried leaves (Williams 1973). A small portion from the central area of each leaf cuticular imprint was used to make cuticular slides for adaxial (upper) and abaxial (lower) leaf surfaces of each population. Microscopic observation were made at 400x magnification. Microscopic data on stomatal frequency, smallest and largest stomatal size, epidermal cell wall undulations, and subsidiary cell complex were recorded by randomly selecting 20 fields (n=20) from each cuticular slide. Means and standard deviations of the cuticular data for the upper and lower side of leaves from each population are shown below (Table 3). Furthermore, means and standard deviation of the vegetative and cuticular data for each population group are summarized below (Table 4).

Table 3. Cuticular characteristics* of *Phytolacca americana* L. population groups

Group and Population	Stomatal Frequency **		Largest Stoma (μ)		Smallest Stoma (μ)		Epidermal Wall Undulations		Subsidiary Cell Complex	
	U	L	U	L	U	L	U	L	U	L
Group A										
1	24.0 ± 2.5	56.8 ± 4.1	35.5 ± 1.7	30.3 ± 1.6	29.0 ± 1.2	19.3 ± 1.5	10.4 ± 1.1	11.1 ± 0.6	4	4
2	24.6 ± 3.1	56.7 ± 4.9	33.1 ± 1.7	28.6 ± 2.2	27.2 ± 1.9	20.0 ± 1.8	10.0 ± 0.9	10.7 ± 0.7	5	4
3	23.6 ± 2.8	55.4 ± 5.2	31.2 ± 1.7	27.3 ± 2.0	22.0 ± 1.9	17.1 ± 2.0	9.9 ± 0.6	10.9 ± 0.7	4	4
Group B										
4	13.4 ± 2.6	49.2 ± 4.6	32.8 ± 1.8	27.7 ± 1.9	21.1 ± 1.2	20.0 ± 1.8	4.8 ± 0.6	4.7 ± 0.7	5	4
5	13.4 ± 2.8	49.5 ± 5.2	30.7 ± 2.1	26.8 ± 1.7	22.2 ± 2.1	19.0 ± 1.4	5.6 ± 0.5	5.5 ± 0.5	5	5
6	12.1 ± 2.4	50.1 ± 4.3	32.7 ± 2.1	28.2 ± 1.8	20.3 ± 2.0	19.5 ± 1.3	5.6 ± 0.5	5.7 ± 0.4	4	5
Group C										
7	20.0 ± 4.3	40.8 ± 4.9	31.1 ± 1.7	35.8 ± 1.4	22.6 ± 1.8	26.1 ± 1.8	6.2 ± 0.6	5.9 ± 0.6	5	5
Group D										
8	11.3 ± 2.3	30.4 ± 3.9	21.4 ± 3.7	30.3 ± 2.7	27.5 ± 1.9	19.7 ± 1.7	4.8 ± 0.6	5.0 ± 0.6	4	5
Group E										
9	12.4 ± 1.7	46.8 ± 3.4	31.8 ± 1.5	28.3 ± 1.6	20.8 ± 1.2	18.7 ± 1.2	5.6 ± 0.4	5.6 ± 0.5	5	5
Group F										
10	6.2 ± 1.6	23.9 ± 3.9	30.1 ± 2.7	31.1 ± 1.8	21.5 ± 1.7	18.3 ± 1.6	5.2 ± 0.6	5.0 ± 0.6	4	5
Group G										
11	29.0 ± 3.9	58.7 ± 5.0	29.2 ± 2.3	30.5 ± 1.7	20.6 ± 1.5	19.6 ± 1.4	9.5 ± 0.5	10.8 ± 0.6	4	5

* Values represent means of 20 measurements ± standard deviation (except mean values for subsidiary cell complex)

** Mean stomatal frequency = stomata of the leaf surface observed at 400x magnification (field of view = 0.152 mm^2).

U = upper surface of leaf, L = lower surface of leaf.

Table 4. Summary of vegetative and cuticular characteristics of population groups of *Phytolacca americana* L.

Trait		Population Group						
		A	B	C	D	E	F	G
Leaf length (cm), x±σ		11.1 ± 0.2	7.3 ± 0.1	14.2 ± 0.3	8.0 ± 0.3	7.3 ± 0.4	10.6 ± 0.7	10.6 ± 0.3
Leaf width (cm), x±σ		4.0 ± 0.2	2.1 ± 0.1	4.9 ± 0.1	2.5 ± 0.1	2.2 ± 0.4	3.8 ± 0.2	3.9 ± 0.2
Petiole length (cm), x±σ		1.2 ± 0.0	1.2 ± 0.0	1.9 ± 0.1	1.6 ± 0.1	1.3 ± 0.1	1.8 ± 0.2	1.3 ± 0.8
Berries in inflorescence, x±σ		38.5 ± 1.6	35.6 ± 2.6	29.9 ± 2.6	13.7 ± 2.1	36.4 ± 1.8	23.2 ± 4.4	41.0 ± 4.5
Berry diameter (mm), x±σ		7.4 ± 0.5	2.7 ± 0.3	4.2 ± 0.7	4.4 ± 0.5	2.9 ± 0.7	4.7 ± 0.6	7.4 ± 0.5
Stomatal frequency, x±σ	U	24.0 ± 0.5	12.9 ± 0.7	20.0 ± 4.3	11.3 ± 2.3	12.4 ± 1.7	6.2 ± 1.6	29.0 ± 3.9
	L	56.3 ± 0.7	49.6 ± 0.4	40.8 ± 4.9	30.4 ± 3.9	46.8 ± 3.4	23.9 ± 3.9	58.7 ± 5.0
Largest stoma (μ), x±σ	U	33.2 ± 2.1	32.0 ± 1.1	31.1 ± 1.7	21.4 ± 3.7	31.8 ± 1.5	30.1 ± 2.7	29.2 ± 2.3
	L	28.7 ± 1.5	27.5 ± 0.7	35.8 ± 1.4	30.3 ± 2.7	28.3 ± 1.6	31.1 ± 1.8	30.5 ± 1.7
Smallest stoma (μ), x±σ	U	26.0 ± 3.6	21.2 ± 0.9	22.6 ± 1.8	27.5 ± 1.9	20.8 ± 1.2	21.5 ± 1.7	20.6 ± 1.5
	L	18.8 ± 1.5	19.5 ± 0.5	26.1 ± 1.8	19.7 ± 1.7	18.7 ± 1.2	18.3 ± 1.6	19.6 ± 1.4
Epidermal wall undulations, x±σ	U	10.1 ± 0.2	5.3 ± 0.4	6.2 ± 0.6	4.8 ± 0.6	5.6 ± 0.4	5.2 ± 0.6	9.5 ± 0.5
	L	10.9 ± 0.2	5.3 ± 0.5	5.9 ± 0.6	5.0 ± 0.6	5.6 ± 0.5	5.0 ± 0.6	10.8 ± 0.6
Subsidiary cell complex, x	U	4	5	5	4	5	4	4
	L	4	4	5	5	5	5	5

U = upper surface of leaf; L = lower surface of leaf

RESULTS

For ease of comparison the population samples were organized into seven population groups (A-G) (Table 1). Statistical analysis of the data (Table 2) shows that leaf length within populations of group A (LBL) showed little variation, the statistical mean ranging from 10.9 cm to 11.4 cm. Similar readings (7.2 - 7.4 cm) were found in population group B representing the polluted habitat of Culvert City. Mean values for leaf length ranged from 7.3 cm in two of the most polluted population groups (group B and group E) to 14.2 cm in group C representing the relatively rural outskirts of St. Louis (Table 4). Leaf width ranged from 2.1 cm in Culvert City to 4.9 cm in the St. Louis outskirts. LBL, obviously one of the least polluted areas, had a mean leaf length value of 11.1 cm and leaf width value of 4.1 cm for all populations combined. Petiole length varied from 1.2 cm in Culvert City population group to 1.9 cm in the population group of St. Louis outskirts. Number of berries per inflorescence had the lowest mean value of 13.7 in one of the most polluted population groups, downtown St. Louis. The second highest number of berries was 38.5 and it was found in the relatively unpolluted group A from LBL. Highest mean value (41.0) for the number of berries was found in another unpolluted habitat of population G, the Reelfoot Lake area. Berry size was lowest (2.7 mm) in group B (Culvert City) and highest (7.4 mm) in groups A (LBL) and G (Reelfoot Lake).

Stomatal frequency on the upper leaf surface ranged from 6.2 in group F (Paducah) to 29.0 in group G of Reelfoot Lake (Table 4). On the lower leaf surface, stomatal frequency means ranged from 23.9 in group F (Paducah) to 58.7 in group G (Reelfoot Lake). LBL (group A) had one of the highest values (56.3), while Culvert City (group B), one of the most polluted habitats, had a mean value of 49.6. Largest stomatal size on the upper leaf surface ranged from 33.2μ in group A (LBL) to 21.4μ in group D (downtown St. Louis). On the lower surface, the mean size variation for the largest stoma was from 27.5μ in group B (Culvert City) to 35.8μ in group C (St. Louis-outskirts). Smallest stoma on the upper leaf surface had a range of 20.6μ (group G, Reelfoot Lake) to 27.5μ (group D, downtown St. Louis). On the lower surface, it ranged from 18.3μ (group F, Paducah) to 26.1μ (group C, St. Louis outskirts).

Number of epidermal wall undulations on the upper leaf surface had the highest statistical mean value of 10.1 in group A (LBL), and the lowest mean value of 4.8 in group D (downtown St. Louis). For the lower leaf surface, the highest mean value (10.9) was in group A, while the lowest value of 5.0 was found in the polluted group D (downtown St. Louis) and group F (Paducah). Subsidiary cell complex consisting of two cells parallel to the stomatal axis and two to three cells at right angles to the stomatal axis -- the "paracytic" type (Metcalfe and Chalk 1950) -- remained the same in all 11 population. The taxonomic significance of this feature should be investigated.

DISCUSSION

The study points out modifications in the morphological and leaf cuticular features of *P. americana* L., possibly in response to environmental contamination. The data suggests a general decrease in leaf length and leaf width with an increase in the degree of pollution in the environment. The reverse was true in the relatively clean habitats of groups A, C, and G. Population groups A and G of the LBL and rural Reelfoot Lake, respectively, had the maximum number of berries in inflorescence. Furthermore, the berry size was the largest in these relatively clean or least polluted areas. In other words, environmental pollution may have a detrimental effect on plant growth and hence its photosynthetic and floral productivity.

Stomatal frequency on both the adaxial (upper) and abaxial (lower) leaf surfaces decreased with an increase in environmental pollution. Reelfoot Lake and LBL plant population groups from the less polluted environs exhibited the highest stomatal frequency. Epidermal wall undulations had the highest mean values again in group A and group G, while the lowest mean values were associated with contaminated sites (Groups B-F), suggesting that this cuticular feature may express a very distinct modification in polluted habitats. Stomatal size seemed to exhibit no distinct trend in the populations of pokeweed growing in habitats of varying degrees of environmental pollution. Subsidiary cell complex remained unaffected by environmental pollution and hence must be regarded as a useful species character owing to its constancy.

The comparisons made in this study suggest that, in pokeweed, leaf length, leaf width, berry size, and the number of berries may be adversely affected by environmental pollution. A decrease in stomatal frequency in pokeweed leaves from polluted areas suggests an adaptive modification that may serve to keep out gaseous pollutants that otherwise may enter the leaf and destroy the plant tissues. A decrease in the epidermal wall undulations suggest another adaptive feature that may reduce the surface area exposed to environmental pollutants.

The leaf morphological and cuticular modifications exhibited by pokeweed populations in this study suggest that these modifications may be of adaptive value in polluted environments. Bennett *et al.* (1974) suggested that plants do adapt to low levels of pollution. It is, therefore, safe to hypothesize that the patterns found in the study may be important bioindicators of environmental pollution. However, additional species are under investigation to confirm the findings for a wider spectrum of the plant kingdom.

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POISONOUS (AMANITIN-CONTAINING) MUSHROOMS IN LAND BETWEEN THE LAKES

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ABSTRACT. Most severe mushroom poisonings occur through ingestion of species containing the bicyclic polypeptide amatoxins known as amanitins. A recent death due to amatoxin mushroom poisoning in the Land Between The Lakes (LBL) area indicates the need for information on amanitin-containing species in the local mycoflora. Sporadic collecting at LBL since 1973 has documented the occurrence of four toxic species--*Amanita bisporigera* Atkinson, *Amanita verna* (Bulliard: Fries) Roques, *Lepiota helveola* Bresadola, and *Galerina autumnalis* (Peck) Singer & Smith. Although not yet known from LBL, *Conocybe filaris* (Fries) Kuhner, may also be there since it has been collected in southern Illinois.

INTRODUCTION

Most severe mushroom poisonings occur through ingestion of species containing amatoxins known as amanitins--toxins now known to occur in some species of *Amanita, Lepiota, Galerina*, and *Conocybe* (Lincoff and Mitchel 1977, Ammirati *et al.* 1985). The only available local reference on mushrooms (Sundberg and Richardson, 1980) lacks edibility data. This fact and a recent death due to amatoxin poisoning from mushrooms collected in the Land Between The Lakes (LBL) area indicate the need for information on amanitin-containing species in the local mycoflora.

Amanitins are bicyclic polypeptides which are composed of eight amino acids (see Simons 1971, Hatfield and Brady 1975, Litten 1975, Lincoff and Mitchel 1977, or Ammirati *et al.* 1985 for details) and cause late-onset gastrointestinal irritation, lesions in the kidneys, and, most significantly, inhibit RNA polymerase B activity in liver cells (see e.g., Simons, 1971, Hatfield and Brady 1975, Lincoff and Mitchel 1977, Ammirati *et al.* 1985). The amount of amanitin in reportedly toxic North American species of *Amanita* varies from 0-0.1 mg/gm dry weight in one species to 2.25-5.0 mg/gm dry weight in another species (Tyler *et al.* 1966). Since the median lethal dose (LD_{50}) for man is 0.1 mg/kg of body weight, a single mushroom cap (or less) can be fatal to an adult (Simons 1971). Thus, 57 gm (2 oz) of fresh mushroom containing about 7 mg of amanitin, would be lethal for someone weighing 70 kg (about 150 lbs; Lincoff and Mitchel 1977). For smaller mushrooms, like *Galerina* species, about 20 average sized specimens would be needed to produce a fatal reaction (Lincoff and Mitchel 1977).

General symptoms of amatoxin poisoning, described in detail by numerous authors (e.g., Lincoff and Mitchel 1977, Ammirati *et al.* 1985), can be summarized as follows. Onset of symptoms is delayed 6 to 24 hours (usually 10-14 hours; Mitchel 1980) after ingestion. A period of abdominal pain, nausea, vomiting, and watery diarrhea ensues, followed by apparent, but transient, remission of a day or so. Then, symptoms resume; damage occurs to the liver and kidneys, and, if untreated, often leads to death on the fourth to seventh day.

Sporadic collecting at LBL since 1973 has documented the occurrence of four toxic species, *Amanita bisporigera* Atkinson, *Amanita verna* (Bulliard: Fries) Roques, *Lepiota helveola* Bresadola, and *Galerina autumnalis* (Peck) Singer & Smith. Although not yet known from LBL, *Conocybe filaris* (Fries) Kuhner most likely occurs there since it has been collected in nearby southern Illinois. Because of their importance to the medical community and the public in general, the characteristics of these species are summarized below.

MATERIALS AND METHODS

Materials were collected, documented, prepared, and preserved using standard mycological techniques (e.g., Smith 1949, Largent *et al.* 1977). Anatomical data were obtained from dried herbarium specimens that were wetted with 95% ETOH, soaked in distilled water, and gently blotted dry prior to sectioning. Free-hand sections were mounted in either 3% KOH or Melzer's reagent. Unless otherwise noted, cells and tissues appear hyaline in KOH and pale yellow in Melzer's reagent. Specimens examined are stored in the Mycological Collections, Southern Illinois University Herbarium or in the private collection of W. J. Sundberg.

RESULTS AND DISCUSSION

Amanita bisporigera Atkinson, Figure A

PILEUS 4-6 cm broad, convex to plane, slightly umbonate; margin decurved to plane; surface glabrous, viscid, white or with a slight yellowish tint on the disc; becoming bright yellow where touched with 3% KOH. FLESH white. ODOR not distinctive. LAMELLAE slightly adnexed (nearly free), close, white, margins smooth to fimbriate. Lamellulae in 2-4 tiers. STIPE 8-13 cm long, 4-7 broad at the apex, enlarging downward to a swollen, nearly globose basal bulb; surface dry, white, striate above. ANNULUS superior, thin and membranous, flaring at first but collapsing on and adhering to the stipe in age. VOLVA thick and membranous, sac-like, white.

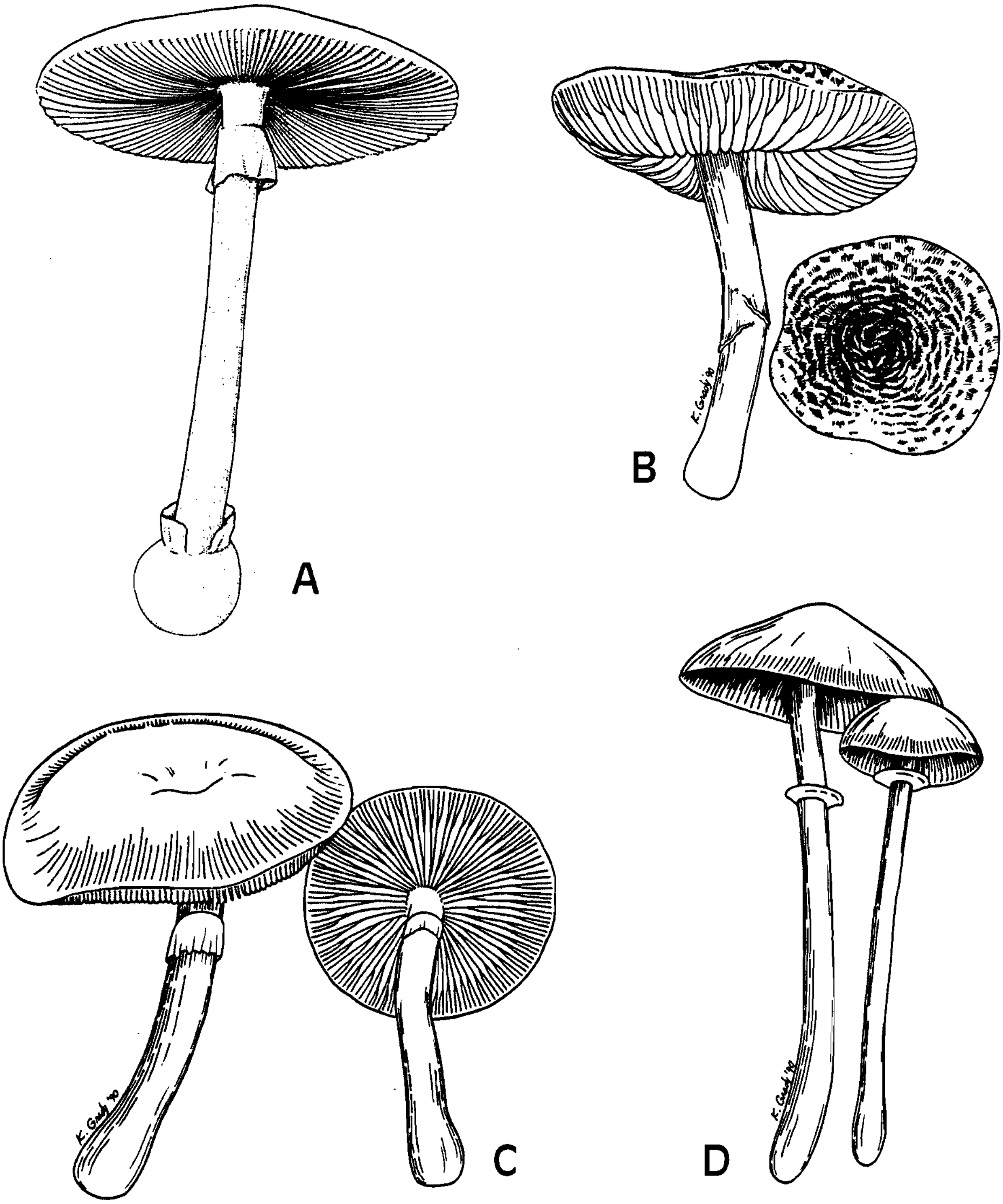
BASIDIOSPORES white, 6.5-10 x 6.5-9 μm, globose to subglobose, smooth, amyloid. BASIDIA predominantly 2-spored, clavate, 20-40 x 9-12 μm. PLEUROCYSTIDIA none. LAMELLAR TRAMA divergent. CHEILOCYSTIDIA 10-64 x 7-48 μm, pyriform to nearly globose. PILEIPELLIS (cuticle) composed of gelatinized, interwoven hyphae 2-6 μm broad. UNIVERSAL VEIL composed of interwoven hyphae 2-10 μm broad. CLAMP CONNECTIONS lacking.

Habit and Habitat: Solitary to scattered in soil and humus under shrubs and mixed hardwoods.

Representative Specimen: Sundberg 4376. Off east Old Ferry Road, Lyon Co., Kentucky. July 3, 1977.

Discussion: *Amanita bisporigera* is one of three morphologically similar all-white species which are nearly indistinguishable--all are sometimes referred to as "death angels."

Like *A. bisporigera*, the pileus of *A. virosa* (Fries) Bertillon turns yellow when touched with 3% KOH, but it has four-spored basidia. *Amanita verna* does not turn yellow with KOH and has ellipsoid spores rather than the globose to subglobose ones found in former two species.



Figs. A-D. Some amanitin-containing mushrooms of Land Between The Lakes and nearby areas. A. *Amanita bisporigera*. B. *Lepiota helveola*. C. *Galerina autumnalis*. D. *Conocybe filaris*.

Although we have no records of *Amanita virosa* at LBL, *A. verna* does occur there (Reference Specimen: Sundberg IX-12-1981-1; September 12, 1981; Wooded lowland area, northwest of Center Station, Trigg Co., Kentucky).

Tyler *et al.* (1966) found that *A. bisporigera* had the highest total amanitin content--2.25-5.0 mg/gm dry weight of mushroom while the values for *A. verna* and *A. virosa* were 0-1.7 mg/gm and 0-<0.1 mg/gm respectively.

Distinguishing field characters of this *Amanita* species complex include the white color, relatively large size, nearly free lamellae, thin and membranous annulus, free and sac-like volva, and white spore print.

Lepiota helveola **Bresadola, Figure B**

PILEUS 2-4 cm broad, convex, becoming plane or nearly so, slightly umbonate; margin decurved to plane, entire; surface dry; cuticle tomentose on the disc, diffracted and irregularly appressed scaly toward the margin, scales somewhat concentric in arrangement; disc chestnut-brown to cinnamon to pinkish cinnamon, scales similar to paler toward the margin, flesh white where showing through between the scales. FLESH up to 2-5 mm thick, white. Odor sweet, sometimes faint. LAMELLAE free; white, becoming pale cream-buff; close to subdistant; thin. Lamellulae in 1-2 tiers. STIPE 4-7 cm long, 4-6 mm broad at the apex, equal to slightly enlarged below; surface dry, innately fibrillose, below the base having evanescent, scattered, superficial, appressed, subfloccose, white to pinkish buff scales each covered by cuticle colored like that on the pileus; background color white to pinkish buff. ANNULUS median or nearly so, consisting of the irregular, band-like, upper limit of the superficial, subfloccose scales.

BASIDIOSPORES white, 5.8-8 x 3-4.6 μm, ovoid to short ellipsoid, smooth, dextrinoid (pale to dark reddish brown in Melzer's reagent). BASIDIA 22-27 x 6-8 μm, clavate, 4-spored. PLEUROCYSTIDIA absent. CHEILOCYSTIDIA 11-22 x 5-10 μm, clavate to subsaccate, rarely tapered at the apex. LAMELLAR TRAMA interwoven to subparallel. PILEIPELLIS a trichodermium of pilocystidia arising from a loosely interwoven subcuticular zone; pilocystidia 60-370 x 6-13 μm, cylindric, tapered toward and rounded at the apex, thick walled, flexuous. CLAMP CONNECTIONS present.

Habit and habitat: Solitary to scattered in soil of disturbed sites; scattered shrubs or hardwoods nearby.

Reference Specimen: Sundberg IX-28-1980-1. Youth Station, Lyon Co., Kentucky. September 28, 1980.

Discussion: *Lepiota helveola* is only one of small group of *Lepiota* species that share many of the same features, including production of amatoxins. Not long ago, one of these species was responsible for a fatal mushroom poisoning in New York (Haines 1984).

Although only found once by us at LBL, the fact that *L. helveola* is also found sporadically in southern Illinois and many other parts of the country (unpublished data, WJS) suggests that it may be more common than collecting records indicate.

Field characters that help distinguish *L. helveola* include its relatively small size, the cinnamon brown to pinkish cinnamon and tomentose pileus with more or less concentric scales toward the margin, an irregular and bracelet-like to pad-like annulus, a faint sweet odor, a white spore print, and the tendency to fruit in disturbed areas.

***Galerina autumnalis* (Peck) Singer & Smith, Figure C**

PILEUS 2.5-6 cm broad, convex to nearly plane, somewhat depressed at the disc; margin translucent-striate when moist; surface glabrous, viscid to subviscid, chestnut brown to dark yellowish brown, hygrophanous (fading or becoming lighter on loss of moisture in the field) and becoming dull brownish yellow. FLESH thick, firm, often appearing water-soaked, pale brown to buff. LAMELLAE adnate to slightly decurrent, close, dark yellowish brown becoming dull rusty reddish brown. STIPE 3-9 cm long, 3-8 mm broad at the apex, equal to somewhat enlarged below; glabrous to innately fibrillose, ochraceous buff to ochraceous tawny. ANNULUS superior, thin, membranous, and fragile, sometimes fragmenting on pileus expansion or becoming more or less fibrillose, often collapsing on the stipe, similar in color to the pileus.

BASIDIOSPORES dark rusty reddish brown, 8.5-10 x 5-6.5 μm, ellipsoid, wrinkled, reddish brown (tawny to russet) in KOH. BASIDIA 24-26 x 7-8 μm, 4-spored, elongate-clavate. PLEUROCYSTIDIA and CHEILOCYSTIDIA 40-65 x 9-12 μm, fusoid-ventricose with elongated, sometimes flexuous necks. PILEIPELLIS gelatinous, composed of hyphae 2-4 μm broad. CLAMP CONNECTIONS present.

Discussion: Although not yet documented by a preserved herbarium voucher specimen, this species has been observed by us at LBL on several occasions.

Data for the description above was taken from collections of typical specimens from southern Illinois (Reference Specimens: Sundberg 3275; Giant City State Park, near Makanda, Jackson Co., IL; June 10, 1976 and Kost 27; Southern Illinois University, Carbondale, Jackson Co. IL; December 2, 1982).

According to Johnson *et al.* (1976), mature specimens of *G. autumnalis* have an average amanitin concentration of 1.5 mg/gm dry weight of mushroom.

Distinguishing features of this species include its relatively small size, smooth and brown to yellowish brown pileus, thin and somewhat fragile annulus, dull rusty reddish brown spore print, and growth on old and usually decorticated logs.

Conocybe filaris (Fries) Kuhner, Figure D

PILEUS up to 2.5 cm broad, conical but becoming convex, often umbonate; margin striate when moist; surface moist to dry, glabrous, dark reddish brown at the center, dark yellowish brown to brownish yellow toward the margins, hygrophanous (fading on slight natural drying). FLESH thin. LAMELLAE adnexed, close, off-white, becoming rusty; margins white. STIPE 1-4 cm long, up to 2 mm broad at the apex, enlarged somewhat below, white to buff, smooth above and silky fibrillose below. ANNULUS superior to median, stout and flaring, white to buff.

BASIDIOSPORES rusty cinnamon-brown; 7.5-13 x 3.5-6.5 μm, elliptical, smooth, with an apical pore, rusty brown in KOH. BASIDIA 15-25 x 5-7 μm, 4-spored, short-clavate. PLEUROCYSTIDIA lacking. CHEILOCYSTIDIA 20-50 x 6-10 μm, ventricose to fusiform-ventricose. PILEIPELLIS a hymeniform layer of pyriform cells with narrow bases, cells 20-36 x 12-18 μm. CLAMP CONNECTIONS present.

Discussion: The description above is adapted from that of Ammirati *et al.* (1985).

Although not yet known from LBL, the discovery of this species complex in southern Illinois (Reference Specimen: JRK sn; Southern Illinois University, Carbondale, Jackson Co., IL; October 20, 1989) indicates that it could occur at LBL, and those concerned with potential mushroom poisonings should be aware of it.

Distinguishing characters of *C. filaris* include its small size, long narrow stipe (in relation to the pileus size), stout and flaring superior annulus which sometimes becomes movable and slides down the stipe, and dull rusty cinnamon-brown spores.

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