JOURNAL OF THE KENTUCKY ACADEMY OF SCIENCE

Official Publication of the Academy

Volume 60
Number 2
Fall 1999

The Kentucky Academy of Science

Founded 8 May 1914

All manuscripts and correspondence concerning manuscripts should be addressed to the Editor.

The JOURNAL is indexed in BIOSIS and in *State Academies of Science Abstracts.*

Membership in the Academy is open to interested persons upon nomination, payment of dues, and election. Application forms for membership may be obtained from the Secretary. The JOURNAL is sent free to all members in good standing.

Annual dues are $25.00 for Active Members; $15.00 for Student Members; $35.00 for Family; $350.00 for Life Members. Subscription rates for nonmembers are: $50.00 domestic; $60.00 foreign. Back issues are $30.00 per volume.

The JOURNAL is issued semiannually in Spring and Fall. Two numbers comprise a volume.

Correspondence concerning memberships or subscriptions should be addressed to the Executive Secretary.

∞ This paper meets the requirements of ANSI/NISO Z39.48-1992 (Permanence of Paper).

INSTITUTIONAL AFFILIATES

Fellow

University of Kentucky
University of Louisville

Sustaining Member

Eastern Kentucky University
Morehead State University
Murray State University
Northern Kentucky University
Western Kentucky University

Member

Bellarmine College
Berea College
Campbellsville University
Centre College
Cumberland College
Somerset Community College
Southeast Community College

Associate Member

Georgetown College
Jefferson Community College
Kentucky State University
Kentucky Wesleyan College
Maysville Community College
Midway College
Owensboro Community College
Spalding University
Thomas More College
Transylvania University

INDUSTRIAL AFFILIATES

Associate Patron

Ashland Oil, Inc.

Member

Corhart Refractories Corporation
MPD, Inc.

Associate Member

All-Rite Pest Control
Wood Hudson Cancer Research Laboratory, Inc.

JOURNAL OF THE KENTUCKY ACADEMY OF SCIENCE
ISSN 1098-7096

Continuation of
Transactions of the Kentucky Academy of Science

Volume 60 Fall 1999 Number 2

J. Ky. Acad. Sci. 60(2):67–72. 1999.

Possible Decline in Reproduction in a Freshwater Unionid (Mollusca: Bivalvia) Community in the Licking River at Butler, Kentucky

Stephen E. McMurray,[1] Guenter A. Schuster, and Barbara A. Ramey

Department of Biological Sciences, Eastern Kentucky University, Richmond, Kentucky 40475

ABSTRACT

In the Licking River at Butler, Pendleton County, Kentucky, glochidia, fishes, and unionids were collected to analyze recruitment in an historically diverse unionid community. Only 14 unionid glochidia and 50 juvenile *Corbicula fluminea,* were collected with drift nets. No fishes collected had any evidence of glochidial infestation. A small percentage of the unionids collected (13.5%) had gills modified as marsupia. Sex ratios, stage of gametogenesis, and marsupial contents of two target species (*Actinonaias ligamentina* and *Elliptio dilatata*) were determined in the laboratory. *Actinonaias ligamentina* was found to exhibit a 1:1 male-to-female ratio; *E. dilatata* had a ratio statistically different from 1:1. Causal factors for this possible decline in reproduction were unclear.

INTRODUCTION

North America's rich unionacean (mussel) (Bivalvia: Unionidae) fauna (297 taxa) has disproportionately more endangered, threatened, and special concern taxa than all the groups of terrestrial organisms in North America combined. Only 70 of the unionid taxa known from the United States are considered stable (Williams et al. 1993). Human activities in Kentucky have severely impacted unionid populations during the last 200 years, making this group of organisms the most endangered in the state (Cicerello et al. 1991). One of the most severe and perplexing problems facing freshwater mussels is the documented loss of recruitment (reproduction) in unionid communities previously thought to be healthy.

The objective of our study was to analyze reproduction in a diverse unionid community in the Licking River at Butler, Pendleton County, Kentucky. Originally, the data were to be compared to those from another community in the Licking River where it was hypothesized recruitment had ceased or been dramatically decreased due to the release of hypolimnionic water from an upstream reservoir (McMurray 1997).

METHODOLOGY

Study Area

The Licking River originates on the unglaciated Allegheny Plateau in the Appalachian Province of eastern Kentucky and is a sixth-order tributary to the Ohio River. The river flows northwesterly through the extremely variable topography of the Bluegrass region of the state for 496 km (Burr and Warren 1986; Hannan et al. 1982; Harker et al. 1979). This drainage covers all or a portion of 21 counties and encompasses ca. 10% of the state (9601 km^2) (Harker et al. 1979). The drainage has a diverse unionid fauna with over half of Ken-

[1] Present address: Kentucky Division of Water, Water Quality Branch, Nonpoint Source Section, 14 Reilly Road, Frankfort, KY 40601.

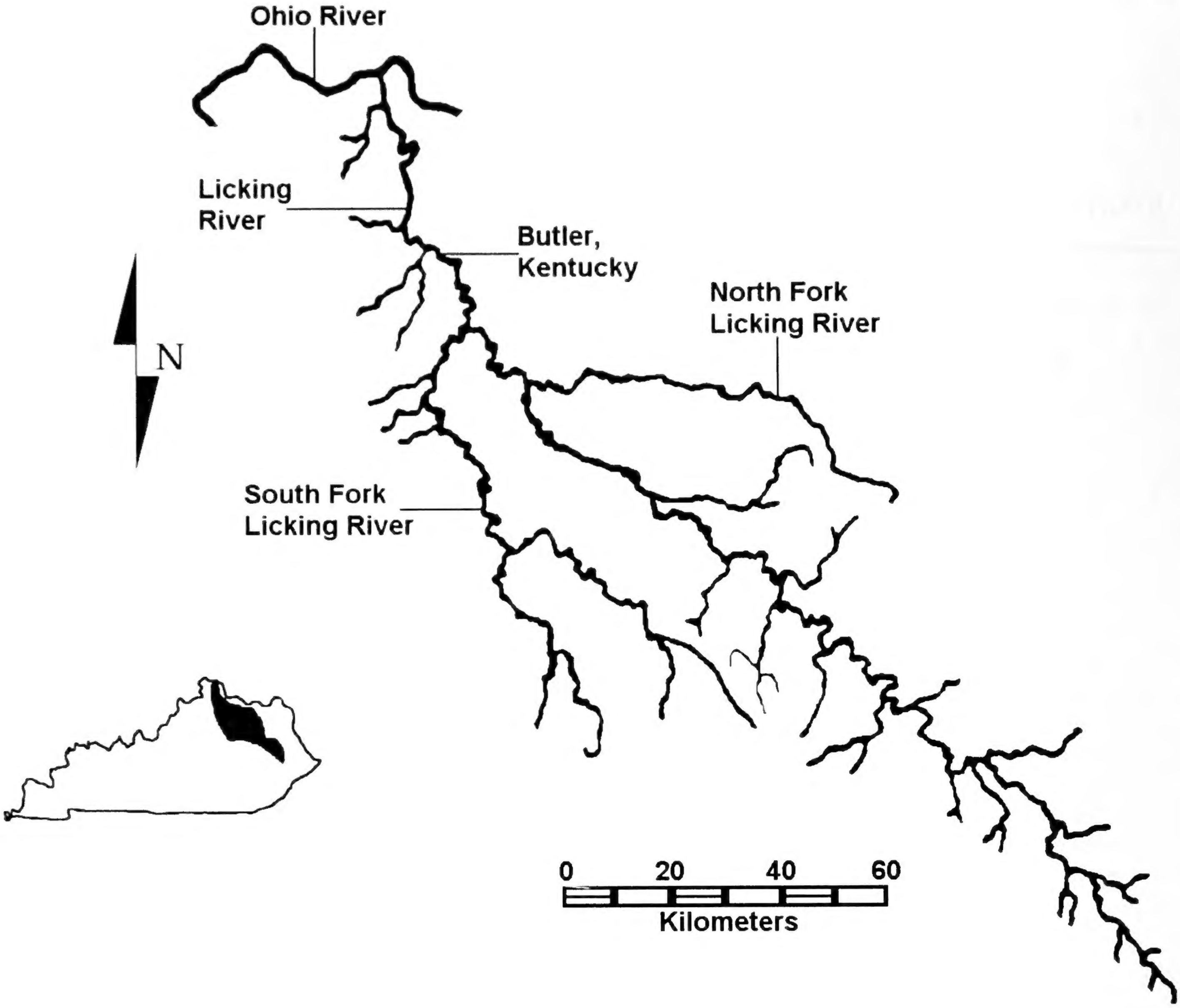

Figure 1. Location of the Butler, Pendleton County, Kentucky, unionid community. Inset shows the location of the Licking River drainage in Kentucky.

tucky's native mussel fauna, 53 taxa, historically existing in the drainage (Cicerello et al. 1991). A recent unionid survey by Laudermilk (1993) indicated that 50 taxa still reside in that portion of the river below Cave Run Reservoir.

The unionid community for our study was located just downstream from the SR 177 bridge at Butler (Figure 1). The watershed at this site is utilized mainly for agriculture, but there is some urbanization of the surrounding area. Substrate consisted mainly of cobble and boulder, with large amounts of gravel and sand intermixed in the riffle areas and along the stream margins. This site has had a diverse unionid community with 35 historical taxa (Laudermilk 1993).

Sampling and Laboratory Procedures

Five collections of glochidia, fishes, and unionids were made from July through October 1995. Unfortunately, high water conditions prevented collections in spring 1996. For each collection period a drift net was randomly placed in the bed to collect glochidia. After 1 hour, the contents of the drift net were preserved in 70% ethanol and returned to the laboratory. Drift net collections were randomly examined using cross-polarized light microscopy techniques (Johnson 1995) at 10–20× magnification. Glochidia were counted and removed along with any juvenile *Corbicula fluminea*.

Fishes were collected for 1 hour using a common sense minnow seine. All fishes retained were initially preserved in 10% formalin and then transferred to 70% ethanol in the laboratory for final preservation. Following sorting and identification, the fins and scales of each individual were examined under a dissecting microscope (10–30×) for attached glochidia. The opercular flaps were removed, and each gill arch was carefully examined under a dissecting microscope for attached glochidia (Bruenderman and Neves 1993).

Unionids were randomly collected for 1 hour by snorkeling or with the use of water scopes. After identification, the shell of each unionid was carefully opened with a small screwdriver and the gills were examined for signs of gravidity. Notes were made of the species collected and the condition of the gills in each individual. All unionids, except for individuals of two target species retained for histological examination, were returned to the river. Two common unionid species, *Actinonaias ligamentina* and *Elliptio dilatata,* were chosen for histological examination. These species represented both breeding regimes of freshwater mussels (bradytictic and tachytictic, respectively), both are commonly encountered throughout their respective ranges (Oesch 1995), and neither has any federal or state protection status (KSNPC 1996). More individuals for histological examination were also collected by the previously described method if enough individuals for analysis were not obtained in the original search. In most cases individuals, and the respective data, for field and laboratory analyses were kept separate.

If possible, three to five individuals of the two target species were retained for histological examination from each collecting period. These individuals were placed into a 10% formalin solution and were then transferred to 70% ethanol in the laboratory for final preservation. The valves were opened by cutting the adductor muscles, and portions of the gonadal and gill tissues were removed and placed into either 70% ethanol or Bouins fixative. These were then dehydrated through a series of alcohols and embedded in paraffin (Humason 1967). Sections were made at a thickness of 10 μm using an American Optical 820 Microtome and were mounted with Permount. The slides were stained with Ehrlich's hematoxylin and counter stained with eosin (Humason 1967). The sections were then examined under a compound microscope (400–430×) to determine a sex ratio for both species, to determine if gametogenesis was occurring, and to determine the contents of the marsupia. All drift net, fish, and unionid collections were deposited in the Branley A. Branson Museum of Zoology, Eastern Kentucky University (EKU).

Five cell types of spermatogenesis (Garner 1993) were used to determine the stage of gametogenesis in males of both target species. Stage 1 males were those that had only spermatogonia present in their acini; Stage 5 males had mature spermatozoa present. Stages 2, 3, and 4 corresponded respectively to sperm morulae, spermatocytes, and spermatids being present in the acini. Three cell types of oogenesis in *Elliptio dilatata* (McMurray 1997) were used to determine the stage of gametogenesis in females of that target species. A similar analysis of female *Actinonaias ligamentina* was not performed due to a lack of this type of classification for females of that species (McMurray 1997). Stage 1 females were those with oogonia as the dominant cell type in their alveoli; Stage 2 were those with oocytes dominant; and Stage 3 were those with mature ova dominant. Marsupia of both target species were classified according to their contents as being empty (EM) or containing mature glochidia (MG), early embryos (EE), or advanced embryos (AE) (Garner 1993). In the case of known females that did not have their gill tissues examined, the marsupia were considered to be empty since sections were made of any gill that showed signs of gravidity.

RESULTS

Only 14 unionid glochidia and 50 juvenile *Corbicula fluminea* were collected with drift nets. A total of 307 fishes was collected; none of these had any attached glochidia. Only 26 of the 193 unionids (13.5%) (Table 1) observed in the field had their gills modified as marsupia. This represented, based only on field observations of the gill condition, a 6.42: 1 male-to-female ratio. A total of 17 *Actinonaias ligamentina* and 22 *Elliptio dilatata* were returned to the laboratory. Histological examination of these individuals revealed that the male-to-female ratio for *A. ligamentina* was statistically 1:1, and for *E. dilatata* was statistically 1:2.7 (χ^2 = 4.5455, α = 0.05).

Table 1. Field observations of unionids with and without modified gills from the Licking River at Butler, Kentucky.

Taxa	With modified gills	Without modified gills	Totals
Actinonaias ligamentina (Lamarck, 1819)	0	1	1
Alasmidonta marginata Say, 1818	0	1	1
Amblema plicata (Say, 1817)	1	52	53
Cyclonaias tuberculata (Rafinesque, 1820)	0	9	9
Elliptio dilatata (Rafinesque, 1820)	1	14	15
Fusconaia flava (Rafinesque, 1820)	0	1	1
Lampsilis cardium Rafinesque, 1820	3	15	18
Lasmigona complanata (Barnes, 1823)	0	3	3
Lasmigona costata (Rafinesque, 1820)	16	24	40
Megalonaias nervosa (Rafinesque, 1820)	0	10	10
Obliquaria reflexa Rafinesque, 1820	0	2	2
Potamilus alatus (Say, 1817)	4	18	22
Ptychobranchus fasciolaris (Rafinesque, 1820)	1	7	8
Quadrula metanevra (Rafinesque, 1820)	0	1	1
Quadrula nodulata (Rafinesque, 1820)	0	2	2
Quadrula pustulosa (Lea, 1831)	0	2	2
Quadrula quadrula (Rafinesque, 1820)	0	3	3
Tritogonia verrucosa (Rafinesque, 1820)	0	2	2
Totals:	26	167	193

Most of the males of the two target species had more than one stage of spermatogenesis present in their gonads, but usually the most advanced stage present dominated the acini of the testes (Table 2). Spermatids and spermatozoa were the only cell types observed in male *Elliptio dilatata*, with spermatids being the most common. The same was observed in male *Actinonaias ligamentina*, with the exception of one male that had spermatocytes present.

The most advanced stage of gametogenesis present did not always dominate the alveoli of the ovaries in the female *Elliptio dilatata*, as was observed in the testes of the males. Most of the female *E. dilatata* were in the first (eight individuals) or second stages (seven individuals) of oogenesis with oogonia and oocytes, respectively, dominating the alveoli. Even though all of the females had mature ova present in their alveoli, none had this as the dominant cell type. One female was categorized as unknown because the stage of oogenesis could not be determined due to technical difficulties. Mature glochidia were present in the marsupia of most of the female *Actinonaias ligamentina* (57.14%). In *E. dilatata* most of the females (81.25%) had empty marsupia (Table 3).

Table 2. Stages of spermatogenesis observed in male *Elliptio dilatata* and *Actinonaias ligamentina* from the Licking River at Butler, Kentucky. Determined from the most advanced cell type present where stage 1 = spermatogonia, 2 = sperm morulae, 3 = spermatocytes, 4 = spermatids, 5 = spermatozoa.

	Stage of spermatogenesis					
Taxa	1	2	3	4	5	Totals
Actinonaias ligamentina	0	0	1	5	4	10
Elliptio dilatata	0	0	0	4	2	6

DISCUSSION

All drift net collections were made between 1000 and 1700 (EST), which corresponds to the period when glochidial densities should have been at their highest (Kitchell 1985). Bradytictic freshwater mussel species, such as *Actinonaias ligamentina,* tend to release their glochidia from ca. August to May; tachytictic species, such as *Elliptio dilatata,* tend to release their glochidia from ca. May to August (Oesch 1995). It should reasonably be expect-

Table 3. Marsupial contents observed in female *Elliptio dilatata* and *Actinonaias ligamentina* from the Licking River at Butler, Kentucky. Abbreviations are as follows: EE = early embryo; AE = advanced embryo; MG = mature glochidia; EM = empty marsupia.

	Marsupial contents				
Taxa	EE	AE	MG	EM	Totals
Actinonaias ligamentina	0	0	4	3	7
Elliptio dilatata	1	1	1	13	16

ed then, that even through our study occurred only in the summer to late fall, the glochidia of bradytictic mussel species would be collected with drift nets. The relatively large number of juvenile *Corbicula fluminea* collected (when compared to the number of glochidia collected) may impact any juvenile unionids present in the bed through resource competition (Neves and Widlak 1987).

One of the most important factors determining the success of reproduction in unionids is the presence of a suitable host. Only 25.7% of the fishes collected were suitable hosts for unionids known from the bed (Watters 1994); none of these had glochidia attached. The reason for the lack of infested fishes is unknown. The attachment of glochidia to their hosts is dependent upon several factors such as infestations of hosts by copepod parasites (Wilson 1916), age of the host, immunity caused by previous infestations (Parker et al. 1984), and water temperature (Matteson 1948).

The determination of a male-to-female ratio from field observations is probably not a true representation of the actual ratio since most unionids are not sexually dimorphic (McMahon 1991). The only way to determine the sex of an individual without using standard histological techniques is to examine the gills for signs of gravidity in the field. Since several species of unionids usually maintain a 1:1 male-to-female ratio (Jirka and Neves 1992), the 6.42:1 ratio from the field observations may indicate a problem. The male-to-female ratio based only on these field observations indicated that less than 25% of the unionids in this community were females. The cause of the 1:2.7 ratio in *Elliptio dilatata* based on histological analysis in the laboratory was not known. Small sample size alone was probably not the reason because sample size did not differ greatly among the two target species.

The lack of earlier stages of spermatogenesis in males of both species is thought to be related to a normal temperature regimen at Butler. Water temperature is believed to be the most important exogenous factor controlling reproduction in unionids (Matteson 1948; Tedla and Fernando 1969; Zale and Neves 1982) and is not regulated at this location by the releases of hypolimnionic water from an upstream reservoir as it was found to be at another site farther upstream and closer to the reservoir (McMurray 1997).

Further study in this and in other freshwater mussel communities needs to be completed to assess the current health of these historically diverse and successful communities that were previously thought to be healthy. For example, the qualitative methods used to collect unionids are not sufficient to search for juveniles. Juveniles need to be extensively searched for in the community at Butler to affirm that recruitment is occurring. Also, a search for possible upstream causes is necessary to try and ameliorate the impacts to this community.

ACKNOWLEDGMENTS

We thank C. Abbruzzese, J. S. Board, M. C. Compton, M. D. Moeykens, A. R. T. Nix, T. E. Oliver, M. A. Patterson, and D. Vey for assistance in the field and laboratory. R. R. Cicerello (KSNPC) and P. A. Ceas (EKU) assisted with fish identification. G. T. Watters (OSU) provided helpful hints on the use of cross-polarized light microscopy. D. L. Batch (EKU) served on the first author's thesis committee. Two anonymous reviewers provided helpful comments. This research was funded by a grant from the Kentucky Department of Fish and Wildlife Resources (Project No. E-2-9).

LITERATURE CITED

Bruenderman, S. A., and R. J. Neves. 1993. Life history of the endangered fine-rayed pigtoe *Fusconaia cuneolus* (Bivalvia: Unionidae) in the Clinch River, Virginia. Am. Malacol. Bull. 10(1):83–91.

Burr, B. M., and M. L. Warren, Jr. 1986. A distributional atlas of Kentucky fishes. Kentucky Nature Preserves Comm. Sci. Techn. Ser. 4.

Cicerello, R. R., M. L. Warren, Jr., and G. A. Schuster. 1991. A distributional checklist of the freshwater unionids (Bivalvia: Unionoidea) of Kentucky. Am. Malacol. Bull. 8(2):113–129.

Garner, J. T. 1993. Reproductive cycle of *Quadrula metanevra* (Unionidae) in Kentucky Reservoir, Tennessee River, Hardin Co., Tennessee. M.S. Thesis. University of Alabama, Huntsville, AL.

Hannan, R. R., M. L. Warren, Jr., K. E. Camburn, and R. R. Cicerello. 1982. Recommendations for Kentucky's outstanding water classifications with water quality criteria for protection. Kentucky State Nature Preserves Comm. Techn. Rep., Frankfort, KY.

Harker, D. F., S. M. Call, M. L. Warren, Jr., K. E. Camburn, and P. Wigley. 1979. Aquatic biota and water quality survey of the Appalachian Province, eastern Kentucky. Kentucky Nature Preserves Comm. Techn. Rep., Frankfort, KY.

Humason, G. L. 1967. Animal tissue techniques, 2nd ed. W.H. Freeman and Company, San Francisco, California.

Jirka, K. J., and R. J. Neves. 1992. Reproductive biology of four species of freshwater mussels (Mollusca: Unionidae) in the New River, Virginia and West Virginia. J. Freshwater Ecol. 7:35–44.

Johnson, L. E. 1995. Enhanced early detection and enumeration of zebra mussel (*Dreissena* spp.) veligers using cross-polarized light microscopy. Hydrobiologia 312: 139–146.

[KSNPC] Kentucky State Nature Preserves Commission. 1996. Rare and extirpated plants and animals of Kentucky. Trans. Kentucky Acad. Sci. 57:69–91.

Kitchell, H. E. 1985. Life history of the endangered shiny pigtoe pearly mussel *Fusconaia edgariana* in the North Fork Holston River, Virginia. M.S. Thesis. Virginia Polytechnic Institute and State University, Blacksburg, VA.

Laudermilk, E. L. 1993. A survey of the unionids (Bivalvia: Unionidae) of the mainstem Licking River and selected tributaries below Cave Run Reservoir, Kentucky. M.S. Thesis. Eastern Kentucky University, Richmond, KY.

Matteson, M. R. 1948. Life history of *Elliptio complanatus* (Dillwyn, 1817). Am. Midl. Naturalist 40:690–723.

McMahon, R. F. 1991. Mollusca: Bivalvia. Pages 315–399 in J. H. Thorp and A. P. Covich (eds). Ecology and classification of North American freshwater invertebrates. Academic Press, San Diego, CA.

McMurray, S. E. 1997. Reproduction in a freshwater mussel (Bivalvia: Unionidae) community downstream of Cave Run Reservoir in the Licking River at Moores Ferry, Kentucky. M.S. Thesis. Eastern Kentucky University, Richmond, KY.

Neves, R. J., and J. C. Widlak. 1987. Habitat ecology of juvenile freshwater mussels (Bivalvia: Unionidae) in a headwater stream in Virginia. Am. Malacol. Bull. 5(1): 1–7.

Oesch, R. D. 1995. Missouri naiades: a guide to the mussels of Missouri. Missouri Department of Conservation, Jefferson City, MO.

Parker, R. S., C. T. Hackney, and M. F. Vidrine. 1984. Ecology and reproductive strategy of a south Louisiana freshwater mussel, *Glebula rotundata* (Lamarck) (Unionidae: Lampsilini). Freshwater Invertebr. Biol. 3(2):53–58.

Tedla, S., and C. H. Fernando. 1969. Observation on the glochidia of *Lampsilis radiata* (Gmelin) infesting yellow perch, *Perca flavescens* (Mitchell) in the Bay of Quinte, Lake Ontario. Canad. J. Zool. 47:705–712.

Watters, G. T. 1994. An annotated bibliography of the reproduction and propagation of the Unionoidea (primarily of North America). Ohio Biol. Surv. Misc. Contr. 1.

Williams, J. D., M. L. Warren, K. S. Cummings, J. L. Harris, and R. J. Neves. 1993. Conservation status of freshwater mussels of the United States and Canada. Fisheries 18(9):6–22.

Wilson, C. B. 1916. Copepod parasites of fresh-water fishes and their economic relations to mussel glochidia. Bull. U.S. Bur. Fish. 34:331–374.

Zale, A. V., and R. J. Neves. 1982. Fish hosts of four species of lampsiline mussels (Mollusca: Unionidae) in Big Moccasin Creek, Virginia. Canad. J. Zool. 60:2535–2542.

J. Ky. Acad. Sci. 60(2):73–77. 1999.

Relationships between Selected Meteorological/Pollution Parameters and Hospital Admissions for Asthma in South Central Kentucky

L. Michael Trapasso

College Heights Weather Station, Department of Geography and Geology, Western Kentucky University, Bowling Green, Kentucky 42101

and

Larisa Keith

School of Planning, University of Cincinnati, Cincinnati, Ohio 45221

ABSTRACT

Relationships between selected meteorological and pollution parameters and the number of hospital admissions for asthma attacks were investigated in the Bowling Green, Kentucky, area during calendar year 1994. Meteorological data were obtained from the College Heights Weather Station, Department of Geography and Geology, Western Kentucky University. Meteorological parameters included temperature, relative humidity, and barometric pressure. Pollution data were received from the Environmental Protection Agency and represented concentrations of carbon monoxide, nitrogen dioxide, and sulfur dioxide. The number of asthma admissions per day was recorded from two area hospitals. Analysis tested whether an increase in the number of asthma attacks would correspond with any or all of the following: low temperatures, low barometric pressure, high relative humidity, and high levels of sulfur dioxide, carbon monoxide, and nitrogen dioxide. Lagged data allowed for correlation between asthma attacks on 1 day with atmospheric variables of up to 2 days previous. The graphical and statistical results showed several weak but significant correlations between the number of asthma attacks and the independent variables.

INTRODUCTION

Asthma is a chronic respiratory disease that occurs when the bronchial tubes in the lungs react negatively to a stimulant. These tubes become narrowed and block the flow of air. Simultaneously, muscles in the bronchial walls contract and a clogging mucus is secreted. The most common symptom of all asthma sufferers is a severe shortness of breath caused by reversible airway obstructions. Other symptoms may include wheezing, chest pain, fatigue, nighttime cough, irritability, and loss of appetite. With allergic asthma, some symptoms are sneezing and itchy and runny nose and eyes (Tromp 1980).

Asthma and Weather

About 5 percent of the nation's population has asthma. Around 2.5 million of those are children up to age of 17 (O'Hollaren et al. 1991). A possible cause of the increased number of affected children could be exposure to dust mites. These tiny pests are more likely to infest a house that is well sealed. In recent years, Americans have more effectively sealed their homes to be more energy conscious.

Adult asthma is more frequent in women than in men. One possible cause is the hormone estrogen. Increasing estrogen has been shown to inhibit airflow through the lungs. Women who take post-menopausal estrogen are 50 percent more likely to develop asthma than those who have never taken it (Seachrist 1995).

There are several meteorological parameters that have been linked to the onset of asthma, most of them very poorly understood. Certain meteorological events can contribute to the problem (Curson 1993): thunderstorms, sand storms, rapid passage of frontal systems, increased wind movement, excessive heat, humid and still air, and spring rains. Rain and thunderstorms can foster the release of pollen, which can affect allergic asthma sufferers. Likewise, precipitation can bring sulfuric acid and other aerosols closer to the ground (Curson 1993). It has been theorized that changes in atmospheric ionization and falling barometric pressure brought on by thunderstorms or frontal passages can aggravate the disease (Tromp 1980). In Helsinki, wind speed was correlated with asthmatic hospital admissions;

however, though temperatures correlated positively, relative humidity seemed to have no effect (Ponka 1991).

In the early 1960s, researchers found that weather cold enough for activation of furnaces increased the number of hospital visits for asthma. Thus it was thought that the gases emitted from furnaces could have been the contributing factor (Greenburg et al. 1964). On the other hand, another study noted that a peak of asthma admissions did correlate with deep layers of cold air (Tromp 1980).

Seasonal releases of pollen and mold appear to have an effect on asthma sufferers. A study in Switzerland found that the increase in hospital admissions for asthma attacks correlated first with birch and grass pollen (Frank et al. 1992)

Some have claimed a seasonality with asthma attacks. The two seasons that seem to irritate asthmatics most are spring and autumn. The increase of warmth and humidity as spring turns to summer increases the growth of mold and other fungi, thus affecting asthmatics (Curson 1993). It was also found that asthma attacks increase during autumnal storms and the strong atmospheric cooling in the transition to winter (Tromp 1980). Other research concluded that the reaction to all seasonal variations will differ strongly among asthmatics (Frank et al. 1992).

Asthma and Pollutants

In addition to allergens in the air, pollution also has been shown to have an effect on asthma sufferers. In 1991 sixty-three percent of asthma sufferers lived in areas where at least one U.S. federal air quality standard was exceeded. Prolonged hot and humid weather is known to increase production of photochemical smog, which is one possible agent triggering asthma attacks (Curson 1993).

In New Jersey, from May to August 1988 and 1989, strong relationships were found between summertime ozone concentrations and hospital admissions for asthma (Cody et al. 1992). Similar results were found in Los Angeles and in Ontario, Canada (Thurston et al. 1994). Using subjects with chronic obstructive pulmonary diseases and who exercised lightly, investigators found that moderate ozone concentrations did not produce serious risk to asthmatics (Linn et al. 1983).

Other studies revealed that ambient air pollution, especially sulfur dioxide, along with cold weather, increases the frequency of asthma episodes (Ponka 1991). In Yokkaichi, Japan, the mortality from chronic obstructive lung disease was measured in sulfur dioxide polluted areas. The findings showed that there was a larger mortality rate in polluted areas (Imia et al. 1986). Sulfur dioxide concentrations and cold air can affect asthma when taken together (Linn et al. 1984).

Another possible contributor to increased asthma attacks is the total suspended particles in the air. In three similar cities close to a volcanic eruption in Japan, it was found that the city closest to the volcano had the highest reported number of respiratory-disease cases (Yano et al. 1986). Around the Mount St. Helens explosion of 18 May 1980 there was an increased number of emergency-room visits from respiratory complaints because of elevated levels of suspended particles (Baxter et al. 1983).

HYPOTHESIZED RELATIONSHIPS

The literature is filled with confusing and sometimes contradictory results concerning the effects of weather and pollution variables on asthma. However confusing it might be, some of the possible causes of asthma attacks taken from the literature were used to develop specific relationships explored in our research.

Relationship One: There is an inverse relationship between temperature and asthma attacks. This argument is supported by Greenburg et al. (1964) and Tromp (1980).

Relationship Two: There is a negative correlation between barometric pressure and asthma attacks. This argument is supported by Tromp (1980).

Relationship Three: There is a positive correlation between relative humidity and asthma attacks. This correlation was suggested by Ponka (1991).

Relationship Four: There is a direct relationship between the amount of sulfur dioxide in the atmosphere and the number of asthma attacks. This suggestion is supported by Ponka (1991) and Linn et al. (1984).

Relationship Five: There is a direct relationship between carbon monoxide and asthma attacks. This is based on the work by Greenburg et al. (1964).

Relationship Six: Nitrogen dioxide and asthma attacks are positively correlated with each other. This was indirectly supported by Yano et al. (1986).

METHODS

Study Area

Our research was conducted in Bowling Green, in Warren County, Kentucky. The city's two hospitals, the Medical Center at Bowling Green and the Greenview Hospital, serve the surrounding 10-county area.

Data Collection

Air pollution data were obtained from the Environmental Protection Agency State Office in Frankfort, Kentucky, which provided maximum and mean values for carbon monoxide, nitrogen dioxide, and sulfur dioxide. These levels were recorded by the Shell Environmental Monitoring Company, subcontracted by General Motors, in Bowling Green. The data were collected in units of parts per million for each hour of the day.

Meteorological data were acquired from the College Heights Weather Station, Department of Geography and Geology, Western Kentucky University, Bowling Green. The daily mean temperatures were calculated from 24 hourly readings from thermograph charts. Daily mean relative humidity was calculated by the same method using hygrograph charts. Daily mean barometric pressure was derived from microbarograph charts.

Asthma data, in the form of hospital admissions per day, were obtained from the two hospitals in Bowling Green. Also included were the age and sex of admitted patients. The confidentiality of hospital records allowed only for selected data to be released. The period of study ran from January to December 1994.

Data Transformation

The incompatibility of the various types of data was a major problem to overcome before any meaningful analysis could take place. The dependent variable of asthma attacks was recorded in admissions per day. These numbers ranged from a minimum of 0 to a maximum of 7. However, all the other types of data took very different formats and units of measure. Daily mean temperatures were measured in degrees F. Daily mean relative humidities were measured in percent. Daily mean barometric pressures were recorded in inches of mercury. Pollution data for both means and maximums were reported in parts per million.

Considering the variety of units found with the raw data, a standard parametric statistical approach would render an invalid analysis. Therefore, a data transformation was necessary. All the data sets were transformed into an equal interval ranking system ranging from 0 through 7, using the Jenks Ranking Program. With this done, a non-parametric statistical approach could yield valid results.

ANALYSIS

After some basic descriptive statistics, the analysis proceeded through two stages. The first involved graphic analysis to check for apparent relationships between any of the variables and the number of attacks through time. Though suggestive, these graphs were not conclusive.

Next, statistical analyses were completed using the Statistical Package for the Social Sciences (SPSS) to calculate Spearman Rank Correlation Coefficients. The number of asthma attacks was then lagged 1 day behind the meteorological/pollution variables. In other words, we correlated the number of asthma admissions for a particular day as a function of the atmospheric conditions of the previous day. The analysis was then repeated with a 2-day lag to test if antecedent conditions of 2 days prior would affect the number of asthma attacks.

RESULTS

The total number of asthma attacks per day underwent basic descriptive statistics. The mean was 1.271 with a standard deviation of 1.705. All dates were used excluding only those with no data. A total of 434 attacks was recorded, of those 255 were female and 179 were male.

The ages of the patients ranged from 4 months to 97 years. The patient's age distribution was as follows: (1) 1 to 10, 100 cases; (2) 11 to 20, 60 cases; (3) 21 to 30, 57 cases; (4) 31 to 40, 66 cases; (5) 41 to 50, 30 cases; (6) 51 to 60, 45 cases; (7) 61 to 70, 43 cases; (8) 71 to 80, 24 cases; (9) 81 to 90, 7 cases and; and (10) 91 to 100, 2 cases.

A graphic analysis took the independent

variables—daily mean temperature, barometric pressure, relative humidity; daily SO_2 mean, SO_2 maximum, CO mean, CO maximum, NO_2 mean, and NO_2 maximum, and superimposed the number of asthma attacks. These were then compared to the hypothesized relationships.

Finally, Spearman Rank Correlation Coefficients were calculated for every variable with the number of asthma attacks per day. Significance level was set at 90%.

Relationship One: The Spearman Rank Correlation Coefficient was only −0.21, the 1-day lag yielded a −0.32, and the 2-day lag dropped back to −0.20. The same-day correlation was found to be significant. Though the correlation coefficients were found to be small, they were all negative relationships as was assumed.

Relationship Two: The Spearman Coefficient was 0.34, a 0.38 for the 1-day lag, and a 0.29 for the 2-day lag. The first two values proved to be significant, and the sign of the relationship supported the original assumption. These were the highest correlations found among the weather variables.

Relationship Three: The Spearman Rank Correlation Coefficient was 0.22, the 1-day lag increased it to 0.31, and the 2-day lag amounted to 0.23. All of the coefficients concerning relative humidity were statistically significant at 90% level of confidence. Again the sign of the relationships held with the original assumption.

Relationship Four: The Spearman Coefficient for sulfur dioxide showed 0.30 for the mean values and 0.37 for the maximum values. The 1-day lag yielded 0.34 and 0.40 for mean and maximum, respectively. The 2-day lag produced a 0.32 for the mean SO_2 and a statistically significant (at the 90% level) 0.34 for the SO_2 maximum. These were among the highest correlations found in all of the analysis; and the sign of the relationships were all positive.

Relationship Five: The Spearman Coefficient for CO mean was a 0.19, and for CO max it was 0.26. For the 1-day lag a 0.27 and a 0.36 were calculated, respectively. The 2-day lag brought forth a 0.21 and a 0.24, respectively. Only one of these coefficients was significant, but again all the signs held with those hypothesized.

Relationship Six: The Spearman Coefficients showed 0.17 for NO_2 mean and, 0.22 for NO_2 maximum values. The 1-day lag yielded a 0.27 and a 0.30; the 2-day lag, a 0.21 and a 0.22. Again only one of these correlations was significant at the 90% level.

DISCUSSION

We attempted to identify some possible factors for the number of asthma admissions per day at the two area hospitals. Both graphic analysis and the Spearman Rank Correlation analysis showed no strong correlations between the number of asthma admissions and weather/pollution parameters. All the correlation coefficients were rather weak. Herein lies the caveat when conducting human biometeorological research. When correlating something as tangible as a temperature reading with something as intangible as pain or feelings of discomfort, the coefficients will not be as strong as those in other types of research. Therefore, correlation coefficients in the 0.20 to 0.30 range are not as weak as they may seem, and coefficients reaching as high as 0.40 are, in the authors' opinions, encouraging.

It is also important to note two other consistencies found within the results. (1) Even with the weakest correlations, the sign of the relationships followed the assumptions made at the outset of our research. (2) With each parameter, the 1-day lag correlation was the highest. Interviews with respiratory specialists concurred with these findings using the following rationale. On the same day as the onset of the asthma attack, chronic suffers may delay a trip to the hospital in hopes of a natural subsidence of the symptoms. The 1-day lag represents a continued discomfort and a consequent request for treatment. The 2-day lag correlation coefficients drop off. This is likely affected by two reasons. The first is that the symptoms have subsided and the asthmatic chooses not to seek treatment; the second, that the asthmatic's medication is taking effect. At any rate, these trends were consistent.

The lack of very srong correlations cause other questions to come to light. For example, are hospital admissions per day a true measure of asthma attacks within the general populace? Future studies may attempt to find other sources for the asthma data, e.g., questionnaires and interviews with asthma sufferers or data from physicians in private practice.

Another question may address the relatively small geographical area used in this study. Future studies may encompass larger metropolitan areas for greater sample size. We certainly urge more research along these lines to help shed light on this still misunderstood disease.

LITERATURE CITED

Baxter, P. J., R. Ing, and H. Falk. 1983. Mount St. Helens eruptions: the acute respiratory effects of volcanic ash in a North American community. Arch. Environm. Health 38:138–143.

Cody, R. P., C. P. Weisel, and G. Birnbaum. 1992. The effect of ozone associated with summertime photochemical smog on the frequency of asthma visits to hospital emergency department. Environm. Res. 58:184–194.

Curson, P. 1993. Climate and chronic respiratory disease in Sydney: the case of asthma. Clim. Change 25:405–420.

Frank, K., A. Boeriu, and P. Degens. 1992. A 3-year cohort study on short term effects of air pollution in Germany. 1. Influences of medication and season. Sci. Total Environm. 127:69–78.

Greenburg, L., P. Field, and J. Reed. 1964. Asthma and temperature change. Arch. Environm. Health 8:642–647.

Imia, M., K. Yoshida, and M. Kitabatake. 1986. Mortality from asthma and chronic obstructive pulmonary disease. Arch. Environm. Health 39:339–345.

Linn, W., D. Shamo, and T. Vinet. 1984. Response to ozone in volunteers with chronic obstructive pulmonary disease. Arch. Environm. Health 38:278–283.

O'Hollaren, M., J. Yunginger, and K. Offord. 1991. Exposure to an allergen as a possible precipitating factor in respiratory arrest in young patients with asthma. New England J. Med. 324:359–363.

Ponka, A. 1991. Asthma and low level air pollution in Helsinki. Arch. Environm. Health 46:262–269.

Seachrist, L. 1995. Estrogen linked to adult asthma risk. Sci. News 148:279.

Thurston, G., I. Ito, and C. Hayes. 1994. Respiratory hospital admissions and summertime haze air pollution in Toronto,Ontario: consideration of the role of acid aerosols. Environm. Res. 65:271–290.

Tromp, S. W. 1980. Biometeorology. W. and J. Mackay Ltd., London.

Yano, E., S. Nishi, and Y. Yokoyama. 1986. Chronic pulmonary effects of volcanic ash: an epidemiologic study. Arch. Environm. Health 41:94–99.

Acad. Sci. 60(2):78–86. 1999.

Managing Red-Cockaded Woodpeckers (*Picoides borealis*) Affects Breeding-Bird Communities of Pine-Oak Forests in Southeastern Kentucky

Martina Hines

Kentucky State Nature Preserves Commission, 801 Schenkel Lane, Frankfort, Kentucky 40601

ABSTRACT

Breeding-bird communities were surveyed on the Daniel Boone National Forest, Kentucky, using point counts, in mid May, late May, and early June 1994 and 1995. Twenty-eight stands of Appalachian pine-oak forest were surveyed of which 14 were managed for red-cockaded woodpeckers (RCWs). Management involved removal of midstories (2.5–17.5 cm dbh) and repeated prescribed burns. Results indicate that these management practices appear to have effects similar to that of timber harvests on species composition and abundance of breeding birds. Prescriptions for RCWs were beneficial to several species associated with early successional and edge habitat, including at least some neotropical migrants whose numbers are decreasing in eastern North America (e.g., indigo bunting, hooded warbler, and prairie warbler). Management for RCWs appears to decrease habitat quality for other neotropical migrants, particularly those associated with forest interiors.

INTRODUCTION

Appalachian pine-oak forests on the southern part of the Daniel Boone National Forest (DBNF) are managed for red-cockaded woodpeckers (*Picoides borealis*). The United States Forest Service (USFS) manages RCW habitat according to guidelines developed in the coastal plains (USFS 1995), where the species inhabits mature open pine forests and where these stands are naturally maintained by fire. These forests are composed primarily of loblolly, slash, or longleaf pines and are considered typical RCW habitat (Hooper et al. 1980; USFS 1995) but do not occur in Kentucky (Braun 1974). Instead, all known RCW colonies in Kentucky are in stands classified as Appalachian pine-oak forest (Evans 1991) and have a large upperstory hardwood component and possess a well-developed hardwood midstory. Forest management for RCWs in Kentucky, involving mechanical removal of hardwood midstories and application of controlled burns, is intended to mimic typical habitat conditions found in the open pine forests of the southeastern United States.

Unfortunately very little is known about the natural history of Appalachian pine-oak forests. Remnant populations of certain plant and animal species with a fire affiliation indicate that fire might have played a role in shaping these stands (Campbell et al. 1990; MacGregor pers. comm. 1993), but uncertainty about the frequency and impact of fires on pine-oak forests exists (Kalisz pers. comm. 1994).

Since current management practices were implemented for RCWs in Kentucky in the late 1980s, the population has decreased from 18 to 1 native birds (Feltner pers. comm. 1998; KSNPC 1999). Because it is doubtful if management benefits RCWs in Kentucky and it is unclear how these management practices affect other components of the ecosystem, additional information is necessary to assess the overall efficacy of existing management practices for RCWs in pine-oak forests.

Breeding-bird communities are one of many components likely to be impacted by RCW management. Previous studies in other parts of the range of RCWs demonstrate that the structure of these communities changes in response to thinning and fire (Holmes et al. 1986; Robbins et al. 1989; Wilson et al. 1995). Wilson observed that those neotropical migrants depending on early-successional or open forest habitats benefit from RCW management, whereas other species, dependent on undisturbed forests, decline. In my study I evaluated the effects of RCW management on breeding-bird communities in pine-oak forest in Kentucky.

MATERIALS AND METHODS

Study Area

The study area, the Daniel Boone National Forest in southeastern Kentucky, lies along the escarpment defining the western edge of the Cumberland Plateau physiographic region (Campbell 1997) and is included in the mixed mesophytic forest region (Braun 1974). All sites were on USFS lands in Whitley, Pulaski, and Laurel counties, the tracts of forest defined by the USFS as in need of management for RCWs.

The terrain, rugged and stream eroded, supports a landscape that has rolling uplands, narrow ridges, steep slopes, and ravines. This geographic heterogeneity explains the presence of numerous forest types. The well-drained soils of the ridge tops are covered predominantly with pine and mixed pine-oak stands. These stands are often small, occurring as narrow bands along elevational contours. According to the USFS, pine and pine-oak stands, considered suitable habitat for RCWs, account for 35% of the total forested area (Kalisz and Boettcher 1991). Stand size ranges from ca. 2 to 5 ha. Upperstory basal area of stands ranges from ca. 5 to 13.3 m^2/ha (Hines and Kalisz 1995). Common species are shortleaf pine (*Pinus echinata*), which accounts for 50 to 75% of the basal area; pitch pine (*Pinus rigida*); Virginia pine (*Pinus virginiana*); various oaks (*Quercus alba, Q. coccinea, Q. falcata, Q. montana, Q. velutina*); and tight-barked hickories (*Carya glabra, C. tomentosa*).

Unmanaged stands have a well-developed hardwood midstory and a sparsely developed understory (Hines and Kalisz 1995). The lower strata are dominated by red maple (*Acer rubrum*), flowering dogwood (*Cornus florida*), blackgum (*Nyssa sylvatica*), and sourwood (*Oxydendrum arboreum*) (Kalisz and Boettcher 1991).

Managed stands have an upperstory basal area comparable to that of unmanaged stands. But hardwood midstories (stem size of 2.5 to 17.5 cm dbh) were cut in 1989 and 1990, resulting in a large amount of woody debris on the ground. Controlled burns are conducted every 3 to 5 years. At the time of my surveys, some treatment stands ($n_{1994} = 6$, $n_{1995} = 4$) had been burned within the previous 2 months and supported limited growth in the understory, whereas the remainder ($n_{1994} = 8$, $n_{1995} = 10$) were burned 1 or 2 years earlier and supported a dense and brushy understory.

Field Methods

During spring 1994 and 1995 I conducted surveys in 28 stands in Appalachian pine-oak forest; 14 of these were managed for RCWs. All stands were visited three times: mid May, late May, and early June of both years. During a survey period, all stands were visited in a random sequence within 3 consecutive days during the hours of 0600 to 1000 EDST. Relative bird abundance was quantified using a fixed-radius point count method (Hutto et al. 1986). Observations were recorded from a point at the approximate center of each stand, ≥75 m from the stand boundary to minimize edge effects. For 12 minutes at each stand, birds were identified by sound and sight. Species, approximate distance to the observer, and location within or outside the survey stand were recorded for each individual bird. Only birds within a 100 m radius, or within the borders of the stand, if that distance was smaller, were recorded.

Statistical Analysis

For the analysis, stands were classified as managed and unmanaged, lumping stands that were recently burned with stands that had been burned in previous years as managed. Mann-Whitney tests were used to compare differences in frequency of occurrence between unmanaged and managed stands for individual bird species and to test for differences in species richness and total abundance of edge and interior species, respectively, between treatments. Bird species were divided into edge and interior species depending on their reported tolerance for edge habitat (AOU 1983; Hamel 1992; Mengel 1965; Palmer-Ball 1995). Interior species were defined as species with a low tolerance for edge habitat; edge species included those that prefer open and disturbed areas (Table 1). A subset of data on forest-interior, neotropical migrants was analyzed separately. Mann-Whitney tests were also used to compare differences in species richness and total abundance between treatments for species with different nesting requirements. Species were grouped into five categories: primary and secondary cavity nesters, ground nesters, shrub nesters, midstory nesters, and canopy nesters. Previous research was used to identify which species were likely to be transients in the study area (Mengel 1965; Palmer-Ball 1995). Accordingly, transient species were excluded from analyses based on their nesting requirements (Table 1). Mann-Whitney tests were also used to test for differences in total abundance and species richness of avian species belonging to different foraging guilds. Species were divided into five guilds: ground/shrub, midstory, canopy, bole, and aerial foragers (Mengel 1965; Palmer-Ball 1995).

RESULTS

A total of 1474 individual birds (n1994 = 626, n1995 = 848) belonging to 44 (plus 5 migrant) species was recorded. Of these, 863 birds (n1994 = 351, n1995 = 512) belonging to 43 species were recorded in managed stands, and 6111 birds (n1994 = 275, n1995 = 336) belonging to 32 species were recorded in unmanaged stands. Overall, species richness did not differ between managed and unmanaged stands. Bird abundance was slightly higher in managed stands, but the difference was not significant (w = 28, $P = 0.07$).

Differences in Abundance and Frequency of Occurrence of Individual Species

The most common species in unmanaged stands were ovenbird (*Seiurus aurocapillus*), red-eyed vireo (*Vireo olivaceus*), pine warbler (*Dendroica pinus*), and indigo bunting (*Passerina cyanea*), respectively (Table 1). Other common species were hooded warbler (*Wilsonia citrina*), Carolina chickadee (*Parus carolinensis*), pileated woodpecker (*Dryocopus pileatus*), white-breasted nuthatch (*Sitta carolinensis*), and scarlet tanager (*Piranga olivacea*), all recorded ≥18 times. Common species in managed stands were indigo bunting, hooded warbler, prairie warbler (*Dendroica discolor*), and rufous-sided towhee (*Pipilo erythrophthalmus*), respectively (Table 1). Other common species were red-eyed vireo, pine warbler, Carolina chickadee, and pileated woodpecker, all recorded ≥35 times.

Mann-Whitney tests indicated differences in frequency of occurrence for some species. Ovenbirds were more common in unmanaged than in managed stands (w = 21, $P < 0.0057$; Table 2). Red-eyed vireos were recorded twice as often in unmanaged as in managed stands (w = 26, $P = 0.05$). During 1994, yellow-breasted chats (*Icteria virens*) were more common in managed stands (w = 21, $P = 0.0057$) and were never recorded in unmanaged stands. In 1995, only a single individual was detected in a managed site. Indigo buntings were more common in managed stands (w = 21, $P < 0.0057$). No statistically significant difference was found for hooded warblers, but about twice as many were detected in managed than in unmanaged stands. The following species were found to be significantly more common in managed than in unmanaged stands: rufous-sided towhee (w = 21, $P = 0.0057$), prairie warbler (w = 25, $P = 0.0036$), and pileated woodpecker (w = 7.5, $P = 0.063$). No difference in frequency of occurrence was found for any other species.

Responses to Treatments by Edge and Interior Species

Species richness of edge species was higher in managed than in unmanaged stands. Twenty-two edge species were recorded in managed stands versus 15 species in unmanaged stands. Nineteen interior species were recorded in managed versus 17 interior species in unmanaged stands. Edge species were significantly more common in managed versus unmanaged stands (496 versus 151 observations; w = 21, $P = 0.0057$). Total abundance of interior species was lower in managed than in unmanaged stands (355 versus 442 observations).

Nearly all species categorized as forest interior species in my study are neotropical migrants (14 of 20), whereas only about one fourth (6 of 24) of edge species are neotropical migrants (Table 1). There was no significant difference in the frequency of occurrence of neotropical migrants (447 vs. 490 observations) between managed and unmanaged stands with 17 species observed in both types of treatments. A more noticeable difference in occurrence between unmanaged and managed stands for neotropical migrants was evident for forest interior species (w = 27, $P = 0.05$). This group of species accounted for 384 occurrences in unmanaged and only 268 occurrences in managed stands.

Comparison of Abundance and Richness of Species of Different Nesting Requirements

Primary and secondary cavity nesters were more abundant in managed than in unman-

Table 1. Species parameters and total observations from 1994 and 1995 recorded in stands managed for RCWs (m) and in unmanaged stands (u) in Kentucky.

Species	Edge/interior	Nesting niche	Foraging niche	Neotropical migrant	Type of residence	Stands	
						m	u
American crow	edge	canopy	pred/scav	no	year round	13	36
American goldfinch[1]	edge	shrub	ground/shrub	yes	year round	21	11
American robin	edge	shrub	ground/shrub	no	year round	4	0
black-and-white warbler	interior	ground	midstory	yes	summer	15	5
black-throated green warbler	interior	midstory	midstory	no	summer	3	13
blue jay	edge	midstory	midstory	no	year round	5	2
blue-gray gnatcatcher	edge	midstory	midstory	yes	summer	0	2
blue-winged warbler	edge	ground	midstory	no	summer	2	3
brown-headed cowbird	edge	parasite	ground/shrub	no	summer	13	0
Cape May warbler[1]	edge	midstory	midstory	yes	transient	0	1
Carolina chickadee	edge	2nd cav	midstory	no	year round	37	29
Carolina wren	edge	2nd cav	ground/shrub	no	year round	7	0
cedar waxwing	edge	midstory	midstory	no	summer	31	4
cerulean warbler	interior	canopy	midstory	yes	summer	1	1
chestnut-sided warbler	edge	shrub	midstory	yes	summer	4	0
chipping sparrow	edge	shrub	ground/shrub	no	year round	2	0
common yellowthroat	edge	shrub	ground/shrub	no	summer	18	0
dark-eyed junco[1]	edge	ground	ground/shrub	no	year round	0	2
eastern wood pewee	interior	canopy	aerial	no	summer	13	2
hairy woodpecker	interior	cavity	bole	no	year round	7	5
hooded warbler	interior	shrub	midstory	yes	summer	56	32
indigo bunting	edge	shrub	ground/shrub	yes	summer	127	41
Kentucky warbler[1]	interior	ground	ground/shrub	yes	summer	1	0
magnolia warbler	interior	midstory	canopy	yes	transient	1	0
mourning dove	edge	midstory	ground/shrub	no	year round	8	0
northern cardinal	edge	shrub	ground	no	year round	2	0
northern flicker	edge	cavity	ground/shrub	no	year round	6	3
ovenbird	interior	ground	ground/shrub	yes	summer	24	135
pileated woodpecker	interior	cavity	bole	no	year round	35	16
pine warbler	interior	canopy	midstory	yes	summer	40	58
prairie warbler	edge	shrub	ground/shrub	yes	summer	68	7
red-bellied woodpecker	edge	cavity	bole	no	year round	17	2
red-cockaded woodpecker	interior	cavity	bole	no	year round	14	0
red-eyed vireo	interior	midstory	canopy	yes	summer	42	88
red-headed woodpecker	edge	cavity	bole	no	year round	8	0
rose-breasted grosbeak[1]	interior	midstory	midstory	yes	summer	1	1
rufous-sided towhee	edge	ground	ground/shrub	no	year round	46	1
scarlet tanager	interior	canopy	midstory	yes	summer	24	18
summer tanager	interior	canopy	midstory	yes	summer	10	13
tufted titmouse	edge	2nd cav	midstory	no	year round	15	5
white-breasted nuthatch	interior	2nd cav	bole	no	year round	31	22
wild turkey	edge	ground	ground	no	year round	0	2
wood thrush	interior	midstory	ground	yes	summer	0	2
worm-eating warbler	interior	ground	midstory	yes	summer	15	14
yellow warbler	edge	srub	canopy	yes	summer	0	4
yellow-billed cuckoo	edge	midstory	midstory	yes	summer	22	9
yellow-breasted chat	edge	shrub	ground/shrub	no	summer	41	1
yellow-throated vireo	interior	canopy	canopy	yes	summer	24	8
yellow-throated warbler	interior	canopy	bole	yes	summer	16	10

[1] Species excluded from analyses because observations fell outside their reported range or breeding season.

aged stands (w = 22.5, P = 0.007). Of these, pileated woodpeckers were the most common woodpecker regardless of stand condition.

Ground-nesting species were slightly more abundant in unmanaged than in managed stands (w = 26, P = 0.036), with ovenbirds accounting for 81.7% of these observations (Table 3). Other ground-nesting species were represented in smaller numbers and did not exhibit patterns between treatments, except

Table 2. Abundance of selected species in stands managed for RCWs (m) versus unmanaged stands (u) in Kentucky observed during each survey.[1]

	Ovenbird		Red-eyed Vireo		Yellow-breasted Chat		Rufous-sided Towhee		Indigo Bunting		Hooded Warbler		Prairie Warbler		Pileated Woodpecker	
Surveys	m	u	m	u	m	u	m	u	m	u	m	u	m	u	m	u
Mid-May 94	8	21	15	14	7	0	7	0	14	10	16	4	18	0	10	5
Late May 94	3	32	5	12	9	0	13	0	30	5	10	12	19	4	4	3
Early June 94	5	9	2	13	8	1	13	0	27	5	14	7	21	0	4	0
Mid-May 95	6	23	7	23	8	0	4	0	14	5	4	2	2	0	3	3
Late May 95	4	24	5	8	7	0	4	0	24	4	4	2	7	2	6	1
Early June 95	6	21	9	18	2	0	5	1	18	12	8	5	1	1	8	4
Mean	5.3	21.7	7.2	14.7	6.8	0.2	7.7	0.2	21.2	6.8	9.3	5.3	11.3	1.2	5.8	2.7

[1] Data are pooled across 14 stands in each category

for rufous-sided towhees, which were more numerous in managed stands. Shrub-nesting species were more abundant in managed than in unmanaged stands (w = 21, $P = 0.0057$). Indigo buntings accounted for most observations in managed stands (38%). Shrub-nesting species observed only in managed stands were yellow-breasted chat, chipping sparrow (*Spizella passerina*), and American robin (*Turdus migratorius*). Other shrub-nesting species represented in small numbers, but not differing in abundance between treatments, were hooded warbler, prairie warbler, and common yellowthroat (*Geothlypis trichas*). Abundance of midstory nesters did not differ between unmanaged and managed stands; however, a high number of red-eyed vireos was recorded in unmanaged stands (n = 88). Red-eyed vireos were also the midstory nester most often recorded in managed stands but in much lower numbers (n = 43). Abundance of canopy-nesting birds did not differ between unmanaged and managed stands. The only nest parasite in the study area, the brown-headed cowbird (*Molothrus ater*), was infrequently observed in managed stands (n = 13) and never in unmanaged stands.

DISCUSSION

Response of Individual Species

Previous studies have shown that ovenbirds and red-eyed vireos are negatively affected by timber harvest regardless of the amount of basal area left standing (Baker and Lacki 1997; Thompson, Probst and Raphael 1992; Welsh and Healy 1993). My study demonstrated that a reduction in midstory basal area alone, even if the upperstory is left untouched, has a similar negative effect on these species. The higher number of hooded warblers observed in managed stands, though statistically not significant, confirms previous studies, which have demonstrated that the species prefers a dense understory (Anderson and Shugart 1974; Baker and Lacki 1997). A reduction of the midstory in managed stands, which encourages this type of habitat, might also improve conditions for fly-catching, a common foraging mode of hooded warblers (Bent 1953; Palmer-Ball 1984).

Baker and Lacki (1997) observed that rufous-sided towhees are positively affected by clearcut and low-leave harvest relative to high-leave harvest or no-harvest; the species is associated with early successional habitat (Hagan 1993). The positive response of rufous-sided towhees to RCW management observed in my study suggests that habitat quality of this species might be determined more by development of the understory than by canopy basal area. A mere reduction in midstory basal area, which facilitates the development of a dense, brushy understory, might be beneficial to towhees. These stands were characterized by a well-developed understory not unlike early successional habitat, which is the stratum this species uses for foraging and nesting (Palmer-Ball 1984).

The higher number of prairie warblers observed in managed stands was expected; this species is associated not only with open, brushy areas and forest edges but also with open forests where much sunlight reaches the ground (Mengel 1965). Mengel specifically mentioned observing the species in pine-oak forests on the Cumberland Plateau. Again, the

Table 3. Total numbers and means of individuals from different bird guilds in stands managed for RCWs (m) versus unmanaged stands (u) in Kentucky observed during each survey.[1]

Surveys	Total abundance		Edge birds		Interior birds		Neotropical interior birds		Nesting guilds: Ground		Shrub		Midstory		Canopy		Cavity	
	m	u	m	u	m	u	m	u	m	u	m	u	m	u	m	u	m	u
Mid-May 94	85	107	56	28	29	79	72	64	12	32	37	11	11	32	4	11	17	11
Late May 94	144	78	102	27	42	51	51	81	14	26	44	9	19	12	11	9	28	10
Early June 94	122	90	76	31	46	59	49	67	15	24	36	18	10	22	15	18	32	9
Mid-May 95	162	109	73	47	89	62	30	73	29	27	60	19	19	18	25	32	28	7
Late May 95	186	127	114	33	72	94	32	47	20	32	75	23	18	15	33	35	38	22
Early June 95	164	100	102	26	62	73	40	67	22	11	67	18	20	22	25	31	25	17
Mean	143.8	101.8	78.7	32	56.7	69.7	45.7	66.5	18.7	25.3	53.2	16.3	16.2	20.1	18.8	22.7	28	12.7

[1] Data are pooled across 14 stands in each category.

presence of a dense, brushy understory, where the species nests and forages (Hamel 1992; Mengel 1965; Palmer-Ball 1995) is probably a key factor in determining habitat quality of this species. Higher abundance of indigo buntings and yellow-breasted chats in managed stands was expected; these species nest and forage in brushy situations and are associated mostly with landscapes altered by humans, e.g., field borders, selectively cut forests, and reclaimed strip-mines (Palmer-Ball 1995).

Even though few brown-headed cowbirds were observed during my study, the presence of this species in managed stands but not in unmanaged stands is reason for concern because of the impact the species can have on nesting birds, particularly neotropical migrants. Cowbird females use trees as perches to locate nests and observe host behavior (Robinson et al. 1992). Stands managed for RCWs might attract cowbirds because of their openness and an abundance of perches, thus increasing detectability of host species.

Impact on Forest-Interior Species and Neotropical Migrants

The positive response of edge species to RCW management indicates that a reduction in midstory basal area and controlled burns has an effect similar to that of other disturbances, such as clearcuts, shelterwood harvests, or selective cuts (Baker and Lacki 1997; Thompson, Dijak et al. 1992; Thompson and Fritzell 1990; Welsh and Healy 1993). The observed difference might have been even larger if most stands had not been located along roads, which can serve as corridors for edge species. Yellow-breasted chats, rufous-sided towhees, prairie warblers, and indigo buntings were all significantly more common in managed stands and are associated with edge habitat. The lack of a positive response by interior species suggests that habitat conditions of these species were not improved by management for RCWs. At least some neotropical migrants associated with forest interiors appear to be negatively affected by this type of management. Ovenbirds and red-eyed vireos, both considered forest-interior species, were significantly more common in unmanaged stands.

Shifts in Species of Different Nesting Requirements

The high number of primary and secondary cavity nesters in managed stands was likely due to the abundance of nesting sites. The number of snags was visibly larger in managed than in unmanaged stands (Feltner pers. comm. 1998). Most primary and secondary cavity nesters forage on boles. Availability of foraging structure in the form of numerous snags and an abundance of dead material on the ground left behind from midstory removal was also likely attractive to these species, particularly woodpeckers. In addition, most species of woodpeckers native to Kentucky engage in fly-catching in open forests (Davis pers. comm. 1995). Hence the open midstory stratum might also have contributed to a higher abundance of woodpeckers in managed stands. Interestingly, pileated woodpeckers, which were significantly more common in managed stands, are generally considered a forest-interior species; however, this species is known to be tolerant of edge and successional habitat as it occurs throughout Kentucky, including the Inner Bluegrass region (Mengel 1965; Palmer-Ball 1995). The higher number of cavity nesters in managed stands was also observed by Palmer-Ball (pers. comm. 1995) and should be considered when making management decisions for RCWs. Increased competition for cavities resulting from management for this species may actually pose a threat to RCWs. In particular, competition for and destruction of cavities by pileated woodpeckers has already been noticed as a problem in managed stands for several years (Murphy 1980).

The availability of open ground in unmanaged stands versus densely vegetated ground in managed stands is likely to contribute to higher numbers of some ground nesters in unmanaged stands. By far the most common ground-nesting species observed was the ovenbird, which is known to prefer habitat with open ground and closed canopy (Mengel 1965; Palmer-Ball pers. comm. 1995). The same might not be true for other ground nesters. Black-and-white warblers, worm-eating warblers, and rufous-sided towhees are known to have an affinity for dense ground cover (Chapman 1968; Palmer-Ball pers. comm. 1995). They might have a preference for managed stands, but, except for rufous-sided towhees, the number of observations was too small to confirm this hypothesis.

The shrub layer was more developed and considerably denser in managed stands than in unmanaged stands. It is therefore not surprising that shrub-nesting species such as hooded warblers were more abundant in managed stands. This confirms the results of Wilson et al. (1994) from a similar study in Oklahoma, which also generated results similar to those reported here for midstory nesters. The lack of midstory in managed stands probably contributed to the fact that midstory nesters were less abundant in managed than in unmanaged stands.

A lower number of observations of birds in the upper canopy could have contributed to a lack of noticeable differences between treatments; however, because the basal area of the upper strata did not differ between treatments (management only involves manipulating under- and midstories), the finding of no difference was not unexpected.

Many questions regarding breeding-bird responses to RCW management still remain unanswered. The response of breeding birds to recently burned pine-oak forests versus 2 to 3 years post-burning is still unknown. While burning results in a dense understory and increases habitat conditions for some species, it can decrease habitat conditions for others. The immediate result of a burn conducted in spring is a decrease in available prey and cover for especially those species that normally feed in these areas while raising offspring, which limits their range size. Cavity nesters, including RCWs, are the group most likely to suffer because, unlike other species, they cannot pick a temporarily more suitable nest site.

CONCLUSION

Managing stands for RCWs in Kentucky does not result in forest openings or a reduction in the canopy basal area, as do most timber harvest prescriptions. Nevertheless, contrary to some previous findings (Dickson et al. 1992; Thompson, Probst et al. 1992), I conclude that management for RCWs, even when the canopy is left intact, changes the breeding-bird community in pine-oak forests in eastern Kentucky. Lowering the midstory basal area and applying controlled burns appears to have effects similar to that of timber harvests on species composition and abundance of breeding birds. Prescriptions for RCWs were beneficial to several species associated with edge and early successional habitat, including at least some neotropical migrants whose numbers are decreasing in eastern North America (e.g., indigo bunting, hooded warbler, and prairie warbler). A lack of habitat is not a limiting factor for edge and early successional species that benefit from RCW management in this region, and creation of additional habitat should not be a management priority. More importantly, management for RCWs appears to decrease habitat quality for some neotropical migrants, particularly those associated with forest interiors. Because of rapid fragmentation and intensive timbering of forests on private lands in Kentucky, interior habitat is becoming an increasingly limited resource.

While RCWs in my study area were observed only in managed stands, preference for either habitat type by this species remains unknown because management was applied to all RCW colonies prior to the initiation of the study. The benefit of this management to RCWs in Kentucky is doubtful, since the already small RCW population on the Daniel Boone National Forest dramatically declined since its initiation in 1989 from 18 to 1 native birds as of summer 1999 (Feltner pers. comm. 1999). Before the ecological impacts of RCW management are better understood, managing for this species in Kentucky should be conducted conservatively. Instead of creating open pine-oak savannahs, which mimic RCW habitat of the coastal plain, at least some pine-oak forests should be left untouched.

ACKNOWLEDGEMENTS

This research was funded by the Daniel Boone National Forest and the Kentucky Department of Fish and Wildlife Resources and was coordinated through The Nature Conservancy. I thank Jutta Krumm and Daryl Hines for assistance in the field and Michael Lacki, Jim Krupa, and Brainard Palmer-Ball for their helpful comments and suggestions.

LITERATURE CITED

[AOU] American Ornithologists' Union. 1983. Checklist of North American birds. American Ornithologists' Union, Lawrence, KS.

Anderson, S. H., and H. H. Shugart, Jr. 1974. Habitat selection of breeding birds in an east Tennessee deciduous forest. Ecology 55:828–837.

Baker, M. D., and M. J. Lacki. 1997. Short-term changes in bird communities in response to silvicultural prescriptions. Forest Ecol. Managem. 96:27–36.

Bent, A. C. 1953. Life histories of North American wood warblers. U.S. Natl. Mus. Bull. 203.

Braun, E. L. 1974. Deciduous forests of eastern North America. Free Press, New York, NY. (Reprint of a work first published in 1950.)

Campbell, J. N. 1997. Ecological regions of Kentucky—draft. The Nature Conservancy, Lexington, Kentucky.

Campbell, J. N., D. D. Taylor, M. E. Medley, and A. C. Risk. 1990. Floristic and historical evidence of fire maintained, grassy pine-oak barrens before settlement in southeastern Kentucky. Pages 359–374 in Fire and the environment: ecological and cultural perspectives. Southeastern Forest Experimental Station, Asheville, NC.

Chapman, F. M. 1968. The warblers of North America. Dover, New York, NY.

Dickson, J. G., F. R. Thompson, III, R. N. Conner, and K. E. Franzreb. 1992. Effects of silviculture on neotropical migratory birds in central and southeastern oak pine forests. Pages 315–330 in Status and management of neotropical migratory birds. USDA Forest Serv. Gen. Techn. Rep. RM-229.

Evans, M. 1991. Kentucky ecological communities—draft. Kentucky Nature Preserves Commission, Frankfort, KY.

Hagan, J. M., III. 1993. Decline of the rufous-sided towhee in the eastern United States. Auk 110:863–874.

Hamel, P. B. 1992. The land manager's guide to the birds of the south. The Nature Conservancy, Chapel Hill, NC.

Hines, M., and P. J. Kalisz. 1995. Foraging of red-cockaded woodpeckers (*Picoides borealis*). Trans. Kentucky Acad. Sci. 56:10–113.

Holmes, R. G., D. L. Krusac, and F. W. Sturges. 1986. Bird community dynamics in a temperate deciduous forest: long term trends at Hubbard Brook. Ecol. Monogr. 50:201–220.

Hooper, R. G., A. F. Robinson, Jr., and J. A. Jackson. 1980. The red-cockaded woodpecker: notes on life history and management. USDA Forest Serv. Gen. Rep. SA-GR 9.

Hutto, R. L., S. M. Pletschet, and P. Henricks. 1986. A fixed-radius point count method for non-breeding and breeding season use. Auk 103:593–602.

Kalisz, P. J., and S. E. Boettcher. 1991. Active and abandoned red-cockaded woodpecker habitat in Kentucky. J. Wildl. Managem. 55:146–154.

Kentucky State Nature Preserves Commission. 1999. Kentucky Natural Heritage Database. Kentucky State Nature Preserves Commission, Frankfort, KY.

Mengel, R. M. 1965. The birds of Kentucky. Ornithological Monographs. The American Ornithologists' Union, Lawrence, KS.

Murphy, G. A. 1980. Status, nesting habitat, foraging ecology, and home range of the red-cockaded woodpecker (*Picoides borealis*) in Kentucky. Unpublished Thesis. Eastern Kentucky University, Richmond, KY.

Palmer-Ball, B. L., Jr. 1984. Niche partitioning among migrant warblers (Parulinae) in the Louisville (Jefferson County), Kentucky area. Unpublished Master's Thesis. University of Louisville, Louisville, KY.

Palmer-Ball, B. L., Jr. 1995. Kentucky breeding bird atlas. The Kentucky Nature Preserves Commission, Frankfort, KY.

Robbins, C. S., J. R. Sauer, R. S. Greenberg, and S. Droege. 1989. Population declines in North American birds that migrate to the neotropics. Proc. Natl. Acad. Sci. 86:7658–7662.

Robinson, S. S., J. A. Grybowski, S. I. Rothstein, M. C. Brittingham, L. J. Petit, and F. R. Thompson III. 1992. Management implications of cowbird parasitism on neotropical migrant songbirds. Pages 93–102 in Status and management of neotropical migrant birds. USDA Forest Serv. Gen. Techn. Rep. RM-229.

Thompson, F. R., III, W. D. Dijak, T. G. Kulowiec, and D. A. Hamilton. 1992. Breeding bird populations in Missouri Ozark forests with and without clearcutting. J. Wildl. Managem. 56:23–30.

Thompson, F. R., III, and E. K. Fritzell. 1990. Bird densities and diversity in clearcut and mature oak-hickory forest. Res. Paper NC-293, USDA Forest Service, St. Paul, MN.

Thompson, F. R., III, J. R. Probst, and M. G. Raphael. 1992. Silvicultural options for neotropical migratory birds. In Status and management of neotropical migratory birds. USDA For. Serv. Gen. Techn. Rep. RM-229.

[USFS] United States Forest Service. 1995. Record of decision. Final environmental impact statement for the management of the red-cockaded woodpecker and its habitat on national forests in the southern region. U.S. Forest Serv. Managem. Bull. R.-MB 73, USFS Southern Region, Atlanta, GA.

Welsh, C. J. E., and W. M. Healy. 1993. Effect of even-aged timber management on bird species diversity and composition in northern hardwoods of New Hampshire. Wildl. Soc. Bull. 21:143–154.

Wilson, C. W., R. E. Masters, and G. A. Bukenhoffer. 1995. Breeding bird response to pine-grassland community restoration for red-cockaded woodpeckers. J. Wildl. Managem. 59:56–67.

J. Ky. Acad. Sci. 60(2):87–93. 1999.

Scientists of Kentucky

Luke Pryor Blackburn, M.D.: Kentucky's Good Samaritan Governor

Did you know that in 1880 the governor of Kentucky and the nation's favorite racehorse were both named Luke Blackburn?[a] Or that the man Blackburn, often praised as the "savior of Hickman" and the "good Samaritan governor," also practiced germ warfare during the Civil War? Or that Blackburn is considered the "father" of Kentucky's prison reforms? And that Blackburn holds the distinction of being the only physician to serve as governor of Kentucky?

Luke Blackburn (Figure 1) came from a large and prominent Woodford County family. His father was an attorney and one of the state's leading breeders of fine horses. His grandfather helped draw up Kentucky's first constitution, an uncle served as the first president of Centre College, and another uncle was a lieutenant governor of the commonwealth. During Blackburn's formative years George Rogers Clark, Henry Clay, and the Marquis de Lafayette were guests in his home.

Little is known about his early life. He graduated from Transylvania's Medical Department in 1835 and practiced his profession in Frankfort and Versailles. In 1846 Blackburn and his wife, Ella, and young son, Cary, moved to Natchez. That wild, unhealthy river town introduced him to a disease then unknown in Kentucky—yellow fever. The scourge of the tropics, yellow fever was an annual threat to life and commerce throughout the 19th century; nearly every summer it spread from the West Indies to the American Gulf Coast, then inland along the South's rivers. As new lands opened and the population of the Mississippi Valley skyrocketed during the 1830s, 1840s, and 1850s, the saffron scourge claimed thousands of American lives.[b]

Blackburn and his contemporaries believed that yellow fever was caused by airborne germs produced by filth and rotting vegetation. Such pathogens, they reasoned, were carried from place to place by the wind or by attaching themselves to clothing or to commercial goods transported by steamboats or railroad. Favorite methods of protecting communities from the poisonous atmosphere included burning tar and other compounds in the streets, setting off cannons and firecrackers to purify the air by concussion, and disinfecting nasty smelling areas with lime. Physicians disagreed on effective therapies, and medical journals carried a multiplicity of medical recipes, most of them heavily laced with narcotics and alcohol. Because those who survived enjoyed a lifetime immunity, newcomers composed a large percent of the scourge's victims.[c]

Blackburn served as health officer for Natchez during the yellow fever epidemics of 1848 and 1854. Believing that refugees fleeing from infected New Orleans could contaminate others, he established a quarantine station below Natchez and prohibited boats from docking at the city's landing. Because Natchez remained relatively free from disease, Blackburn concluded that his quarantine was responsible for the town's deliverance. Consequently, he campaigned before the Louisiana legislature and spoke to a number of southern medical groups, urging them to institute a permanent quarantine station below New Orleans. Unfortunately, the measure he advocated would hamper commerce, and thus businessmen who controlled state and local governing bodies opposed it.

Following the death of his wife in the mid 1850s Blackburn spent a year studying European hospitals. Shortly after his return to the states he married Julia Churchill of Louisville and moved to New Orleans. On the outbreak of the Civil War in spring 1861 Blackburn served the South in a number of civilian capacities and in autumn 1863 joined a group of Confederate sympathizers living in Toronto. He remained in Canada for the duration of the conflict, except for at least one brief visit to Bermuda to aid physicians there in battling a yellow fever epidemic.

On the day after President Lincoln was assassinated, the United States consul in Bermuda wired details of a newly discovered plot to the already hysterical officials in Washing-

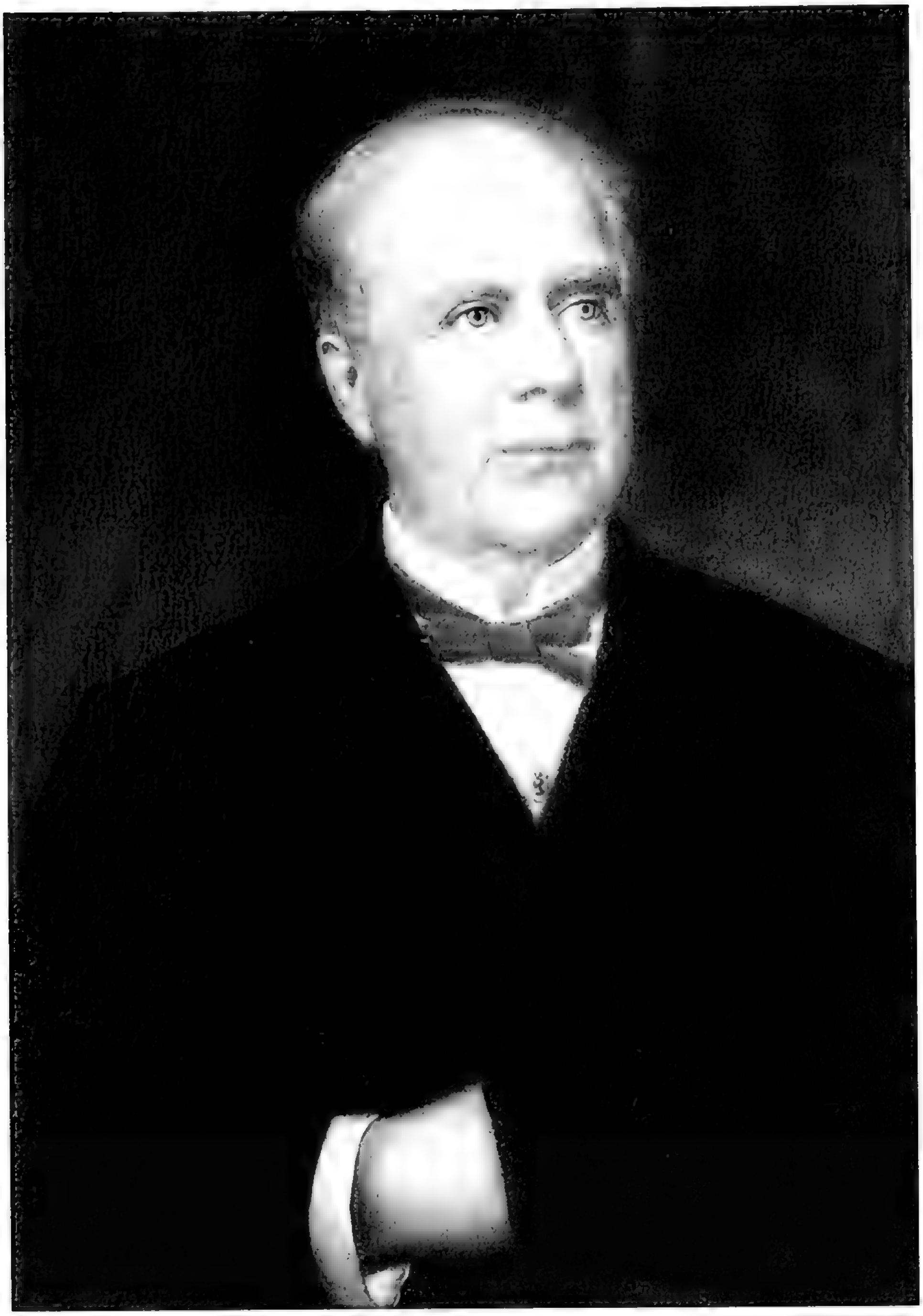

Figure 1. Luke Pryor Blackburn. Courtesy Kentucky Historical Society.

ton. A confederate sympathizer named Dr. Blackburn had visited the island the previous year, he said, gathering blankets and clothing from the beds and bodies of yellow fever patients. These items had been placed in trunks and shipped to Halifax. The soiled items, Bermuda officials learned, were destined for used-clothing stores in northern cities where Blackburn hoped an epidemic among the civilian and military population would bring the Union's war machine to a standstill.[d]

A few days later, northern newspapers reported sensational revelations given in Detroit by a man who claimed Blackburn had employed him to take the trunks from Halifax to Boston, New York, Washington, and Philadelphia, as well as to New Bern, North Carolina, then occupied by Federal troops. When the disease did not break out in the metropolitan areas, Blackburn assumed the informer had not followed his instructions and refused to pay him. However, when he heard that yellow fever had felled several hundred in the New Bern area, Blackburn assumed his scheme had succeeded and vowed to try again the following year on a grander scale, claimed the informer.[e]

On receipt of these details, Union officials issued a warrant for the doctor's arrest. Blackburn was in Canada, however, and beyond their jurisdiction. Details of the plot were aired at the trial of Lincoln's assassins but interest waned when it became apparent that high-ranking Confederate officials could not be linked to the germ warfare scheme. Nevertheless, the murder indictment against Blackburn was never dropped.

Although Blackburn was not accessible to American courts, Canadian authorities arrested and tried him for violating that nation's neutrality. He was acquitted. Had he been brought before an American court, he undoubtedly would have been hanged for murdering the several hundred people who died of yellow fever at New Bern.

Blackburn remained in Canada for a number of years, lived in Arkansas for a while, and returned to Louisville in 1873. In late summer of that year yellow fever traveled up the Mississippi River and struck Memphis, killing more than 2000 residents in a 6-week period. Volunteering his services to the authorities, Blackburn spent 6 weeks in the river town nursing the sick. Instead of prescribing the usual "heroic" measures favored by most of his medical colleagues, Blackburn generally limited his treatments to "blistering" to eliminate "poisons" in the body and to toddies of warm lemonade and ice water to reduce fever. The local press praised his successes and humanitarian efforts. The media also reported a disagreement he had with a local priest over a young orphan and the caning he gave to a visiting quack who tried to interfere with the treatment he had prescribed for a patient.

Blackburn accepted no pay for his services at Memphis. To show its appreciation, the city presented him with a handsome silver tray. Several years later one of his grateful patients named a thoroughbred for the Kentucky physician. "King of the Turf" Luke Blackburn was the nation's number one racehorse in 1880, which was also the first year Dr. Blackburn served as Kentucky's chief executive.[f]

In February 1878 Blackburn announced that he planned to run for governor. Most of his friends believed that the doctor's efforts would be in vain, for although his family was politically prominent and his brother Joseph then represented Kentucky in the U.S. Congress, Luke Blackburn had little knowledge of state politics. Nevertheless, he made a number of speeches during spring and early summer and laid plans for the campaign he hoped would win for him the Democratic Party's nomination the following spring. Yellow fever, not his political ideas, catapulted him into the executive mansion.

During summer 1878 an unusually vicious strain of yellow fever visited the Mississippi River Valley. The disease appeared earlier in the season than usual and by mid summer every town along the lower Mississippi had been hit. As the South's refugees fled northward from the killer, cities on the upper river (including Paducah, Cairo, and Cincinnati) closed their doors by instituting strict quarantines. Blackburn advised Louisville to do likewise. But the rest of the city's physicians, none of whom had experience with the disease, insisted that Kentucky was immune; the scourge had never visited the state, nor would it do so now, they maintained. Thus the mayor and council welcomed refugees fleeing from infected cities. In early August the *Courier-Journal* denied rumors of "yellow Jack" in the Falls City, then admitted the existence of a few cases among visitors. By mid month, many indigenous cases had been diagnosed and a number of deaths reported. Between early August and the first frost in mid October, 50 Louisvillians died from yellow fever.

The disease also hit Bowling Green (Warren County), a transportation center located at the junction of the L&N railroad with its Memphis line. Nearly 50 indigenous cases were reported in the area near the railroad. "Yellow Jack" killed 26 of them.

In western Kentucky, however, the disease reached epidemic proportions. A paddle wheeler that had previously docked at New Orleans and Memphis landed at the wharf in Hickman (Fulton County) on 3 August to discharge cargo. A day or so later a tow boat taking barges from New Orleans to St. Louis anchored near the town; three members of the crew visited the telegraph office and bakery. Another steamboat going upriver stopped at Hickman on 10 August to take on coal, and many of its 300 passengers strolled about the town. All of these vessels reported multiple fever fatalities before they reached their destinations.

Hickman's first cases of yellow fever were diagnosed in mid August among a teenager and two small children who peddled apples at the wharf. All three died within 4 days. A youngster who played outside his father's riverfront law office also sickened as did the baker and his wife and several members of the town band, who practiced three nights a week at a hotel near the river. The number of cases escalated.

The *Courier-Journal* reported the children's deaths but quoted Hickman physicians who disavowed that the disease was yellow fever. For 3 weeks rumors and denials appeared in the Louisville paper but on 5 September Hickman's mayor telegraphed the president of the newly formed Kentucky State Board of Health that yellow fever was epidemic and requested help. Blackburn also received a plea for aid and volunteered to go to western Kentucky as the board's official representative to direct medical and nursing care.

On his arrival Blackburn found businesses and grocery stores locked and most of Hickman's 1200 residents gone. Of the 150 remaining, 50 were mortally ill and the others suffered from a state of near hysteria. Three of the town's six doctors were also sick.

Blackburn quickly organized relief committees to acquire and dispense food, clothing, and bedding. He also converted the local hotel into a hospital and instructed a group of women in nursing techniques. Cleanup crews "disinfected" the town with lime and burning tar. A group of African Americans volunteered their services to shroud and bury the dead and to guard vacant homes and businesses against vandalism. Blackburn reported to the Board of Health that additional volunteers were needed. He received a wire from the Louisville City Council saying, "Don't let your people want for anything—call on us and you shall be supplied." He answered with a request for 25 mattresses, 25 blankets, 5 gallons of bourbon, 5 gallons of sherry, 1 barrel of hams, 3 barrels of bacon, 1 barrel of sugar, and 100 pounds of coffee. Louisvillians filled the request.

In answer to Blackburn's plea for additional personnel, three physicians, several nurses, a telegraph operator, and a druggist hastened to Hickman. Despite his warnings that volunteers should be southerners immune to the disease, all of them were from areas previously untouched by yellow fever and all but two contracted the malady and died.

By late September the disease at Hickman appeared to be abating. Leaving the town in the care of volunteer physicians and well-trained nursing teams, Blackburn traveled to Martin, Tennessee, to organize patient care for fever victims at Memphis. Ten days after his departure the doctor received word that yellow fever had broken out with renewed force at Hickman, had been diagnosed in nearby Fulton (Fulton County), and had stricken the doctors of both towns. Blackburn returned immediately to Hickman and for several weeks worked day and night as the only physician in the Hickman-Fulton area. Despite a hectic schedule in which he frequently made 30 or more house calls per day, Blackburn never admitted fatigue. He promised that as long as fresh horses were available he would attend to everyone who needed his help. According to contemporary reports, he not only treated the sick but also built fires, fixed coffee, prepared food, and even "bathed the feet" of his patients. Blackburn became the hero of the Purchase area. On 18 October, the masthead of the *Paducah Daily News* carried Blackburn's name as its favorite candidate for governor; a week later Tennessee's *Union City Chronicle* declared that Kentucky could not give the doctor a "more fitting reward" than the governorship.

Shortly after the first frost Blackburn announced that the epidemic was over. But it had taken the lives of more than 162 residents in the Hickman-Fulton area and was fatal to all but one of the local physicians and two of the volunteers who went to that area. The saffron scourge had also crippled area trade and commerce at a loss of hundreds of thousands of dollars.[g]

He was not the epidemic's only hero, but Luke Blackburn received greater publicity for his deeds at Hickman than did other volunteers. When he returned to Louisville from western Kentucky, his arrival was marked by a grand reception at the Galt House and by other activities usually reserved for military heroes. Poems, resolutions, and costly gifts were heaped on him. The most lavish display came from the citizens of western Kentucky, who gathered at Paducah a few weeks later to honor their savior. Street banners, a brass band, a glittering reception, a formal dance, and the presentation of a gold medal feted the man whose "heroic devotion to the people of Hickman . . . during the plague of 1878" had won the state's respect and admiration.

After the epidemic, Blackburn returned to the campaign trail and everywhere was greeted as a hero. By spring 1879 even his chief opponent for the Democratic nomination, Lieutenant Governor John Cox Underwood, realized that Blackburn's popularity overshadowed the medical man's lack of political acumen. Kentuckians apparently believed that if the doctor wanted the governorship he should have it; it was a small enough reward for his humanitarian activities. On 1 May 1879 the Democratic State Convention selected the Hero of Hickman as the party's candidate for governor.

A few days after being named his party's choice, Blackburn retreated to a resort at Crab Orchard (Lincoln County) and did not again appear in public until after the mid-August election. Explanations and accusations for his sudden disappearance included poor health, refusal to debate with his Republican opponent, and charges about germ warfare. The initial mud-slinging came from the *Cincinnati Gazette*. Always eager to cast aspersions at Kentucky, who was her political and commercial rival, the Queen City tabloid printed excerpts from the Lincoln assassination trial about Blackburn's yellow-fever scheme. The paper's comments were quoted and misquoted by other journals across the nation. What would have otherwise been a quiet election commanded national attention as Kentucky and her hero were pelted with abuse.

Many of the statements carried by northern newspapers bordered on the ludicrous. A Canton, Ohio, newspaper, for example, suggested that if Kentucky elected Dr. Blackburn, the commonwealth should be forced to secede from the Union. The *Philadelphia Press* begged that someone remove the "sacred remains" of Henry Clay from Kentucky's now-polluted soil. A Chicago daily predicted that Kentuckians would probably vote for John Wilkes Booth if the assassin were still alive. Republican papers contended that only Democrats would nominate a "fiend" and "mass murderer," but northern Democrats argued that it was only typical of southern Democrats to elevate the "worst monster since Nero" to the governor's chair.

Blackburn remained silent during the months of name calling, and most Kentucky papers ignored the diatribes. Many of his supporters probably feared that more harm than good would result from refuting the statements; some perhaps applauded the doctor's efforts to bring the Union to its knees; and others did not care what had occurred more than 2½ decades earlier. Whatever their sentiments, more than 60 percent of the voting electorate cast their ballots for Blackburn. Professional politicians rejoiced that a novice—a puppet they could manipulate—would occupy the governor's office. But they misjudged him; Blackburn would be no one's lackey.

Blackburn's major crusade as governor involved improving conditions at the overcrowded and poorly administered state penitentiary in Frankfort. Built in 1800 on a marshy area along the Kentucky River, the Kentucky Penitentiary had been earlier dubbed "Kentucky's Black Hole of Calcutta." An open sewer ran through its poorly drained and debris-filled quadrangle, and its overcrowded cell houses suffered from poor ventilation, inadequate heat, and filthy quarters. The noxious odor emanating from the institution so permeated Frankfort that windows in the nearby governor's home remained closed year round to keep out the stench. The death rate had always been high, but during the 1870s, scurvy joined intestinal and respiratory diseases to set new records.[h]

In his first message to the legislature Blackburn urged its members to appropriate money to build a new state prison and to provide better management of the existing facility. When the penny-pinching politicians refused to consider his suggestions, he used the only means at his disposal to aid the wretched prisoners—his executive pardon. The very young—some as young as nine—the elderly, and the seriously ill received his attention. At first the state's papers praised the humanitarian who had taken as his cause the plight of the "forgotten man." But as the pardons increased, so did the opposition to freeing "cutthroats and murderers" who returned to communities that did not want them. Consequently, pressure on the lawmakers increased.

Despite loud opposition, the legislature finally passed two reform bills. One created a better system for governing the prison by substituting a warden for the lessee; the other established a committee to study penal institutions elsewhere and make recommendations for a new state prison. Although it would be several years before money was allocated and the facility constructed, the fortress-like penitentiary at Eddyville resulted from Blackburn's efforts.[i]

To relieve overcrowded conditions until a new prison was completed, the legislature farmed out about half of the prisoners to build and repair railroads and other public works. Blackburn opposed the use of "chain gangs." He frequently visited the railroad camps and presented horrifying proof to the legislature about inhumane treatment endured by the prisoners. But the politicians refused to make other arrangements. Thus, Blackburn continued the liberal use of his executive prerogative.

Every segment of society howled about Blackburn's crusade. Taxpayers resented the expenditure of money to aid felons; property owners feared the return of criminals to their communities; and laborers resented having to work along side of prisoners or compete with them for jobs. Members of his administration with political ambitions feared that Blackburn's actions would harm their futures; journalists, knowing that controversy sold newspapers, reported complaints, scorn, and ridicule. Consequently, the roar of criticism swelled and rumors and accusations ran rampant.

In an effort to defend his actions, Blackburn occasionally became so frustrated that he made matters worse by hurling epithets at his critics. By the end of his administration, even the papers of western Kentucky had few kind words for the Hero of Hickman. Most of the state's press expressed delight that the term of the "old loon" was nearly over and that "Lenient Luke" would soon return to private life where he could no longer harm the commonwealth.

Blackburn's efforts on behalf of prisoners at the Kentucky Penitentiary were not the only reforms of his administration. At his urging the legislature abolished the public whipping post and eliminated many padded accounts and fraudulent expenses concerning trials and the conveyance of prisoners from one county to another. He also insisted that unnecessary courts be abolished and that judges and district attorneys be paid pre-determined salaries rather than remunerated on the number of cases tried and won. He recommended the reorganization of Kentucky's strife-ridden A&M College, suggesting the creation of a "people's college." The resulting University of Kentucky opened in February 1882.

Perhaps his most far-reaching act was the appointment of Dr. Joseph N. McCormack of Bowling Green to the State Board of Health. As the board's secretary from 1883 until shortly before his death in 1922, McCormack fought for legislation that required smallpox vaccinations for school children, Wassermann tests for marriage licenses, pasteurization of milk, and scores of other laws designed to improve public health. Under his direction Kentucky's Board of Health grew from an advisory group with no power to an effective, farsighted organization that worked diligently to educate Kentuckians on matters of life and health. A master in mixing medicine and politics, McCormack also served as the American Medical Association's spokesman, traveling the length and breath of the nation to aid with reforms and reorganization.

Elected on a wave of popularity that ignored his lack of political experience, Blackburn nevertheless instituted the first major reforms in post Civil War Kentucky. However, he left office as one of the most unpopular executives of the century. Blackburn returned to Louisville and opened a sanitarium near Cave Hill Cemetery. He died 4 years later and was buried in Frankfort. His tombstone, erected by the state, salutes the man who "defied disease and disapproval to help those unable to help themselves." The monument also contains a handsome brass plaque that depicts the New Testament parable of the Good Samaritan, who was also a physician named Luke.

Nancy Disher Baird
Kentucky Library
Western Kentucky University
Bowling Green, KY 42101

ENDNOTES

a. Further information about the career of Blackburn is available in Nancy Disher Baird, *Luke Pryor Blackburn: physician, governor, reformer* (Lexington: University Press of Kentucky, 1979).

b. In 1822 Louisville was visited by what may have been yellow fever. Generally diagnosed as "bilious fever," it claimed at least 140 of Louisville's 4000 residents. Believing that ponds generating miasma were responsible for the disease, the city trustees appointed an engineer to begin draining the ponds that dotted the town.

c. During the colonial and early federal period, yellow fever killed thousands along the east coast, but after 1825 its most vicious attacks were in the Deep South, especially the Mississippi River Valley. Transported from the West Indies to New Orleans and other gulf ports, yellow fever was usually present and, when conditions were right, it flared into frightening epidemics, depopulating urban areas, paralyzing trade and industry, and keeping southerners in a state of perpetual dread. The cause of the disease was unknown until 1900, when Dr. Walter Reed discovered that the female *Aedes aegypti* mosquito (which is native to a large portion of the United States, including Kentucky) acted as a vector host and transmitted the virus from person to person. Yellow fever was carried upriver by sick refugees fleeing from infected areas; the severity and northward extension of its nearly annual appearance depended on how early in the season the disease appeared in the gulf area, how great was the concentration of mosquitoes and of susceptible persons, and when the first autumnal frost killed the insects. The mortality rate from yellow fever was 40–50 percent. A few days after being bitten by an infected mosquito, a victim experienced increasingly severe headache and backache, high fever, and extreme nausea; signs of impending death included "black vomit" (caused by hemorrhaging mucous membranes) and jaundice (a symptom of liver-cell destruction). Those who survived the lengthy convalescence enjoyed a lifelong immunity to "yellow Jack." Since most of its victims were newcomers to the South, yellow fever was often called the "stranger's disease."

d. "American Consular Reports—Civil War Period," *Bermuda Historical Quarterly*, 19 (spring 1962) contain reports of Blackburn's activities, and the *New York Times* printed detailed accounts of testimony given at the assassins' trial.

e. For additional information about the Memphis epidemics, see D. A. Quinn, *Heroes and Heroines of Memphis: Or Reminiscences of the Yellow Fever Epidemic that Affected the City of Memphis during the Autumn Months of 1873, 1878 and 1879* (Providence, R.I., 1887), and J. M. Keating, *The Yellow Fever Epidemic of 1878* (Memphis, 1879).

f. Details about the epidemic in Kentucky were published in E. O. Brown, *Official Report of Dr. E. O. Brown, Physician in Charge of the Yellow Fever Hospital, Louisville, Kentucky.* (Louisville, 1878) and *First Annual Report of the State Board of Health of Kentucky, 1878* (Frankfort, 1879). Contemporary newspapers, especially the Louisville *Courier-Journal*, carried long columns of news and rumors regarding the epidemic.

g. The area of the Hickman cemetery where the fever victims lie contains no landscape plantings or individual gravestones. A large monument lists the dead and also salutes the "Hero of Hickman." Over the years some of the graveyard's caretakers have been reluctant to mow the area because of rumors that it is "unhealthy" and "haunted."

h. For additional information about the conditions at the prison, see *Report of the Special Committee on the Penitentiary to the Senate, February 26, 1880, Kentucky Documents, 1880* (Frankfort, 1880); *Report of Committee to Investigate Conditions of Convicts, Kentucky Documents, 1882* (Frankfort, 1882), and other state documents and contemporary newspapers.

i. Throughout most of the penitentiary's history, a keeper or lessee rented the institution and its inhabitants from the state and had complete control over them. Chosen by the legislature, the lessee fed, clothed, and provided bedding for the prisoners, hired the guards, and maintained order. The prisoners worked at a variety of tasks, including the production of hemp rope and bagging, chairs, tables, and various other household items. Profits from their labors paid for food, supplies, and general prison maintenance; the net gains belonged to the lessee, who increased his profits by cutting corners on necessities and by neglecting to keep the buildings and grounds in good condition. Operating a prison was very lucrative, and money and favors passed between candidates for the position and members of the legislature every 4 years at lessee-selection time. Although aware of the prison's abominable conditions, the solons hesitated to interfere with the lessee's contract because of the money and politics involved. Under the law approved by the 1880 general assembly, a salaried warden, selected for a 4-year term by the legislature, took charge of the prison and its inhabitants. The new law defined his administrative and supervisory duties and created a commission composed of the governor and members of his cabinet who made monthly visits to the prison to see that the law was enforced. Although he arranged for the sale of convict-made products, the warden received no pecuniary profits from them.

J. Ky. Acad. Sci. 60(2):94-107. 1999.

Geographic Variation in the Blackside Darter, *Percina maculata* (Teleostei, Percidae), in the Ohio River Drainage of Kentucky

Ralph Steinberg and Lawrence M. Page

Illinois Natural History Survey, 607 East Peabody Drive, Champaign, Illinois 61820

ABSTRACT

Geographic variation in the blackside darter, *Percina* (*Alvordius*) *maculata*, in the Ohio River Basin of Kentucky was investigated by gathering meristic and morphometric data on 486 individuals from 16 drainages (13 Ohio River drainages). Character data were analyzed using frequency distribution tables and principal components analysis to identify trends in geographic variation and to recognize taxonomically distinct populations. Results did not indicate the need to diagnose new taxa, but populations show considerable variation. Among the most unusual populations are those in the Cumberland and Kentucky rivers, two drainages known for endemism and unusual biological communities.

INTRODUCTION

The blackside darter, *Percina maculata* (Figure 1), is the most widespread of the eight described species of the subgenus *Alvordius* (Page 1974). Its range extends from southeastern Saskatchewan and North Dakota east to southern Ontario and New York and south to northeastern Texas and Gulf Coast drainages as far east as the Mobile Bay drainage of Alabama (Page 1983). The species is distributed over four major basins, the Mobile Bay, Mississippi River, Great Lakes (excluding Lake Superior), and Hudson Bay; and three minor drainages of the Gulf Slope west of the Mobile Bay: the Calcasieu River, Lake Pontchartrain, and Pearl River (Beckham 1983, 1986). *Percina maculata* occurs in small to moderate-sized, clear streams with sand and gravel bottoms and typically is taken from the margins of large pools with some current or small pools associated with riffles (Trautman 1957). Less often the species is found over mud and among accumulations of brush (Page 1983).

Beckham (1983) studied geographic variation in *P. maculata* and found that meristic data exhibited pronounced clinal variation with relatively high interpopulational variability. The major trend was for a south-to-north decrease in counts for lateral line, transverse, caudal peduncle, and modified midventral scales and for lateral and dorsal blotches. Dorsal spine counts also exhibited a south-to-north decrease but to a lesser degree than other characters. Dorsal and anal ray counts showed the reverse trend, a south-to-north increase.

Beckham tested these trends within and between six major basins occupied by *P. maculata*: Hudson Bay, Great Lakes, Ohio River, Upper Mississippi, Lower Mississippi, and Gulf Slope. An analysis of variance (ANOVA) indicated a significant difference between at least two sample means for the majority of meristic characters examined. However, an ANOVA table was not presented in the analysis, and there was no indication of any significant or non-significant differences when more than two sample means were considered.

Beckham also conducted a stepwise discriminant functions analysis of nine meristic characters exhibiting the most variation to determine where differences in sample means were occurring and whether differences were the result of breaks between interior drainages or due primarily to geographic extremes. Transverse scale count was the most reliable character in discriminating populations. Successive steps in the analysis added dorsal blotches, caudal peduncle scales, lateral blotches, lateral line scales, dorsal spines, dorsal rays, midventral scales, and anal rays. Samples varied from a high of 82.4% being correctly identified for Hudson Bay to a low of 15.7% for Ohio River.

According to Beckham, the inability to demarcate populations in the Ohio River drainage resulted from the high variability of meristic characters. Only 132 specimens were examined from all Ohio river tributaries in Ken-

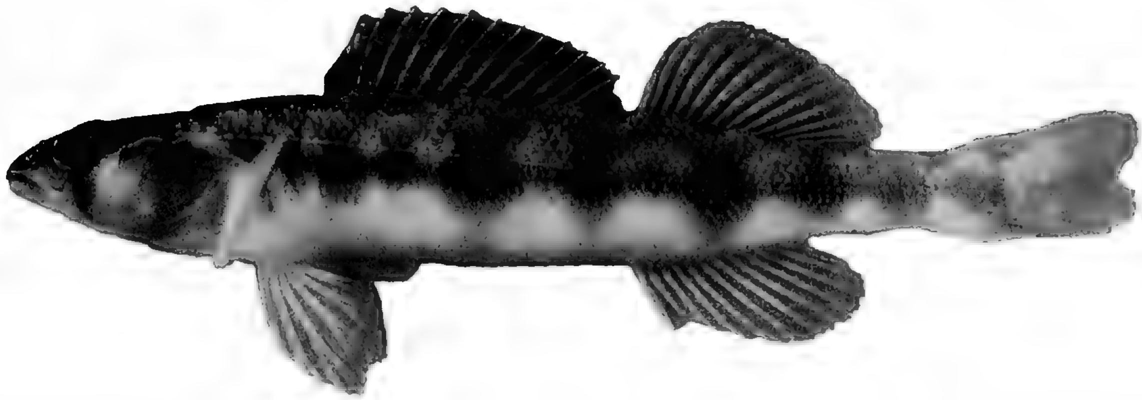

Figure 1. *Percina maculata.* INHS 43425 (60.1 mm SL, male); Eagle Creek, Carroll Co., Kentucky. Photo by K. S. Cummings.

tucky, and it is possible that distinct taxa from the Ohio river system were not detected. Specimens from above Cumberland Falls were not included in Beckham's study. Hubbs and Raney (1939) examined variation in the blackside darter over its entire range and described the species as "probably a complex of subspecies." Burr and Warren (1986) noted that this species exhibits considerable geographic variation in Kentucky. Our study was undertaken to examine geographic variation in *P. maculata* in the north and west-flowing tributaries of the Ohio River in Kentucky and to determine whether distinct taxonomic units exist.

Percina maculata is variably distributed in southern tributaries of the Ohio River (Beckham 1983; Burr and Warren 1986). It is widespread and common in the Tradewater, Green, Salt, Kentucky, Licking, Little Sandy, Big Sandy, and Kanawha rivers but is more rare in the Tennessee River system, with most records being from the Clarks River in western Kentucky, the last tributary of the Tennessee River before its confluence with the lower Ohio River. *Percina maculata* is present in the lower and upper portions of the Cumberland River but is absent from the middle portion (Etnier and Starnes 1993).

METHODS AND MATERIALS

Four hundred eighty-six specimens of *P. maculata* were examined meristically; morphometric data were collected on 149 specimens. Specimens examined were from 16 drainages (see "Material Examined"); 13 of the drainages are major tributaries of the Ohio River, and three drainages (Lake Huron, Lake Michigan, and Mississippi River) were examined for comparison to Ohio River populations (Figure 2). Standard length (SL) was used throughout. Only specimens greater than 45 mm SL were used for morphological analysis in order to reduce allometric bias. Counts were made only on specimens greater than 38 mm SL.

Counts and measurements were made as described by Hubbs and Lagler (1964), except for the number of transverse scales, which was counted from the origin of the second dorsal fin down and back to the anal fin, as proposed by Raney and Suttkus (1964). Counts of bilateral features were made on the left side.

Meristic characters included the number of total lateral line scales, pored lateral line scales, transverse scales, scales above the lateral line, scales below the lateral line, caudal peduncle scale rows, dorsal rays, dorsal spines, anal rays, anal spines, pectoral fin rays, and lateral blotches. Cheek, nape, and opercular squamation were analyzed as meristic variables. Only large lateral blotches were counted from the first full blotch posterior to the pectoral fin base back to, and including, the blotch ending at the hypural plate (Beckham 1983). Data were arranged in frequency distribution tables, and sample means and modes from each drainage were compared for geographic variation.

Morphometric characters included head length, head depth, head width, snout length, predorsal length, eye diameter, gape width, pectoral fin length, pelvic fin length, spinous dorsal fin base length, soft dorsal fin base length, anal fin base length, caudal fin length, caudal peduncle width, caudal peduncle depth, spinous dorsal fin origin to pelvic fin origin, spinous dorsal fin origin to anal fin or-

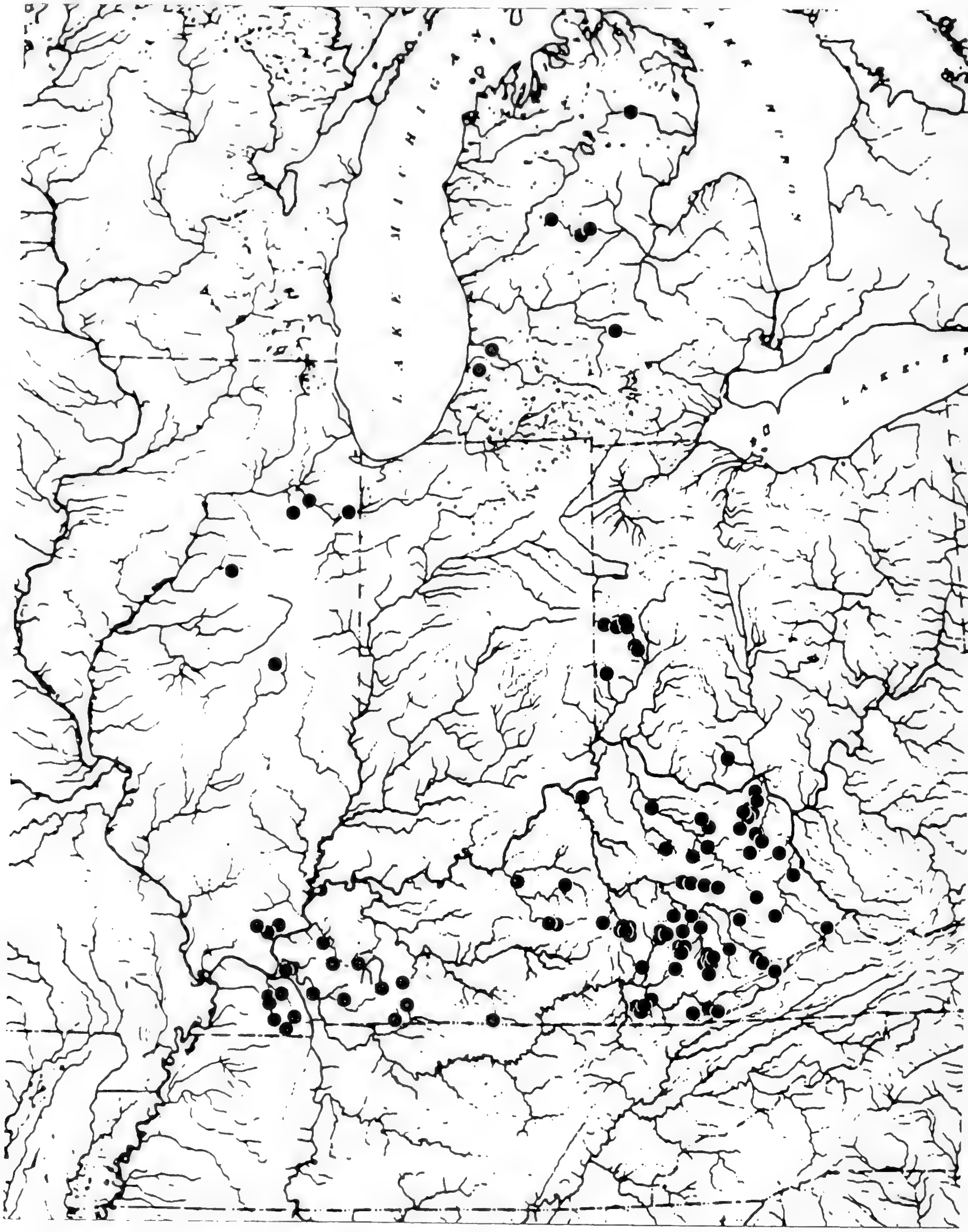

Figure 2. Collection localities for specimens of *P. maculata* examined.

igin, soft dorsal fin origin to anal fin insertion, soft dorsal fin origin to pelvic fin origin, spinous dorsal fin insertion to anal fin origin, and anal fin origin to soft dorsal fin insertion. The data were analyzed with the use of principal components analysis whereby the original set of variables was used to generate a new set of variables, uncorrelated with each other, that were linear combinations of the original variables (Pimentel 1979).

RESULTS

Although data for all populations are shown in Tables 1–12, comparisons are restricted to Ohio River tributaries and exclude the population in Scioto River because only four specimens from it were available for examination.

The number of lateral line scales (Table 1) varied from a low mean of 61.1 and a mode of 59 in Little Sandy River to a high mean of 70.2 and mode of 71 in Cumberland River above Cumberland Falls. In general, populations in extreme eastern Kentucky (e.g., Tygarts Creek, Little Sandy, and Big Sandy rivers) had the lowest counts, and those in the southeast and north (e.g., Cumberland, Kentucky, and Great Miami rivers) had the highest. The Kentucky River population had a bimodal count with a concentration of individuals around 67 scales and another around 71 scales.

The number of pored lateral line scales (Table 2) varied from a low mean of 59.7 and a mode of 57 in Little Sandy River to a high mean of 68.9 and mode of 70 in Cumberland River above the Falls. As for the lateral line scale count, populations in extreme eastern Kentucky (e.g., Tygarts Creek, Little Sandy, and Big Sandy rivers) had the lowest count, and populations in the southeast and north (e.g., Cumberland River above the Falls and Kentucky and Great Miami rivers) had the highest. The population in Cumberland River below the Falls had a mean of 65.9 and a mode of 67 scales; that above the Falls had a mean of 68.9 and a mode of 70 scales.

The number of transverse scales (Table 3) varied from a low mean of 16 and a mode of 16 in Tygarts Creek to a high mean of 18.3 in Cumberland River below the Falls (mode = 18–19), Tradewater River (mode = 19), and Green River (mode = 18). Populations in the north and the east (e.g., Tygarts Creek and Great Miami River) generally had the lowest counts, and those in western Kentucky (e.g., Tradewater and Green rivers) had the highest.

The number of scales above the lateral line varied from a low mean of 6.9 and a mode of 7 in Tygarts Creek to a high mean of 8.8 and mode of 9 in Tradewater River. Those populations in the east (e.g., Tygarts Creek and Lit-

Table 1. Frequency distribution of lateral line scale counts in *Percina maculata*.

Drainage	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	N	X	SD	CV
Lake Huron							1	3	1	5	9	2	6	5	2	1		2	2			1			40	67.6	3.31	0.05
Lake Michigan				1			3	2	1	1	1	1	1	1	1										13	64.6	3.23	0.05
Mississippi River					1	3	2	3	4	3	8	8	5		3	4			1						45	66.2	3.12	0.05
Direct tribs. lower Ohio R. (IL)				1				2				1	3		2	1		1		1					12	67.9	4.50	0.07
Tennessee River				1			3	1			1							1		1					7	63.9	4.53	0.07
Cumberland River (below falls)								1	1	1	2	3	2	4	2	2	2	1		1	1			2	25	69.8	4.19	0.06
Cumberland River (above falls)									1	1	1	3	1	4	4	5	1	2	2	3					28	70.2	3.01	0.04
Tradewater River									2	2	1	2	4	1		4	1	1	1						19	68.3	3.28	0.05
Green River			1				2	2	8	4	3	4	8	3	3	2	1	1							42	66.6	3.06	0.05
Salt River								1	1		1	2	3	3		2		1							12	68.8	1.99	0.03
Kentucky River	1					1	1	1	1	4	9	17	14	10	7	18	8	4	2	4	1	2	1		106	69.2	3.43	0.05
Licking River						1		4	3	3	4	1	4	2	4	3	1		1	1	1				33	67.6	3.73	0.06
Tygarts Creek			1	1		3	1	2	2	6	2				3										21	64.2	3.28	0.05
Little Sandy River				3	1		1		1	1															7	61.1	2.55	0.04
Big Sandy River					1	2	6	5		6	4	5	4	4	3		1								41	65.6	3.03	0.05
Great Miami River								1	1		1	2	3	4	5		3		1				1		22	69.3	3.21	0.05
Scioto River									1	1	1		1												4	65.8	1.71	0.03
Total	1		2	7	3	10	20	28	28	38	48	51	59	41	39	42	18	14	10	11	3	3	2	2	487			

Table 2. Frequency distribution of pored lateral line scale counts in *Percina maculata*.

Drainage	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	N	X	SD	CV
Lake Huron						1	3	2	6	4	6	7	2	1	2	1	2		1	1					40	66.2	3.71	0.06
Lake Michigan			1		1	3		3		1	2		1		1										13	63.5	3.41	0.05
Mississippi River			1		3	2	3	3	3	11	3	9	1	2	3				1						45	65.2	3.14	0.05
Direct tribs. lower Ohio R. (IL)	1					1	1			1	1	1	1	2	1		1			1					12	66.7	5.16	0.08
Tennessee River			1		2		2				1					1									7	62.7	4.42	0.07
Cumberland River (below falls)		1		1		1	2		2	2	2	4	1	1		1	1	1	1				1	1	25	65.9	6.36	0.10
Cumberland River (above falls)							2	1		1	2	3	3	2	6	1	2	2	3						28	68.9	3.43	0.05
Tradewater River					1		2		3	3	2	1		3	2		2								19	66.4	3.44	0.05
Green River			1	1		3	1	6	7	2	8	5	4	1	3		1								42	65.2	3.02	0.05
Salt River									1		3	3	1	2	2										12	67.4	1.83	0.03
Kentucky River	1	1			2	3	2	1	7	12	14	9	16	7	10	10	5	3		2	3	1			111	67.4	4.36	0.06
Licking River				2	2	3	2	3	2	4	2	4	3	1	2	2				1					33	65.2	3.89	0.06
Tygarts Creek	1	1	1		3	1	3	3	5				3												21	62.4	3.30	0.05
Little Sandy River		3		1		1		1	1																7	59.7	2.98	0.05
Big Sandy River			1		6	2	7	3	7	4	3	2	5	1	1										43	63.7	3.21	0.05
Great Miami River							1		1	1	2	6	3	3	1	2		1			1				22	68.1	3.00	0.04
Scioto River								1		2	1														4	64.8	1.26	0.02
Total	3	6	6	5	20	21	31	27	45	48	52	54	44	26	34	18	14	7	6	5	4	1	1	1	484			

tle Sandy River) had the lowest counts, and those in the west (e.g., Tradewater and Green rivers) had the highest.

The number of scales below the lateral line varied from a low mean of 9.9 and a mode of 9–10 in Tygarts Creek to a high mean of 12.2 and mode of 12 in Tradewater River. In general, populations in the north and east (e.g., Tygarts Creek and Great Miami River) had the lowest counts; those in western Kentucky (e.g., Tradewater and Green rivers) had the highest. The population in Cumberland River below the Falls had a mode of 12 scales; that above the Falls had a mode of 10.

The number of scale rows around the caudal peduncle (Table 4) varied from a low mean of 21.4 and a mode of 22 in Little Sandy River to a high mean of 24.4 and mode of 24 in Cumberland River below the Falls. As for scales below the lateral line and transverse scales, the populations in the north and east (e.g., Tygarts Creek, and Great Miami, Licking, and Little Sandy rivers) had the lowest counts, and those in western Kentucky (e.g., Tradewater and Green rivers) had among the highest.

Pectoral fin rays showed little variation (Table 5); 8 of 13 populations had a mode of 14 rays. Except for the Salt River population, which had a mode of 10 anal fin rays, little variation was found in the number of anal rays (Table 6); other Ohio River populations had modes of 8–9 rays.

The number of dorsal rays (Table 7) varied from a low mean of 11.7 and a mode of 12 in Kentucky River to a high mean of 12.5 and mode of 13 in Cumberland River below the Falls. Populations in eastern Kentucky (e.g., Cumberland River above the Falls, Kentucky River, and Tygarts Creek) generally had the lowest counts; those in western Kentucky (e.g., Tradewater, Green, and Salt rivers) had the highest. Most populations (9 of 13) had a mode of 14 dorsal spines (Table 8).

The number of lateral blotches (Table 9) varied from a low mean of 6.5 and a mode of 7 in Great Miami River, to a high mean of 7.7 and mode of 7 in Kentucky River. Populations in western Kentucky (e.g., Tradewater and Green rivers) generally had the lowest counts, while those populations in the east (e.g., Tygarts Creek, Kentucky, and Big Sandy rivers) had the highest.

Table 3. Frequency distribution of transverse scale counts in *Percina maculata.*

Drainage	14	15	16	17	18	19	20	21	N	X	SD	CV
Lake Huron	1	10	18	9	1				39	16.0	0.84	0.05
Lake Michigan			6	6	1				13	16.6	0.65	0.04
Mississippi River		2	12	17	9	4			44	17.0	1.02	0.06
Direct tribs. lower Ohio R. (IL)			2	3	3	4			12	17.8	1.14	0.06
Tennessee River				2	4		1		7	18.0	1.00	0.06
Cumberland River (below falls)		1		5	8	8	2	1	25	18.3	1.24	0.07
Cumberland River (above falls)			8	8	11		1		28	17.1	1.01	0.06
Tradewater River			1	5	4	6	3		19	18.3	1.19	0.07
Green River			2	4	21	9	5	1	42	18.3	1.05	0.06
Salt River			2	2	5	2		1	12	17.9	1.38	0.08
Kentucky River		1	9	32	43	18	7	1	111	17.8	1.08	0.06
Licking River		4	7	9	12	1			33	17.0	1.10	0.07
Tygarts Creek	2	4	9	5	1				21	16.0	1.02	0.06
Little Sandy River		1	3	2	1				7	16.4	0.98	0.06
Big Sandy River		3	13	18	7	2	1		44	16.9	1.06	0.06
Great Miami River		2	9	4	6		1		22	16.8	1.22	0.07
Scioto River			1	3					4	16.8	0.50	0.03
Total	3	28	102	134	137	54	21	4	483			

The percentage of the opercle covered with scales (Table 10) varied little among populations (most means were 94–99 and 100) with the exception of the population in Cumberland River above the Falls which had a mean of 51 and a mode of 50–75. The population in Cumberland River below the Falls and those populations to the east and north (e.g., Tygarts Creek, and Kentucky, Licking, Little Sandy, and Big Sandy rivers) had a few individuals with reduced squamation on the opercle.

The percentage of the nape covered with scales (Table 11) varied from a low mean of 28 and a mode of 10 in Cumberland River above the Falls to a high mean of 97 and a mode of 100 in Tennessee River. In general, populations in eastern Kentucky (e.g., Tygarts Creek and Kentucky, Licking, Little Sandy, and Big Sandy rivers) had the lowest percentages, and those in the west (e.g., Tennessee, Tradewater, and Green rivers) had the highest. With a mean of 87 and a mode of 100, the population in Cumberland River below the Falls differed substantially from that above the Falls with a mean of 28 and a mode of 10.

The percentage of the cheek covered with

Table 4. Frequency distribution of counts of scales around the caudal peduncle in *Percina maculata.*

Drainage	18	19	20	21	22	23	24	25	26	27	28	N	X	SD	CV
Lake Huron			6	16	13	4						39	21.4	0.88	0.04
Lake Michigan				1	4	5	3					13	22.8	0.93	0.04
Mississippi River			1	10	21	12	1					45	22.0	0.82	0.04
Direct tribs. lower Ohio R. (IL)					1	3	7	1				12	23.7	0.78	0.03
Tennessee River				1	1	3	2					7	22.9	1.07	0.05
Cumberland River (below falls)				1		3	10	7	3		1	25	24.4	1.33	0.05
Cumberland River (above falls)				1	11	10	5	1				28	22.8	0.92	0.04
Tradewater River					2	1	7	7	2			19	24.3	1.11	0.05
Green River					1	5	23	13				42	24.1	0.72	0.03
Salt River					2	3	4	3				12	23.7	1.07	0.05
Kentucky River	1			2	9	22	57	16	2		1	111	23.7	1.15	0.05
Licking River				4	14	6	8	1				33	22.6	1.08	0.05
Tygarts Creek			1	7	7	4	2					21	22.0	1.07	0.05
Little Sandy River			2	2	3	1						8	21.4	1.06	0.05
Big Sandy River			2	3	17	13	8	1				44	22.6	1.09	0.05
Great Miami River				4	9	4	4	1				22	22.5	1.14	0.05
Scioto River			1		3							4	21.5	1.00	0.05
Total	1		13	52	117	99	141	51	7		2	483			

Table 5. Frequency distribution of pectoral ray counts in *Percina maculata*.

Drainage	12	13	14	15	N	X̄	SD	CV
Lake Huron		7	24	8	39	14.0	0.63	0.04
Lake Michigan	1	5	5	2	13	13.6	0.87	0.06
Mississippi River	3	31	11		45	13.2	0.53	0.04
Direct tribs. lower Ohio R. (IL)		10	2		12	13.2	0.39	0.03
Tennessee River		3	3	1	7	13.7	0.76	0.06
Cumberland River (below falls)	1	7	17		25	13.6	0.57	0.04
Cumberland River (above falls)		7	17	4	28	13.9	0.63	0.05
Tradewater River	1	9	9		19	13.4	0.61	0.05
Green River	1	21	18	2	42	13.5	0.63	0.05
Salt River		3	7	2	12	13.9	0.67	0.05
Kentucky River	1	23	68	19	111	13.9	0.64	0.05
Licking River		8	21	4	33	13.9	0.60	0.04
Tygarts Creek		8	10	3	21	13.8	0.70	0.05
Little Sandy River			6	2	8	14.3	0.46	0.03
Big Sandy River		14	29	1	44	13.7	0.51	0.04
Great Miami River		11	10	1	22	13.5	0.60	0.04
Scioto River		2	2		4	13.5	0.58	0.04
Total	8	169	259	49	485			

scales (Table 12) varied from a low mean of 33 and mode of 15 in Cumberland River above the Falls to a high mean of 95 and mode of 100 in Great Miami River. Populations in northeastern Kentucky (e.g., Licking River and Tygarts Creek) had the lowest percentages, and those in the west (e.g., Tennessee and Tradewater rivers) had the highest. As for nape squamation, a large difference in mean and mode occurred between populations below (mean = 84, mode = 90–100) and above (mean = 33, mode = 15) the Falls in the Cumberland River.

A principal components analysis of meristic characteristics of Ohio River populations in Kentucky failed to show any clear separations. In contrast, when morphometric data for these same populations were analyzed, populations in the Kentucky, Big Sandy, and Tradewater rivers emerged from one another. The best separation was shown by the plot of PCII against PCIII (Figure 3). A MANOVA indicated that all three populations differed significantly from one another (Kentucky River vs. Big Sandy River, $P < 0.0001$; Kentucky River vs. Tradewater River, $P = 0.0007$; Big

Table 6. Frequency distribution of anal ray counts in *Percina maculata*.

Drainage	6	7	8	9	10	11	N	X̄	SD	CV
Lake Huron			1	24	13	2	40	9.4	0.63	0.07
Lake Michigan			1	6	6		13	9.4	0.65	0.07
Mississippi River			10	31	4		45	8.9	0.55	0.06
Direct tribs. lower Ohio R. (IL)			2	10			12	8.8	0.39	0.04
Tennessee River			3	3	1		7	8.7	0.76	0.09
Cumberland River (below falls)			10	12	3		25	8.7	0.68	0.08
Cumberland River (above falls)			7	18	3		28	8.9	0.59	0.07
Tradewater River		1	2	12	4		19	9.0	0.75	0.08
Green River	1		7	31	3		42	8.8	0.66	0.07
Salt River			2	2	7	1	12	9.6	0.90	0.09
Kentucky River			42	66	3		111	8.6	0.53	0.06
Licking River			10	21	2		33	8.8	0.56	0.06
Tygarts Creek			11	10			21	8.5	0.51	0.06
Little Sandy River			4	4			8	8.5	0.53	0.06
Big Sandy River		2	15	25	2		44	8.6	0.65	0.08
Great Miami River			1	16	5		22	9.2	0.50	0.05
Scioto River	1		2	1			4	7.8	1.26	0.16
Total	2	3	140	282	56	3	486			

Table 7. Frequency distribution of dorsal ray counts in *Percina maculata.*

Drainage	9	10	11	12	13	14	15	N	X	SD	CV
Lake Huron			2	15	23			40	12.5	0.60	0.05
Lake Michigan				5	8			13	12.6	0.51	0.04
Mississippi River			8	26	11			45	12.1	0.65	0.05
Direct tribs. lower Ohio R. (IL)			1	10	1			12	12.0	0.43	0.04
Tennessee River			1	3	2	1		7	12.4	0.98	0.08
Cumberland River (below falls)		1	4	7	9	3	1	25	12.5	1.16	0.09
Cumberland River (above falls)		1	9	14	4			28	11.8	0.75	0.06
Tradewater River			1	11	7			19	12.3	0.58	0.05
Green River	1		3	20	16	2		42	12.3	0.87	0.07
Salt River		1	1	4	6			12	12.3	0.97	0.08
Kentucky River		5	38	58	10			111	11.7	0.71	0.06
Licking River			4	23	6			33	12.1	0.56	0.05
Tygarts Creek		1	3	16	1			21	11.8	0.60	0.05
Little Sandy River			1	4	3			8	12.3	0.71	0.06
Big Sandy River			5	29	9	1		44	12.1	0.63	0.05
Great Miami River			2	14	4	2		22	12.3	0.77	0.06
Scioto River			1	2	1			4	12.0	0.82	0.07
Total	1	9	84	261	121	9	1	486			

Sandy River vs. Tradewater River, $P < 0.0001$). Additionally, the plot of PCII against PCIII indicated that three other populations overlapped with Kentucky, Big Sandy, or Tradewater river populations but were separate from the remaining two. Tygarts Creek overlapped with Kentucky River but was separate from Big Sandy and Tradewater rivers (Figure 3). Both the Tennessee and Green rivers overlapped with the Tradewater River population but were separate from the Kentucky and Big Sandy rivers (Figure 3).

For morphometric data, the first principal component (PCI) explained 90.1% of the variance (Table 13); however, PCI is primarily a size component strongly influenced by variation in size of the specimens and provides little taxonomic information (Pimentel 1979). Loading most heavily on PCII (2.4% of the variance) were eye diameter, pectoral fin length, gape width, snout length, and caudal peduncle width; on PCIII (1.5%) were gape width, snout length, eye diameter, anal fin base length, and the length from the spinous dorsal fin origin to the anal fin insertion; on PCIV (1.2%) were caudal peduncle width, soft

Table 8. Frequency distribution of dorsal spine counts in *Percina maculata.*

Drainage	12	13	14	15	16	N	X	SD	CV
Lake Huron		2	28	10		40	14.2	0.52	0.04
Lake Michigan		2	8	3		13	14.1	0.64	0.05
Mississippi River	3	27	9	6		45	13.4	0.81	0.06
Direct tribs. lower Ohio R. (IL)	3	8			1	12	13.9	0.79	0.06
Tennessee River	1	1	5			7	13.6	0.79	0.06
Cumberland River (below falls)	2	9	12	2		25	13.6	0.77	0.06
Cumberland River (above falls)		4	13	9	2	28	14.3	0.82	0.06
Tradewater River		7	7	5		19	13.9	0.81	0.06
Green River	1	18	17	6		42	13.7	0.75	0.06
Salt River		3	5	4		12	14.1	0.79	0.06
Kentucky River	2	27	63	16		109	13.8	0.70	0.05
Licking River		15	16	2		33	13.6	0.61	0.04
Tygarts Creek		6	11	3	1	21	14.0	0.80	0.06
Little Sandy River		4	4			8	13.5	0.53	0.04
Big Sandy River	1	4	28	11		44	14.1	0.65	0.05
Great Miami River	2	1	10	7	1	21	14.2	0.98	0.07
Scioto River		1	2			3	13.7	0.58	0.04
Total	15	139	238	84	5	482			

Table 9. Frequency distribution of counts of lateral blotches in *Percina maculata*.

Drainage	5	6	7	8	9	10	N	X	SD	CV
Lake Huron	8	26	4	1			39	6.0	0.65	0.11
Lake Michigan	4	8	1				13	5.8	0.60	0.10
Mississippi River	5	24	10	4	1		44	6.4	0.89	0.14
Direct tribs. lower Ohio R. (IL)			11				11	7.0	0.00	0.00
Tennessee River		2	4		1		7	7.0	1.00	0.14
Cumberland River (below falls)	1	5	15	3			24	6.8	0.70	0.10
Cumberland River (above falls)		2	21	5			28	7.1	0.50	0.07
Tradewater River	2	2	15				19	6.7	0.67	0.10
Green River		7	33	1	1		42	6.9	0.53	0.08
Salt River			10	2			12	7.2	0.39	0.05
Kentucky River		1	51	46	12	1	111	7.7	0.72	0.09
Licking River		3	23	7			33	7.1	0.55	0.08
Tygarts Creek		1	11	8	1		21	7.4	0.68	0.09
Little Sandy River		1	5	2			8	7.1	0.64	0.09
Big Sandy River		1	27	15	1		44	7.4	0.57	0.08
Great Miami River	4	6	9	3			22	6.5	0.93	0.15
Scioto River			2	2			4	7.5	0.58	0.08
Total	24	89	252	99	17	1	482			

dorsal fin base length, anal fin base length, and eye diameter; and on PCV (0.9%) were anal fin base length, soft dorsal fin base length, length between spinous dorsal fin origin and pelvic fin origin, pectoral fin length, and the length from the spinous dorsal fin origin to the anal fin insertion.

DISCUSSION

Populations examined in our study exhibit considerable geographic variation, with the most extreme character states in individuals from the Cumberland and Kentucky rivers. However, it appears that gene flow is occurring even among the most divergent populations, and no population is taxonomically diagnosable.

Percina maculata in the Cumberland River above Cumberland Falls has several characteristics that distinguish it from the Cumberland River population below the Falls. Lateral line and pored lateral line scale counts were higher above the Falls than below (Tables 1, 2); transverse scales, scales above the lateral line, scales below the lateral line, caudal peduncle scales, and dorsal rays were much low-

Table 10. Frequency distribution of percentages of opercle covered with scales in *Percina maculata*.

Drainage	10	25	50	75	100	N	X	SD	CV
Lake Huron					40	40	100	0.00	0.00
Lake Michigan					13	13	100	0.00	0.00
Mississippi River					45	45	100	0.00	0.00
Direct tribs. lower Ohio R. (IL)					12	12	100	0.00	0.00
Tennessee River					7	7	100	0.00	0.00
Cumberland River (below falls)		1	1	1	22	25	94	0.18	0.19
Cumberland River (above falls)	4	5	8	9	2	28	51	0.27	0.53
Tradewater River					19	19	100	0.00	0.00
Green River					42	42	100	0.00	0.00
Salt River					12	12	100	0.00	0.00
Kentucky River			1	3	107	111	99	0.06	0.06
Licking River				2	31	33	98	0.06	0.06
Tygarts Creek				1	19	20	99	0.06	0.06
Little Sandy River				1	7	8	97	0.09	0.09
Big Sandy River			1	2	39	42	98	0.09	0.09
Great Miami River					22	22	100	0.00	0.00
Scioto River					4	4	100	0.00	0.00
Total	4	6	11	19	453	483			

Table 11. Frequency distribution of percentages of nape covered with scales in *Percina maculata*.

Drainage	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	N	X	SD	CV
Lake Huron	2		4	2	2	5	2	1	4	1	2		1		3	7	2	1	2			40	44	0.27	0.62
Lake Michigan			1				2				1		1			1		2	2	3		13	68	0.29	0.43
Mississippi River	1		3	2	1	1	1	2	4	1	3		4			3	7	1	5	4	2	45	60	0.30	0.50
Direct tribs. lower Ohio R. (IL)											1					1	2		3	1	4	12	88	0.15	0.17
Tennessee River																			1	2	4	7	97	0.04	0.04
Cumberland River (below falls)									1		2			1		2	2	1	3	1	12	25	87	0.18	0.21
Cumberland River (above falls)		2	7	2	4	3	1	2	3		1					1	1				1	28	28	0.24	0.84
Tradewater River																2	1		2	1	13	19	95	0.09	0.09
Green River						1							1			5		6	3	5	21	42	91	0.15	0.16
Salt River				1	2		1		1		2					2			1	2		12	55	0.30	0.56
Kentucky River	6		16	2	2	5	4	3	10		5		10		5	2	5	6	11	12	5	109	54	0.33	0.62
Licking River	2	2	1	2	4	1	1	4	6		1		2		3	2			1	1		33	39	0.26	0.67
Tygarts Creek			1				1	1	4		6		1		1			4		2		21	57	0.24	0.41
Little Sandy River						2		3		1	1							1				8	42	0.19	0.46
Big Sandy River				7	1		4	1	3		6		4		1	3	3	1	6	4		44	56	0.28	0.50
Great Miami River						1				1	3		1	1		2		2	7	3	1	22	76	0.21	0.27
Scioto River					1	1			1								1					4	41	0.27	0.66
Total	11	4	33	18	17	20	17	17	47	4	34	0	25	2	13	33	24	25	47	41	63	484			

Table 12. Frequency distribution of percentages of cheek covered with scales in *Percina maculata*.

Drainage	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	N	X	SD	CV
Lake Huron											2				1	1	1	6	13	2	14	40	90	0.12	0.13
Lake Michigan																	1		1		11	13	98	0.06	0.06
Mississippi River									1		2		2		2	2	6		7	5	18	45	87	0.16	0.18
Direct tribs. lower Ohio R. (IL)					1				1		1				1		1		3		4	12	78	0.27	0.35
Tennessee River																	1	1	1		4	7	94	0.09	0.09
Cumberland River (below falls)						1							2		1	3	2	1	7	1	7	25	84	0.17	0.21
Cumberland River (above falls)		4	3	5	2		1	3	1	1	2		1	1		4						28	33	0.25	0.76
Tradewater River													3				3		2	4	7	19	88	0.14	0.16
Green River							2				3		2			1	6	1	15	9	2	42	80	0.22	0.27
Salt River													2		1				3	1	5	12	88	0.16	0.18
Kentucky River	3		2		4		3		4		9		5		5	3	16	7	23	2	25	111	75	0.27	0.36
Licking River					1					1	2	1	1	1	3	2	3	7	7		4	33	78	0.18	0.23
Tygarts Creek			1	2	2				1		4						1		3		7	21	65	0.35	0.53
Little Sandy River																1	1	1	3	2		8	88	0.07	0.08
Big Sandy River			2		1		1		1		2		3	1		3	2	1	7	1	19	44	81	0.26	0.32
Great Miami River																1	1	1	5		14	22	95	0.08	0.08
Scioto River																			1		3	4	98	0.05	0.05
Total	3	4	8	7	11	1	7	3	9	2	27	1	22	3	14	21	45	26	101	27	144	484			

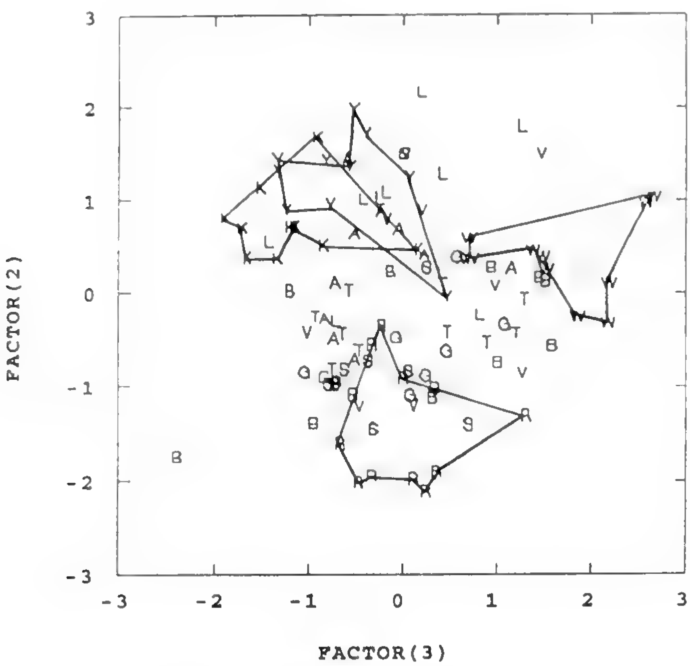

Figure 3. Principal component analysis of morphometric variables for *P. maculata*. T = Tennessee River, K = Kentucky River, W = Big Sandy River, V = Little Sandy River, G = Green River, R = Tradewater River, L = Licking River, S = Salt River, Y = Tygarts Creek, A = Cumberland River (above Falls), B = Cumberland River (below Falls). Outlined populations are ones with extreme values.

er above the Falls than below (Tables 3, 4, 7). The population above the Falls exhibited much reduced opercle, nape, and cheek squamation. *Percina maculata* was described by Beckham (1983) as having a fully scaled opercle; however, the majority of specimens examined from above the Falls had percentages of squamation at 75% and below (Table 10). Mean percentages of scales covering the nape and cheek (28% and 33%, respectively) fall well below the means for other Ohio River populations (Tables 11, 12).

Three fishes are endemic to the upper Cumberland River drainage: *Phoxinus cumberlandensis, Etheostoma sagitta sagitta,* and *E. nigrum susanae* (Starnes and Starnes 1978). The closest relatives of *P. cumberlandensis* are *P. tenneseensis* and *P. oreas* (Starnes and Jenkins 1988). *Phoxinus tenneseensis* occurs in the upper Tennessee River drainage, and *P. oreas* is found in the upper Tennessee, New, and Atlantic Slope drainages. The ancestor of these three species is thought to have lived in the preglacial Teays River drainage, and a population isolated in the Cumberland River drainage above the Falls differentiated into *P. cumberlandensis* (Starnes and Jenkins 1988).

The arrow darter, *E. sagitta,* includes two subspecies, *E. s. sagitta,* an endemic of the Cumberland River above the Falls, and *E. s. spilotum* of the upper Kentucky River basin (Kuehne and Bailey 1961). The two forms are readily distinguishable (Kuehne and Bailey 1961) and presumably differentiated after a stream capture event isolated them (discussed below).

Table 13. Variable loadings for principal component analysis of measurements of *Percina maculata.*

Variable	PCI	PCII	PCIII	PCIV	PCV
Head length	0.0598	−0.0067	0.0022	0.0045	0.0026
Head depth	0.0719	−0.0067	0.0032	−0.0001	−0.0081
Head width	0.0631	−0.0073	−0.0016	0.0077	0.0003
Snout length	0.0835	−0.0182	−0.0149	−0.0097	−0.0022
Predorsal length	0.0616	−0.0051	0.0039	0.0083	0.0004
Eye diameter	0.0497	−0.0126	−0.0023	0.0155	0.0093
Gape width	0.0859	−0.0332	−0.0186	−0.0188	−0.0061
Pectoral fin length	0.0645	−0.0164	−0.0021	0.0133	0.0121
Pelvic fin length	0.0631	−0.0061	0.0038	0.0064	0.0092
Spinous dorsal fin base length	0.0683	0.0023	0.0078	0.0057	−0.0033
Soft dorsal fin base length	0.0757	0.0105	0.0136	−0.0131	0.0146
Anal fin base length	0.0736	0.0085	0.0062	−0.0211	0.0115
Caudal fin length	0.0592	−0.0099	0.0041	0.0093	0.0052
Caudal peduncle width	0.1060	0.0389	−0.0344	0.0082	0.0013
Caudal peduncle depth	0.0672	0.0056	0.0027	−0.0019	−0.0045
Spinous dorsal fin origin to pelvic fin origin	0.0780	0.0034	0.0117	0.0003	−0.0147
Spinous dorsal fin origin to anal fin origin	0.0690	0.0008	0.0079	0.0101	−0.0079
Soft dorsal fin origin to anal fin insertion	0.0769	0.0098	0.0087	−0.0051	0.0004
Soft dorsal fin origin to pelvic fin origin	0.0649	0.0014	0.0063	0.0069	−0.0068
Spinous dorsal fin insertion to anal fin origin	0.0800	0.0094	0.0078	0.0002	−0.0062
Anal fin origin to soft dorsal fin insertion	0.0730	0.0096	0.0054	−0.0108	−0.0001

Studies by Kuehne and Bailey (1961) and Starnes and Starnes (1979) suggest that multiple faunal exchanges have occurred between the Cumberland and Kentucky rivers. *Etheostoma sagitta* and *E. baileyi* both occur only in the upper Cumberland and upper Kentucky river basins (Kuehne and Bailey 1961). The absence of close relatives of these two darters in the central Ohio River basin suggests that their presence in the upper Kentucky River is a result of transfer by stream capture. Kuehne and Bailey (1961) hypothesized that the transfer occurred when Little Richland Creek, an upper Cumberland tributary, was captured by Collins Fork, a small tributary of the upper Kentucky River. Alternatively, these darters entered the Cumberland from the Kentucky River. This latter hypothesis is based on the Pliocene connection of the Kentucky River to the Teays River (which flowed west to the Mississippi River) and the fact that the closest relative to *E. sagitta* is *E. nianguae,* an inhabitant of the Missouri River system in Missouri (Burr and Page 1986; Burr and Warren 1986).

Etheostoma nigrum susanae, endemic to the upper Cumberland River, appears to intergrade with *E. n. nigrum* in the headwaters of the adjacent Kentucky River system to the north (Starnes and Starnes 1979). Several populations from the upper Kentucky River system, particularly in the Middle Fork, have reduced head and belly squamation, closely approaching that of *E. n. susanae,* that probably results from gene flow between upper Cumberland and Kentucky river populations (Starnes and Starnes 1979). Strange (1998) interpreted mitochondrial DNA variation in the upper Cumberland and upper Kentucky River drainages to suggest that *E. n. susanae* had invaded the upper Cumberland system at least twice, the first time from an unknown source and the second time from the Kentucky River.

Percina maculata in the Kentucky River has several unusual characteristics. In particular, lateral line scales exhibit a bimodal distribution; a strong cluster of individuals centers around 67 scales and another around 71 scales (Table 1). Mean lateral line scale counts for the Licking River, which lies just northeast of the Kentucky River, and Cumberland River above the Falls (just to the south) were 67.6 and 70.2, respectively, suggesting that introgression into the Kentucky River population is occurring from the Licking and upper Cumberland river systems. Specimens from the Kentucky River also share with the Cumberland River population reduced squamation on the nape, cheek, and opercle, again suggesting intergradation.

Populations of *P. maculata* in Tygarts Creek and Licking, Little Sandy, and Big Sandy rivers exhibit low values in several meristic characters compared to values for other Ohio River tributaries. The Little Sandy River population has the lowest mean values for lateral line scales, pored lateral line scales, scales around the caudal peduncle, anal rays (shared with Tygarts Creek), and dorsal spines (Tables 1, 2, 4, 6). The Tygarts Creek population has the lowest mean values for transverse scales, scales above the lateral line, scales below the lateral line, and anal rays (shared with Little Sandy River) (Tables 3, 6). *Percina maculata* in the Licking River groups with Little Sandy River and Tygarts Creek for scales around the caudal peduncle, percentage opercle squamation, percentage nape squamation, and percentage cheek squamation. *Percina maculata* in the Big Sandy River groups with Little Sandy River and Tygarts Creek for lateral line scales, pored lateral line scales, percentage opercle squamation, and percentage nape squamation. Geological evidence indicates that these and other eastern tributaries of the Ohio River were tributaries of the ancestral Teays River and were separated from the Kentucky River in the early Pleistocene (Hocutt et al. 1986). As a result, the Licking River fauna closely resembles the Big Sandy fauna, rather than that of the adjacent Kentucky River, which has faunal affinities with lower Ohio River tributaries (Hocutt et al. 1986).

Populations of *P. maculata* in the Tradewater, Green, and lower Cumberland rivers, tributaries of the lower Ohio River, exhibit high values in several meristic characters. The highest mean value for transverse scales in *P. maculata* is shared by the Tradewater, Green, and lower Cumberland rivers (Table 3). The Tradewater river population has the highest means and modes for scales above the lateral line, scales below the lateral line, and number of pectoral fin rays (Table 5). The population of *P. maculata* in the lower Cumberland River has the highest values for scale rows around the caudal peduncle and dorsal rays (Tables 4, 7). The extreme values for these populations can be attributed to the fact that they are geographically distant from drainages to the east (e.g., Kentucky and Big Sandy rivers). The Tradewater, Tennessee, and Green river populations overlap each other on the plot of PCII and PCIII but are separate from the Kentucky and Big Sandy river populations (Figure 3). The distance between eastern and western drainages effectively serves as a barrier to gene flow and has led to populational differences in meristic characters and body shape.

Although *P. maculata* shows considerable variation in tributaries of the Ohio River, new taxa cannot be diagnosed. The examination of large samples from Ohio River tributaries suggests that gene flow has prevented speciation, even in geologically distinct areas such as the upper Cumberland River.

MATERIAL EXAMINED

Numbers of specimens of *P. maculata* are in parentheses. Complete locality data may be obtained from the authors upon request. Institutional abbreviations are as listed in Leviton et al. (1985).

Lake Huron drainage. MICHIGAN: Oscoda Co., UMMZ 194283 (29); Isabella Co., INHS 57895 (8), 57913 (1), 57924 (2). Lake Michigan drainage. MICHIGAN: Ingham Co., INHS 79581 (1); Allegan Co., INHS 38819 (2), 41972 (10). Mississippi River drainage. ILLINOIS: Kankakee Co., INHS 5356 (6), 5630 (4); Woodford Co., INHS 10930 (14); Piatt Co., INHS 8541 (10); Will Co., INHS 4872 (11). Direct tributaries, Ohio River. ILLINOIS: Pope Co., INHS 1350 (6), 1468 (4), 41009 (2). Tennessee River drainage. KENTUCKY: Calloway Co., INHS 40872 (1); SIUC 7681 (1), 10405 (2); Graves Co., SIUC 8755 (1), 11866 (1); Marshall Co., INHS 77681 (1). Below Cumberland Falls, Cumberland River drainage. KENTUCKY: Trigg Co., INHS 41907 (1); SIUC 12274 (1); Livingston Co., INHS 75545 (1), 75546 (4); Laurel Co., EKU 536 (1); SIUC 8511 (2); Rockcastle Co., SIUC 15568 (2); Jackson Co., SIUC 14902 (1), 27174 (2); Logan Co., SIUC 11616 (6); Todd Co., SIUC 10333 (4). Above Cumberland Falls, Cumberland River drainage. KENTUCKY: McCreary Co., SIUC 6872 (9), 9466 (13), 23852 (1); Whitley Co., SIUC 2382 (1), 8451 (1); Bell Co., SIUC 186 (1), 16894 (1); Letcher Co., SIUC 23251 (1). Tradewater River drainage. KENTUCKY: Crittenden Co., INHS 78370 (1); Caldwell Co., SIUC 8913 (18). Green River drainage. KENTUCKY: Todd Co., INHS 58214 (4); SIUC 9241 (30); Christian Co. INHS 27502 (7); Allen Co., EKU 140 (1). Salt River drainage. KENTUCKY: Marion Co., SIUC 14257 (8); EKU 757 (1); Bullitt Co., SIUC 16987 (2); Washington Co., INHS 75543 (1). Kentucky River drainage. KENTUCKY: Clay Co., INHS 43044 (19), 64303 (3), 79026 (8), 79196 (4), 86873 (1), 88555 (3); EKU 593 (2); Lincoln Co., EKU 342 (7), 387 (1), 400 (1), 411 (2), 429 (2); Jackson Co., EKU 435 (2), 576 (3), 968 (1); Owsley Co., EKU 765 (1); INHS 79213 (1), 88536 (1); Letcher Co., EKU 1299 (8), 1303 (8); Carroll Co., EKU 485 (2); INHS 42992 (1); Wolfe Co., EKU 24 (2); INHS 39096 (3); Powell Co., EKU 1270 (8); INHS 87422 (3); Rockcastle Co., EKU 455 (2); Lee Co., EKU 1271 (2); Breathitt Co., INHS 64290 (6); Leslie Co., INHS 78497 (4). Licking River drainage. KENTUCKY: Montgomery Co., EKU 1304 (1); INHS 75544 (1); Bath Co., EKU 1272 (2); Nicholas Co., EKU 1315 (1); Fleming Co., SIUC 11375 (3), 16834 (1); Magoffin Co., SIUC 8243 (25). Tygarts Creek drainage. KENTUCKY: Carter Co., EKU 137 (4), 1061 (2), 1068 (5); SIUC 5660 (2), 9314 (1); INHS 88040 (7); Greenup Co., EKU 164 (1). Little Sandy River drainage. KENTUCKY: Elliott Co., EKU 1038 (1); SIUC 11225 (2); Carter Co., SIUC 7177 (7), 13387 (1). Big Sandy River drainage. KENTUCKY: Pike Co., EKU 59 (2); INHS 76999 (20); Lawrence Co., SIUC 8824 (7); Martin Co., SIUC 8864 (13); Floyd Co., SIUC 16587 (2). Great Miami River drainage. OHIO: Darke Co., OSM 63502 (2), 63538 (4), 63556 (4), 63562 (2), 63594 (1); Miami Co., OSM 63533 (3), 63572 (1), 63609 (1), 63902 (1); Preble Co., OSM 4836 (3). Scioto River drainage. OHIO: Scioto Co., OSM 62750 (4).

ACKNOWLEDGEMENTS

We thank S. Kohler and R. Warner for helpful reviews of the manuscript, and J. W. Armbruster, K.S. Cummings, M. Hardman, J.H. Knouft, T.J. Near, J.C. Porterfield, M.E. Retzer, M.H. Sabaj, J. Serb, and C.A. Taylor for thoughtful discussions and assistance. Specimens were loaned to us by B.M. Burr (SIUC), P.A. Ceas (EKU), T. Cavender (OSM), and D. Nelson (UMMZ). Financial support was provided by the Illinois Natural History Survey and the University of Illinois Department of Natural Resources and Environmental Sciences.

LITERATURE CITED

Beckham, E. C. 1983. Systematics, redescription, and geographic variation of the blackside darter, *Percina maculata*. Ph.D. Dissertation. The Louisiana State Univ. and Agricultural and Mechanical College, Baton Rouge, LA.

Beckham, E. C. 1986. Systematics and redescription of the blackside darter, *Percina maculata* (Girard), (Pisces: Percidae). Occas. Papers Mus. Zool., Louisiana State Univ. 62:1–11.

Burr, B. M., and L. M. Page. 1986. Zoogeography of fishes of the Lower Ohio-Upper Mississippi Basin. Pages 287–324 in C. H. Hocutt and E. O. Wiley (eds). Zoogeography of North American freshwater fishes. Wiley-Interscience, New York, NY.

Burr, B. M., and M. L. Warren Jr. 1986. A distributional atlas of Kentucky fishes. Kentucky Nature Preserves Comm. Sci. Techn. Series 4.

Etnier, D. A., and W. C. Starnes. 1993. The fishes of Tennessee. Univ. Tennessee Press, Knoxville, TN.

Hocutt, C. H., R. E. Jenkins, and J. R. Stauffer Jr. 1986. Zoogeography of the fishes of the central Appalachians and central Atlantic Coastal Plain. Pages 161–211 in C.H. Hocutt and E. O. Wiley (eds). Zoogeography of North American freshwater fishes. Wiley Interscience, New York, NY.

Hubbs, C. L., and K. F. Lagler. 1964. Fishes of the Great Lakes region. Univ. Michigan Press, Ann Arbor, MI.

Hubbs, C. L., and E. C. Raney. 1939. *Hadropterus oxyrhynchus*, a new percid fish from Virginia and West Virginia. Occas. Papers Mus. Zool., Univ. Michigan 396:1–9.

Kuehne, R. A., and R. M. Bailey. 1961. Stream capture and the distribution of the percid fish *Etheostoma sagitta*, with geologic and taxonomic considerations. Copeia 1961:1–8.

Leviton, A. E., R. H. Gibbs Jr., E. Heal, and C. E. Dawson. 1985. Standards in herpetology and ichthyology: Part I. Standard symbolic codes for institutional resource collections in herpetology and ichthyology. Copeia 1985:802–832.

Page, L. M. 1974. The subgenera of *Percina* (Percidae: Etheostomatini). Copeia 1974:66–86.

Page, L. M. 1983. Handbook of darters. T.F.H. Publications, Neptune City, NJ.

Pimentel, R. A. 1979. Morphometrics the multivariate analysis of biological data. Kendall/Hunt Publishing Co., Dubuque, IA.

Raney, E. C., and R. D. Suttkus. 1964. *Etheostoma moorei*, a new darter of the subgenus *Nothonotus* from the White River system, Arkansas. Copeia 1964:130–139.

Starnes, W. C., and R. E. Jenkins. 1988. A new cyprinid fish of the genus *Phoxinus* (Pisces: Cypriniformes) from the Tennessee River drainage with comments on relationships and biogeography. Proc. Biol. Soc. Wash. 101: 517–529.

Starnes, W. C., and L. B. Starnes. 1978. A new cyprinid of the genus *Phoxinus* endemic to the upper Cumberland River drainage. Copeia 1978:508–516.

Starnes, W. C., and L. B. Starnes. 1979. Taxonomic status of the percid fish *Etheostoma nigrum susanae*. Copeia 1979:426–430.

Strange, R. M. 1998. Mitochondrial DNA variation in johnny darters (Pisces: Percidae) from eastern Kentucky supports stream capture for the origin of upper Cumberland River fishes. Am. Midl. Naturalist 140:96–102.

Trautman, M. B. 1957. The fishes of Ohio. Ohio State Univ. Press, Columbus, OH.

J. Ky. Acad. Sci. 60(2):108-112. 1999.

Potential Influence of Predator Presence on Diel Movements of Small Riverine Fishes in the Ohio River, Kentucky

Richard K. Kessler

Department of Biology, Campbellsville University, Campbellsville, Kentucky 42718

ABSTRACT

I investigated the hypothesis that onshore night migrations by small riverine fishes are potentially linked to offshore increases in predator abundance. Offshore predator presence was determined by fishing a gill net offshore from two separate cobble beds near Westport, Kentucky, on the Ohio River over two 24-hour periods. Shoreline fishes were collected along cobble beds by boat electrofishing in water <1 m depth at over two 24-hour periods. Small, non-schooling fishes such as *Cyprinella spiloptera, Percina* spp., and Micropterus spp. young-of-the-year (YOY) were most common at night; their increase in abundance was significantly correlated with increases in abundance of piscivores offshore. Schooling fishes such as *Dorosoma cepedianum* and *Notropis atherinoides* were most common during the day; their abundances were significantly correlated with light levels

INTRODUCTION

The phenomenon of diel fish movement is well documented in many systems, including coral reefs (Helfman 1993) and lakes (Tonn and Paszkowski 1987). Coral reefs are often represented by distinct day-versus-night fish communities, and studies of lakes and reservoirs have shown that many species of fishes occur in shallow, littoral zones in greater numbers at night. Others have shown that some small cyprinids stay inshore during the day then move offshore at night in lakes (e.g., Bohl 1980). These results are not surprising for temperate aquatic systems, especially given the importance of the changing light intensities to fish ecology (Copp and Jurajda 1993). Similar results were obtained in large river systems, but such studies have not typically addressed the ecological factors associated with such movements (Sanders 1992). Research by Copp (1992), Kessler (1997), and Sanders (1992) have shown that species richness and/or overall abundance of fishes (aged 0+ and small adults) occurring along the shorelines of rivers often increases at night, and Clark (1979) demonstrated a similar pattern for fish larvae occurring near the shore in the Ohio River. Such in-shore diel movements are poorly understood in riverine systems compared to our knowledge of such movements in lakes and reservoirs (Copp and Jurajda 1993).

Diel shifts in fish distribution within rivers may be linked to the influence of predation risk. Predation may affect fishes directly (by killing) or indirectly (shifts in distribution, habitat use, foraging behavior, or a combination of these). Shoreline habitats are among the most structurally heterogeneous of riverine habitats (Lobb and Orth 1991) and probably represent an important refuge from predation. Suspended structure is important to some small cyprinids as a diurnal predator refuge (Fraser 1983), and shoreline habitats may also function as a refuge from piscivorous fishes due to their size-limiting shallowness (Copp and Jurajda 1993). It has been observed and experimentally demonstrated that the depth distribution of fishes in small (1st–3rd order) streams is linked to the type and intensity of predation pressure (Power 1987; Schlosser 1988). The hypothesis of Power and Schlosser was that larger fishes are limited in their ability to exploit shallow-water habitats (pool margins) due to presence of non-gape limited wading bird predators. Small fishes are at greatest risk of predation from gape-limited swimming predators in deeper water (pools). The differential influence of these predator types should result in diel shifts in fish distributions.

The purpose of my study was to address the following two basic questions. First, are night migrations of many small fishes toward shore in the Ohio River correlated with an increasing occurrence of piscivores offshore, as shown in some European rivers? Second, do different types of predator threats (i.e., swimming, gape-limited versus wading, non-gape limited piscivores) influence fishes in the same way?

METHODS AND MATERIALS

I conducted two diel field studies were conducted during base-flow (August–October) 1994 in the McAlpine Pool of the Ohio River near Westport, Kentucky. All fish sampling occurred at six 4-hour intervals from 0800 to 0400 (0800–1200–1600–2200–2400–0400–0800). In August, I estimated the diel abundance of potential piscivores (those individuals >150 mm whose diets are known to consist mainly of fishes in nearshore waters of the main channel. A 30 m by 2.5 m experimental nylon gill net was fished during two separate 24-hour periods offshore from two extensive (200–400 m long) cobble beds. The gill net consisted of three equal-area panels of nylon mesh with mesh sizes of 2.54, 3.75, and 5.08 cm^2. A 180 m transect in 2.5–3.0 m deep water was established parallel to shore at each site and six 30 m sections were marked with fluorescent floats. The gill net was fished at each section in random order during each 24-hour period at both sites. Fishes were collected and preserved in 10% formalin for identification and measurement. Shoreline fishes were sampled over two 24—hour periods in October. Physical conditions during both periods are historically very similar, and prior fish collections yielded mostly the same species and size classes in August and October (Pearson and Krumholz 1984; Kessler 1997). For collection of shoreline fishes, 100 m transects were established parallel to shore at each of the cobble beds previously mentioned. Both transects were sampled every 4 hours over each 24-hour period. Boat electrofishing was used to collect fishes. Two forward booms (1.8 m apart) each supported one 2.5-cm diameter electrode. A 3500 W generator was used to power the electrodes with 220 V AC. This method was well suited for Ohio River cobble beds (versus other shoreline habitats, e.g., macrophyte beds) because consistent straight-line sampling in water <1 m deep could be consistently achieved. All stunned fishes between the two booms were collected by one person with a mesh dip net (45 cm wide, 35 cm deep, mesh = 6.5 mm). Night collections were aided by two boat headlights and halogen headlamps. Fishes were retained in an aerated cooler until they could be identified and measured; they were released after each 100 m sample was completed. Downwelling light intensity (footcandles) was measured just below surface at each 4-hour interval over one 24-hour period using a digital photometer. Diel relative abundance was determined for offshore piscivores and shoreline fishes (<100 mm). Fish abundances for separate diel collecting periods were combined for both offshore and shoreline samples and relative abundance for each 4-hour interval (total sum of individuals of species *a* collected during that interval/ total sum of individuals of species *a* over the 24-hour period) was tabulated for all species or assigned taxonomic groups represented by >five individuals. Data were combined for the following taxa: *Micropterus salmoides* and *M. dolimieui* (Lacepede); *Etheostoma blennioides* (R.) and *E. flabellare* (R.); *Percina caprodes* (R.) and *P. shumardi* (Girard). Data were standardized against the hypothetical average value of relative abundance for each interval (0.167). The resulting values were used in further between-group comparisons. Distributions over time were then compared using the Pearson Correlation Coefficient (PCC). A simple linear regression (SLR) was employed to compare fish frequency distribution to light intensity.

RESULTS

The field study demonstrated that there are differences in distribution of schooling and non-schooling fishes at shoreline cobble beds. Non-schooling fishes were collected at all sample intervals (except for *Etheostoma* spp. and *A. grunniens*) but were most abundant during the 2000 and 2400 samples (Table 1). This was a consistent trend for *Cyprinella spiloptera* (Cope), *Micropterus* spp., *Percina* spp., *A. grunniens,* and combined non-schooling fishes (Table 1). The schooling fishes (*N. atherinoides* and *Dorosoma cepedianum* (LeSueur) were collected only during the day along the cobble shorelines. The highest occurrence of both was during the 1600 sample. Piscivores were present offshore at all sample intervals but increased in night samples (2000–0400). The offshore increase of piscivores and the shoreline increase in small, non-schooling fishes at night was positively correlated for *C. spi-*

Table 1. Light intensity and total number and (relative occurrence) of taxa of Ohio River fishes over two 24-hour periods.

Time	0800	1200	1600	2000	2400	0400	Total
Light intensity (footcandles)	100	500	950	1	0	0	—
Cyprinella spiloptera	1 (.100)	0	1 (.100)	3 (.300)	3 (.300)	2 (.200)	10
Notropis atherinoides	8 (.066)	32 (.262)	82 (.672)	0	0	0	122
Dorosoma cepedianum	0	32 (.151)	180 (.849)	0	0	0	212
Micropterus spp.	0	0	1 (.143)	2 (.286)	2 (.286)	2 (.286)	7
Etheostoma spp.	1 (.143)	0	0	0	2 (.286)	4 (.571)	7
Percina spp.	6 (.188)	1 (.031)	2 (.062)	9 (.281)	9 (.281)	5 (.156)	32
Aplodinotus grunniens	0	0	0	47 (.412)	51 (.447)	14 (.140)	112
Total	24 (.047)	67 (.131)	267 (.520)	60 (.117)	67 (.131)	28 (.055)	513
Combined schooling	8 (.023)	64 (.192)	262 (.784)	0	0	0	334
Combined non-schooling	16 (.089)	3 (.017)	5 (.028)	60 (.335)	67 (.374)	28 (.156)	179
Piscivores	6 (.111)	2 (.037)	3 (.056)	15 (.278)	18 (.333)	10 (.185)	54

loptera (PCC = 0.964; P = 0.002), *Micropterus* spp. (PCC = 0.813; P = 0.049), *Etheostoma* spp. (PCC = 0.363; P = 0.479), *Percina* spp. (PCC = 0.933; P = 0.007), *A. grunniens* (PCC = 0.966; P = 0.002), and the combined non-schooling category (PCC = 0.991; $P < 0.001$). The relative abundances of *N. atherinoides, D. cepedianum,* combined schooling and total fishes were all negatively correlated to the increase of piscivores offshore at night, but not significantly. The abundance each of these was significantly related to light intensity, however. This relationship was consistent for emerald shiners (SLR; $P < 0.001$, $r^2 = 0.966$), gizzard shad (SLR; $P = 0.007$, $r^2 = 0.864$), combined schooling (SLR; $P = 0.004$, $r^2 = 0.905$), and total fishes (SLR; $P = 0.031$, $r^2 = 0.979$).

DISCUSSION

Although several studies have demonstrated shifts in diel fish distribution in rivers, most collections have not been designed to assess the purposes of such community shifts (Sanders 1992). Sanders (1992), Copp and Jurajda (1993), and the present study have shown that species richness increases along shallow riverine habitats at night. Copp and Jurajda (1993) also found that densities of those same species increased at night within the same habitat. This increase of species at night does not support the hypothesis that fishes use shoreline habitats as a velocity refuge or for other abiotic reasons that are constant on a diel basis. Instead it suggests the influence of a biotic factor that may exhibit some diel variation, like predator-prey interactions.

My field study, and that of Copp and Jurajda (1993), have drawn similar conclusions from the Ohio River and the River Morava (a Danube River tributary), Czech Republic, respectively. Both studies demonstrated that an increase in the densities of small fishes inshore at night is often correlated with a rise in the numbers of potentially piscivorous fishes in adjacent deeper offshore waters. As an example from the present study, densities of five of the seven taxa analyzed were positively correlated with increasing numbers of piscivores offshore at night. Copp and Jurajda (1993) showed that the number of small fishes (<100 mm) in the River Morava increased along a shallow sandy bank with decreasing light levels and decreased along a steep boulder bank at night. Interestingly, this general pattern was associated with an increase in the numbers of "potentially" piscivorous fished (>80 mm) along the deeper, boulder bank at night. They found this pattern to be consistent for all species occurring along the shallow sand bank.

Fish size is one of the most important determining factors when assessing the influence of piscivores on their prey. Even though piscivores usually broaden diets as they grow to include larger prey, most continue to show a selective preference for small-sized prey; this is probably due to some form of "differential size-based capture success" (Juanes 1994). Schlosser (1988) demonstrated that small, hornyhead chubs (*Nocomis bigutattus* (Kirtland)), 60–65 mm) were three times more at risk from predation by smallmouth bass than were larger chubs (100–110 mm). Also, it is not uncommon that habitat choice by small fishes, under increased need to seek refuge due to threat of predation, results in a concentration of those fishes in some common habitat (Mittlebach and Chesson 1987; Osenberg et al. 1994; Werner 1986).

While such arguments may explain the presence of small fishes in shallow refuge habitats, they do not account for the diel differences exhibited in these riverine systems. Diel shifts in light intensity are likely to account for at least some of the observed patterns. Some piscivores are known to be most effective under low-light conditions (Cerri 1983; Helfman 1993). Cerri (1983) further suggested that small prey fish encounter an increased risk of predation with twilight conditions and that the survival of the prey largely depends amount of and access to refuge areas during early life-history stages. Sanders (1992) attributed observed differences in diel fish distributions in his Ohio River study to twilight movements of fishes from offshore to nearshore habitats.

Why not simply remain in the shallow refuge areas day and night? One explanation might be the influence of avian predators. I have noted that herons and other wading birds are quite common along the shorelines of the Ohio River during summer when turbidity levels are low. The threat from such predators is greater during periods of high light intensity (Cerri 1983). This may explain the absence of all but the small, schooling fishes (emerald shiners and gizzard shad) during the day in shallow zones. Both Power (1987) and Schlosser (1988) demonstrated that non gape-limited avian predators may discourage use of shallow areas by larger fishes, while gape-limited piscivores represent the largest predation threat in deeper water. In related experiments using live bass and a great blue heron model, Kessler (1997) demonstrated that gape-limited and non-gape limited predators exert different effects on small prey compared to larger ones. The experiments suggested that indicated a dominant effect of gape-limited, swimming predators (bass) on emerald shiners versus the effect of a diurnal, non gape-limited wading predator (heron). Larger, non-schooling freshwater drum YOY were more influenced by the non gape-limited wading predator. The differential influence of a swimming, gape-limited predator supports the hypothesis that such predators affect small prey more than large prey, while the opposite holds true for the effect of non-gape limited avian predators. Such results suggest that differential predatory influences on prey depth distributions are probably mediated by prey size and/or behavioral differences in prey species.

It is still not clear why the small, schooling fishes were present along the shoreline only during the day. Schooling behavior, however, is a visual behavior largely dependent on light, and this group behavior may afford some protection from avian predators. The present study revealed a significant positive correlation between light intensity and the onshore presence of schooling species. However, given their small size and the fact that schooling behavior usually breaks down at night (Helfman 1993), one would assume that offshore movements would be risky for small emerald shiners and gizzard shad knowing that piscivores increase in number and effectiveness during this time. Interestingly, Schael et al. (1995) found the density of threadfin shad in a North Carolina reservoir greatly increased in open surface waters at night versus day; they concluded that this may be due to an onshore movement of this fish during the day, suggesting a possible important link between the littoral and limnetic food webs. Earlier, Bohl (1980) demonstrated that movements of juvenile roach (*Rutilus rutilus* (L.), rudd (*Scardinius erythrophtalamus* (L.), and bleak (*Alburnus alburnus* (L.), to pelagic zones offshore at night in Bavarian lakes was correlated with increased feeding rates. While the present study did not reveal any discoveries relating to the offshore presence/absence of emerald shiners, it is plausible that the distribution of YOY emerald shiners in particular may be influenced by another factor—the distribution of their prey. Zooplankton is an important component in the diet of such fishes; it has been suggested that some zooplankton may undergo a lateral and/or horizontal migration in large rivers (J. D. Jack and J. H. Thorp, pers. comm.); many zooplankton organisms actually increase nearshore during the day followed by a rise in densities in the channel at night. Therefore, it could be that species such as the emerald shiner, which are especially dependent on zooplankton when young, are afforded sufficient protection from avian predators in shallow water during the day by virtue of their schooling behavior and that the risk of offshore predators at night is outweighed by the presence of a necessary food source. The increased number of small piscivores along the shore at night (e.g., YOY sauger) may provide an additional impetus for their offshore movement. However, much further study is needed before such interactions can be conclusively determined.

In conclusion, it is clear that offshore predation threat was a strong correlate of the onshore occurrence of many species of small, riverine fishes. A number of field studies and experiments strongly suggest that gape-limited piscivores and shallow avian predators elicit different responses from larger, solitary species versus smaller, schooling species. A complete understanding of the influence of predators and related factors on the diel distribution of small fishes in large rivers depends on future comparative studies from a variety of large river systems. Future studies should incorporate simultaneous diel sampling of shoreline and offshore fishes as well as in situ predator-prey experiments.

ACKNOWLEDGMENTS

I thank the Sport Fishing Institute and University of Louisville's Center for Environmental Studies for supporting this project; James H. Thorp, Paul Bukaveckas, William Pearson, Jeff Jack, and Mike Delong for reviewing various components of the manuscript; and Andrew Casper, Tim Sellers, Richard Sodano, and Kim Greenwood for assistance in the field.

LITERATURE CITED

Bohl, E. 1980. Diel pattern of pelagic distribution and feeding in planktivorous fish. Oecologia 44:368–375.

Cerri, R. D. 1983. The effect of light intensity on predator and prey behaviour in cyprinid fish: factors that influence prey risk. Anim. Behav. 31:736–742.

Clark, A. L. 1979. Temporal and spatial distribution of ichthyoplankton at Ohio River Mile 571. Master's Thesis, University of Louisville, Louisville, KY.

Copp, G. H. 1992. An empirical model for predicting microhabitat of 0+ juvenile fishes in a lowland river catchment. Oecologia 91:338–345.

Copp, G. H., and P. Jurajda. 1993. Do small riverine fishes move inshore at night? J. Fish Biol. 43:229–241.

Fraser, D. F. 1983. An experimental investigation of refuging behavior in a minnow. Canad. J. Zool. 61:666–672.

Helfman, G. S. 1993. Fish behaviour by day, night, and twilight. Pages 479–507 in T. Pitcher (ed). Behaviour of teleost fishes. Chapman and Hall, New York, NY.

Juanes, R. 1994. What determines prey selectivity in piscivorous fishes? Pages 79–103 in D. J. Stouder, J. L. Fresh, and R. J. Feller (eds). Theory and application in fish feeding ecology. University of South Carolina Press, Columbia, SC.

Kessler, R. K. 1997. The functional importance of shoreline habitats to fishes of the Ohio River. Ph.D. Dissertation, University of Louisville, Louisville, KY.

Lobb, M. D., III, and D. J. Orth. 1991. Habitat use by an assemblage of fish in a large warmwater stream. Trans. Am. Fish. Soc. 120:65–78.

Mittlebach, G. G., and P. L. Chesson. 1987. Predation risk: indirect effects on fish populations. Pages 315–332 in W. C. Kerfoot and A. Sih (eds). Predation: direct and indirect impacts on aquatic communities. University Press of New England, Hanover, NH.

Osenberg, C. W., M. H. Olson, and G. G. Mittlebach. 1994. Stage structure in fishes: resource productivity and competition gradients. Pages 151–170 in D. J. Stouder, K. L. Fresh, and R. J. Feller (eds). Theory and application in fish feeding ecology. Belle W. Baruch Library in Marine Sciences, no. 18. Univ. South Carolina Press, Columbia, SC.

Pearson, W. D., and L. A. Krumholz. 1984. Distribution and status of Ohio River fishes. Oak Ridge Natl Lab. Publ. ORNL/Sub/79-7831/1.

Power, M. E. 1987. Predator avoidance by grazing fishes in temperate and tropical streams: importance of stream depth and prey size. Pages 333–352 in W. C. Kerfoot and A. Sih (eds). Predation: direct and indirect impacts on aquatic communities. University of New England Press, Hanover, New Hampshire.

Sanders, R. E. 1992. Day versus night electrofishing from near-shore waters of the Ohio and Muskingum rivers. Ohio J. Sci. 92:51–59.

Schael, D. M., J. A. Rice, and D. J. Degan. 1995. Spatial and temporal distribution of threadfin shad in a southeastern reservoir. Trans. Am. Fish. Soc. 124:804–812.

Schlosser, I. J. 1988. Predation risk and habitat selection by two size classes of a stream cyprinid: experimental test of a hypothesis. Oikos 52:36–40.

Tonn, W. M., and C. Paszkowski. 1987. Habitat use of the central mudminnow (*Umbra limi*) and yellow perch (*Perca flavescens*) in *Umbra-Perca* assemblages: the roles of competition, predation, and the abiotic environment. Canad. J. Zool. 65:865–870.

Werner, E. E. 1986. Species interactions in freshwater fish communities. Pages 344–358 in J. Diamond and T. Case (eds). Ecological communities. Harper and Row, New York, NY.

Wilkinson, L. 1989. Systat: the system for statistics. Systat, Evanston, Illinois.

J. Ky. Acad. Sci. 60(2):113–123. 1999.

Empirical Measurements of the Antenna Radiation Pattern of the Morehead Radio Telescope

Benjamin K. Malphrus and Michael S. Combs

Morehead Astrophysical Observatory, Morehead State University, Morehead, Kentucky 40351

Randolph P. Lillard

Department of Physical Sciences, Morehead State University, Morehead, Kentucky 40351

Jeff Kruth

Kruth Microwave Electronics, Ellicott City, Maryland 21043

ABSTRACT

The Morehead Radio Telescope, an instrument designed for undergraduate research, consists of a surplused 44-foot Nike-Hercules radar antenna modified for astronomical observations, an automated alt-azimuth positioning system, a custom-designed sensitive front and back-end receiver system, and supporting electronics and hardware. The telescope incorporates a modular design in which components may be easily removed for use in laboratory investigations and student research and design projects. The performance characteristics of the telescope allow a varied and in-depth scientific program. The sensitivity and versatility of the telescope design facilitate the investigation of a wide variety of astrophysically interesting phenomena.

The radiation or beam pattern of the antenna of a radio telescope is of primary importance to the instrument's overall performance. The radiation pattern of an antenna is its sensitivity response as a function of direction. The radiation pattern is a three-dimensional representation of the magnitude, phase, and polarization of the antenna's directivity function. Empirical measurements of the radiation pattern of the Morehead Radio Telescope's parabolic antenna have been completed. A mathematical model of the far-field radiation pattern will be produced from the results of this experiment.

INTRODUCTION

The design of the Morehead Radio Telescope (MRT), Morehead State University (MSU), Morehead, Kentucky, provides an instrument capable of supporting scientific research in observational astrophysics at radio frequencies. The design and fabrication of the basic MRT systems are complete; first light was achieved on 12 Oct 1996. Among the most important characteristics that determine a radio telescope's performance is the antenna's radiation (beam) pattern, its pattern of sensitivity to the sky. The beam pattern is a three-dimensional representation of the magnitude, phase, and polarization of the antenna's directivity function and therefore determines the instrument's spatial resolution, which is typically expressed as the half-power beam width (HPBW), that is, the width of the sensitivity profile at half maximum. The intent of this experiment was to empirically measure the MRT antenna's far-field radiation pattern, model its geometry, and compare this model to the theoretical performance characteristics of the antenna. The instrumentation used, the experimental procedures, and project significance are described.

MRT INSTRUMENTATION

The basic design of the MRT includes a wire-mesh parabolic reflecting antenna (Figure 1), alt-azimuth tracking positioner control and drive systems, receiver and signal processing system, a controlling computer with an interface device, and supporting electronics and hardware. The system is designed around a total power receiver that converts radiation from space concentrated by the antenna system to an electrical signal, which is amplified, modified, and interpreted. The MRT system is controlled by a Macintosh IIsi controlling computer and utilizes a National Instruments Lab NB interface board, optical isolation system, and robotic drive and control systems developed by MSU faculty and students. The controlling computer positions the telescope, instructs it in robotic tracking of cosmic sources, and controls data collection and storage. (Malphrus et al. 1992).

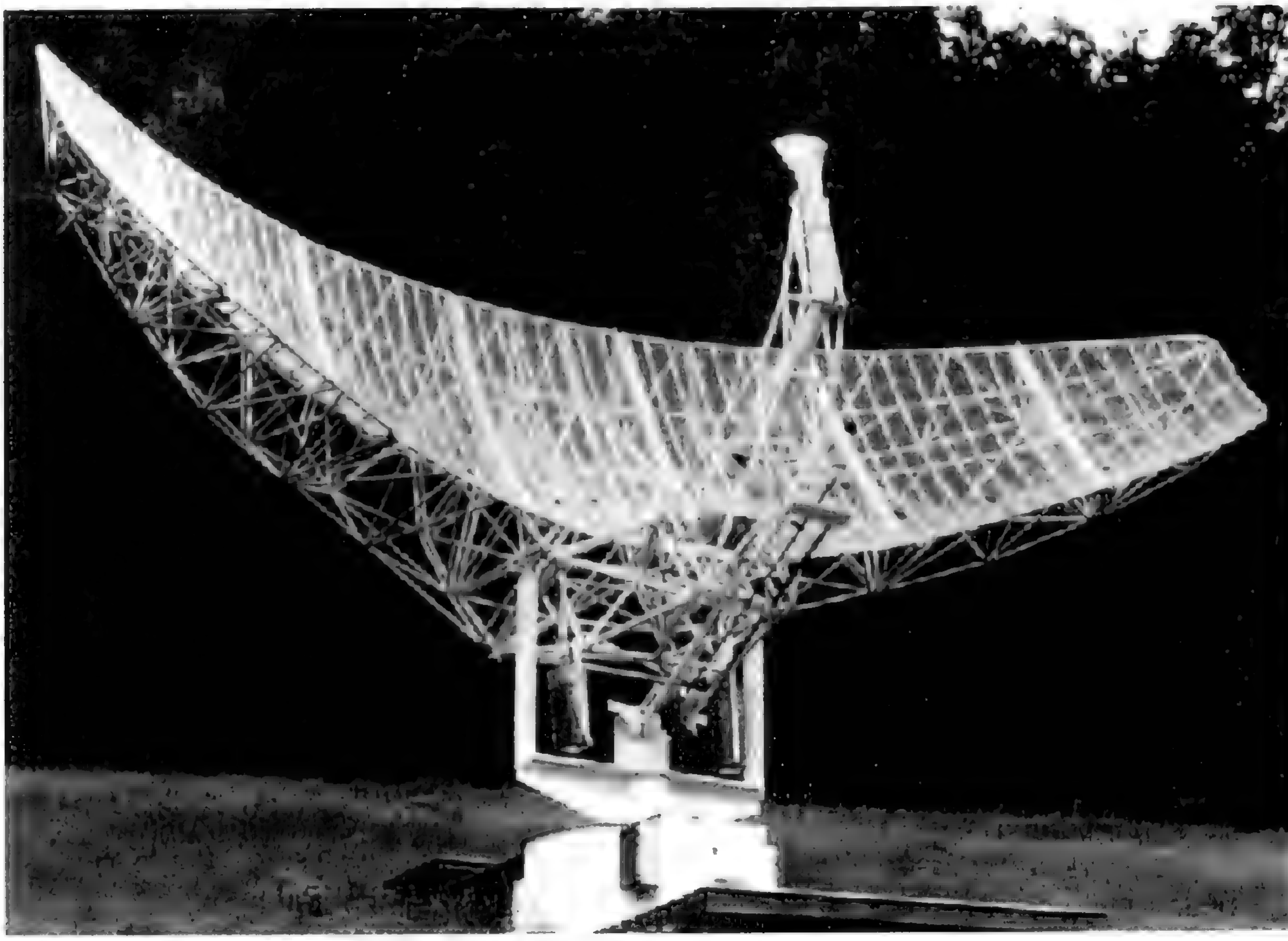

Figure 1. Morehead Radio Telescope, Morehead State University, Morehead, KY. The wire-mesh parabolic reflecting antenna and positioning system as it sits above the Morehead Astrophysics Laboratory.

The telescope utilizes a total power receiver system operating over a 6 MHz band centered at 1420 MHz. This receiver configuration allows observation of the atomic hydrogen line and sufficient bandwidth to observe most of the hydrogen in the galaxy. The measured and estimated performance characteristics of the system are as follows: spatial resolution = 0.9 arcdegrees, total receiver system temperature = 67.3 K, and the minimum detectable flux density = 4.3 Jy. The instrument is described in some detail in Section II along with a brief description of observations made with the MRT. A detailed description of the instrument has been published previously (Malphrus et al. 1998). The current experiment utilized the MRT system and a 1420 MHz radio frequency transmitter operated from atop a remote mountain. The primary components of the system utilized in this experiment and the 1420 MHz radio frequency transmitter are summarized below.

Antenna

The MRT employs a high-gain, 40-foot antenna designed for L-Band operation. A surplused Army NIKE-Hercules ANS-17 Radar antenna was obtained and modified for radio astronomy applications. The basic system includes a parabolic reflector, antenna feed horn, waveguide system, and azimuth-elevation positioning system. The current, third-iteration-positioning system provides azimuth coverage of 360° at a maximum antenna rotation speed of one revolution in 12 minutes and elevation coverage of 0 to 90° in 10 minutes. The positioning system also allows for continuous drive in tracking mode, essentially one degree in 4 minutes of time at the celestial equator and slower by the cosine of the declination as the angle increases or decreases.

Control and Indication Systems

Controlling computer. The MRT controlling computer currently in use is a 400 MHz Pentium processor with 128 MB of RAM and 9 GB of hard disk space. A multifunction analog, digital, and timing I/O (Input/Output) board is installed in the computer. It contains a 12-bit successive approximation A/D converter with 16 analog inputs, two 12-bit D/A converters with voltage outputs, 8 lines of transistor-transistor logic compatible I/O, and two counter/timer channels for timing I/O. The board has a 500kS/s single channel sampling rate. The multifunction interface board is controlled by LabVIEW, a software system that features interactive graphics, a state-of-the-art user interface, and a powerful graphical programming language "G." This software is used to (1) send the input pulses to both the azimuth and elevation translators, (2) move the telescope, (3) analyze the data collected from the optical encoder and clinometer, and (4) collect the data from receiver system.

Position Indication Systems

Azimuth indication system. The Azimuth indication system is based on measuring the rotation of an axle in the drive system with an optical absolute shaft encoder. The optical absolute shaft encoder is a noncontacting rotary-to-digital position feedback device mounted on the azimuth drive shaft at the stepper motor assembly. The internal monolithic electronic module converts the real-time shaft position angle, speed, and direction into TTL-compatible outputs. The encoder is used to count the rotations of the stepper motor shaft. These data basically provide feedback as they are used to determine if the shaft rotation count is equal to the number of pulses sent to the stepper motor. The number of steps per degree of sky has been empirically determined for the azimuth system during a series of experiments. Azimuth calibration experiments were performed from the period of 1994–1996 and again in 1998 after relocation to the new Astrophysical Laboratory facility. The resulting indication system provides feedback for the telescope position in azimuth to an accuracy of 0.10° and allows the telescope to position itself to any desired azimuth.

Elevation indication system. The elevation indication system is based on precisely measuring the tilt of the antenna focal plane with a high-precision bi-axial clinometer developed by Applied Geomechanics. The clinometer utilizes a precision electrolytic transducer that comprises the sensing elements. It produces two orthogonal tilt angles (X and Y tilt) and one temperature channel as its output channels. The clinometer is mounted on the parabolic reflector of the MRT and the orthogonal Y tilt angle is used for elevation positioning. As the antenna is moved from the local horizon to the zenith, the electrolytic transducer's voltage changes accordingly. This value is collected by the computer, and the software converts this value to elevation degrees utilizing a look-up table produced from a series of elevation calibration experiments performed during 1997–1998.

Remote 1420 MHz transmitter. A 1420 MHz transmitter was designed and constructed to generate an artificial signal to sweep the antenna beam through in order to determine the directivity pattern. The transmitter was designed and constructed by K-MEC and Morehead State University students. The device uses a voltage oscillator to create the 1420 MHz signal (Figure 2). The final transmitter design is seen in Figure 3. The final iteration produced a phase stable radiation source at 1420 MHz that allowed the radiation pattern experiment to be performed.

THEORETICAL PERFORMANCE CHARACTERISTICS OF THE MRT ANTENNA

The response of an antenna as a function of direction is given by its radiation pattern. This pattern is the same for receiving as it is for transmitting—a phenomenon known as antenna reciprocity. Typically, there is one main lobe flanked by several smaller lobes. The evaluation of the radiation pattern and lobes it contains can reveal important characteristics of the antenna's performance. To measure this pattern, a transmitter must be used to create the desired frequency. There is a point in the measurement process at which the pattern will not change if the transmitter is taken any farther away. This is called the far-field pattern. For measurements inside this distance, the pattern obtained is a near field pattern, which is a function of angle and distance. There are constraints that must be satisfied for the far-field pattern to be effectively measured. The minimum range distance must be much greater than the diameter (or greater than the major axis aperture of a non-circular antenna) $S_{min} \gg D$, and the minimum range distance must be much greater than the incident wavelength $S_{min} \gg \lambda$. Specifically, the minimum range distance equation is

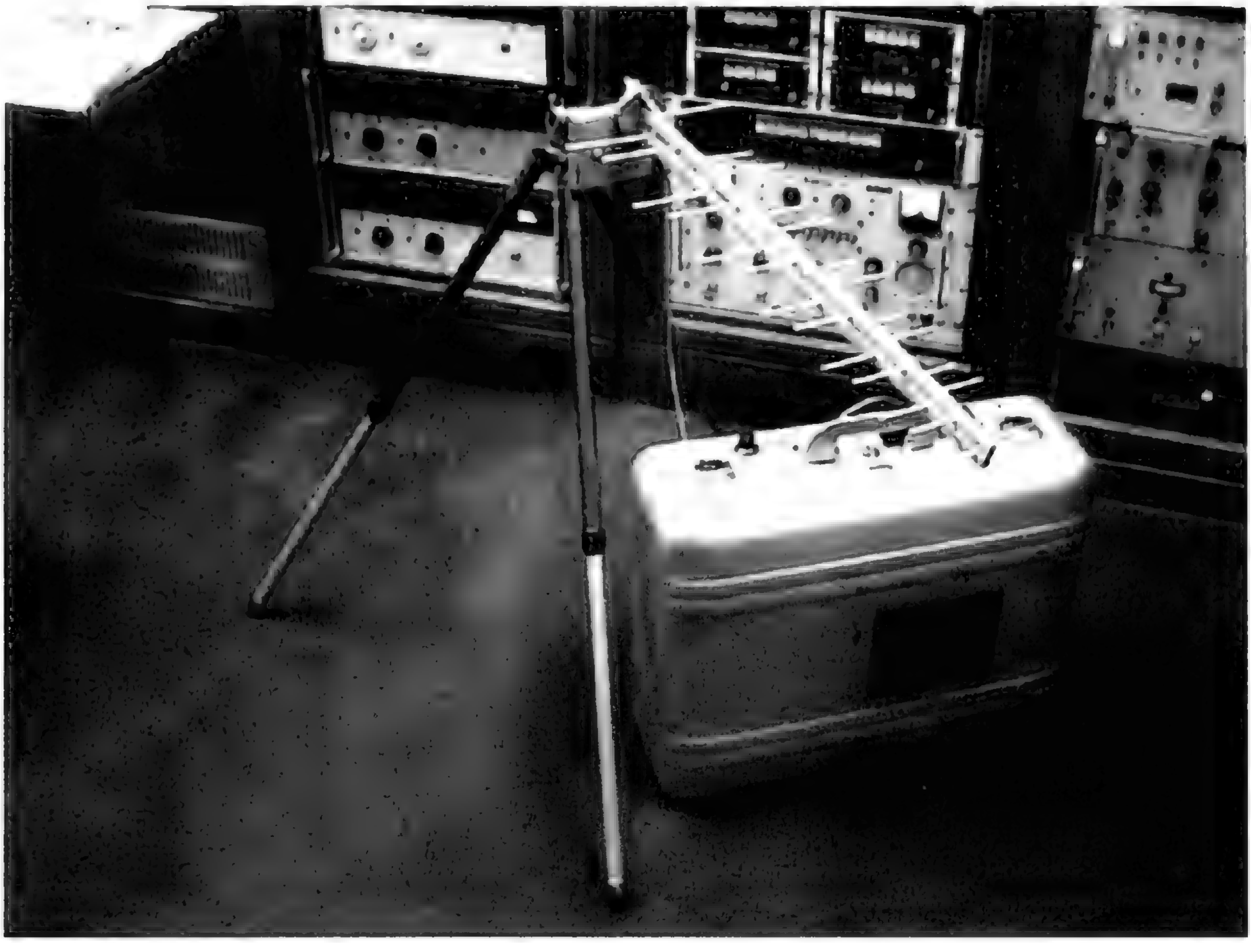

Figure 2. Morehead Radio Telescope, Morehead State University, Morehead, KY. The portable 1420 MHz transmitter and the accompanying Yagi antenna used to propagate the test signal.

$$S_{min} = \frac{D^2}{\lambda}$$

where S_{min} is the minimum range distance, D is the largest aperture dimension of the antenna, and λ is the wavelength. Using 13.25 m for D and 0.2112 m for the wavelength, the minimum range distance is 1662 m (The ARRL Antenna Book).

The field intensity measured as a function of azimuth angles proves to be the most useful method when evaluating antenna performance characteristics. After the measurements of the far-field pattern are collected, a useful numerical specification to describe the pattern is the beam solid angle.

This is the angle through which all the power from a transmitting antenna would stream if the power achieved its maximum value. It can be represented by the following double integral:

$$\Omega_A = \iint_{all\ sky} A(\theta, \phi)\, d\Omega$$

$A(\theta,\phi)$ represents the relative antenna power pattern as a function of angle (Napier et al. 1989).

An important relationship in antenna theory states that the product of the effective area, A_O, and the beam solid angle is equal to the square of the wavelength.

$$A_O \Omega_A = \lambda^2$$

If A_O is equal to 1 everywhere, then Ω_A has a maximum value of 4π. This also demonstrates that the primary antenna is isotropic and can see the whole sky with equal sensitivity.

Another important antenna parameter is the directivity. This property is very important for all directional antennas. It can be defined as the ratio of the maximum radiation intensity to the average radiation intensity, given below

$$D = \frac{U(\theta, \phi)_{max}}{U_{avg}}$$

Where $U(\theta,\phi)_{max}$ equals the maximum radiation intensity (watt sr^{-1}), and U_{avg} is the average radiation intensity (watt sr^{-1}). The av-

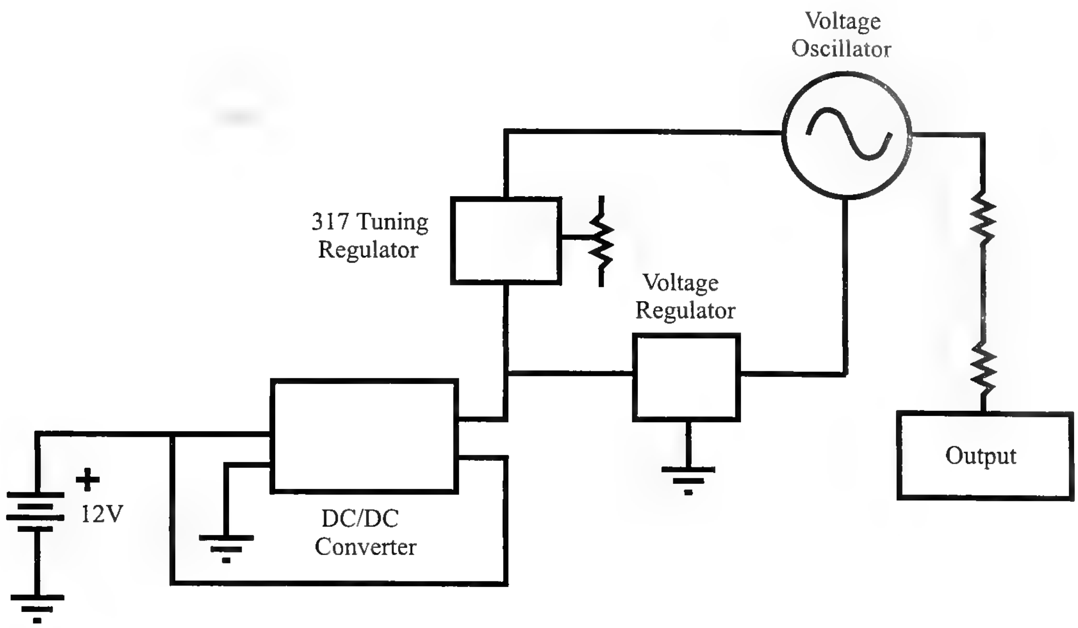

Figure 3. Morehead Radio Telescope, Morehead State University, Morehead, KY. Schematic diagram of the portable 1420 MHz transmitter.

erage radiation intensity is given by the total power W divided by 4π. The total power is equal to the radiation intensity $U(\theta,\phi)$ integrated over 4π.

$$D = \frac{U(\theta, \phi)_{max}}{\frac{W}{4\pi}} = \frac{4\pi}{\iint_{4\pi} \frac{U(\theta, \phi)\, d\Omega}{U(\theta, \phi)_{max}}}$$

Since the radiation intensity is proportional to the Poynting vector, D can be simplified to the following

$$D = \frac{4\pi}{\iint_{4\pi} A(\theta, \phi)\, d\Omega} = \frac{4\pi}{\Omega_A}$$

The directivity of an antenna is a fixed numerical (dimensionless) quantity. If the directivity is multiplied by the normalized power pattern, the directive gain is produced. The directive gain, which is a function of angle, is below

$$D = D(\theta, \phi)_{max} \iint_{4\pi} D(\theta, \phi)\, d\Omega = 4\pi\ .$$

Antenna patterns may be plotted in terms of directive gain. For a nondirectional antenna the pattern would be everywhere equal to the level $D(\theta,\phi) = 1$. This is referred to as the isotropic level. This isotropic level is referenced with the sidelobe structure in many cases (Kraus 1986). Figure 4 is an ideal plot of the radiation pattern in terms of the directive gain. These characteristics along with the half-power beam width (HPBW), which is qualitatively related to the directivity function, define the overall spatial resolution of the anten-

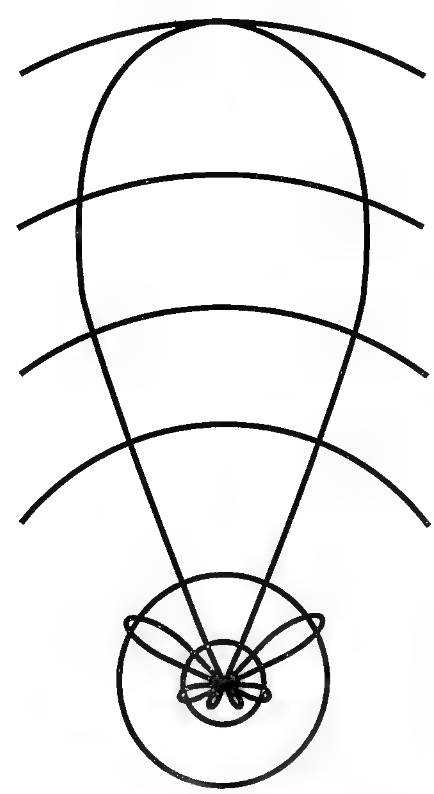

Figure 4. Morehead Radio Telescope, Morehead State University, Morehead, KY. An idealized polar plot of the radiation pattern of a circular antenna in terms of the directive gain.

na. Knowing the performance of the telescope allows proper subtraction of noise and interpretation of data received. If the far-field radiation pattern is obtained experimentally, then the theoretical aspects of the antenna can be observed and a better understanding of data taken during observations can be obtained.

The spatial resolution (expressed as half-power beam width–HPBW°) is derived from the radiation pattern and may be theoretically determined for a uniform reflector from the following relationship:

$$HPBW° = \frac{58\lambda(m)}{D(m)}$$

where:

HPBW° = Half-power beam width in degrees

λ = Operating wavelength in meters

D = Aperture diameter in meters

Calculation of the HPBW of the existing MRT system must be performed in two steps as the antenna is symmetric about a major and a minor axis (Malphrus et al. 1998). HPBW of the major axis = 0.911°; HPBW of the minor axis = 3.6°.

EXPERIMENTAL PROCEDURES

The far-field radiation pattern is often quoted as the most demanding of all antenna measurements. For optimum measurements, the transmitter must be placed well past 1662 m. Other factors that must be considered are: is the terrain relatively flat, is it free of obstructions, and is it of uniform consistency (i.e., gravel, dirt, buildings, etc.). All of these factors contribute to the radiation pattern measured. Any variability in these factors will cause deviations in the true pattern. To deter some of these problems, the source antenna used was directive, that is the waves were focused in one direction. A Yagi arrangement was found to meet this criterion and allowed for easy adjustment to the appropriate polarization. This allowed the radio waves to be relatively unaffected by radio frequency reflective structures (mountains, buildings, etc.) which could cause aberrations in the experimental data (ARRL Handbook).

To begin the experiment, the transmitter was located atop a mountain, located 3.8 km away, a distance well beyond the far-field pattern limitation. Initial measurements of the transmitted signal were contaminated by the 300K radiation contribution from the ground (mountain) on which the transmitter antenna was located. This necessitated installing the antenna on a television tower at a height of ca. 185 ft. Elevating the antenna provided a better line of sight, one uncontaminated by ground radiation. The transmitter was then tuned to the desired frequency of 1420 MHz by analyzing the signal with the back-end spectrum analyzer located at the Astrophysical Laboratory. Pre-detection and post-detection gains were then adjusted until the signal produced on the virtual strip-chart recorder stayed within a 10-volt range allowed by the receiver system. The virtual strip chart recorder is a virtual instrument (VI) developed utilizing the LabView environment using "G." It has been calibrated relative to three conventional electro-mechanical strip chart recorders and relative to two voltmeters. Next, the antenna position of maximum signal was obtained by aiming the antenna at the transmitter and then scanning very slowly in azimuth and elevation. A maximum signal of 8.18 volts was detected at 89° azimuth.

The next component of the experiment was to map the radiation pattern by scanning across the signal in a raster scan method, analogous to the motion of the electron beam in a standard television set. The procedure was to produce scans with the telescope in azimuth for a specific altitude, increasing the telescope's altitude by 2° each scan, which allowed for polar plots of the data at each altitude. This procedure also provided three-dimensional information from which a data cube of azimuth, altitude, and induced voltage could be produced. Scans ranged in azimuth from 76° to 102°, and in elevation from −4° to 21°. (In local horizon coordinates, 180° azimuth is true south and 0° elevation is the local horizon.) A 26 square degree area of sky was mapped in this manner. An essentially complete measurement of the topography of 3-D radiation pattern was attained during this scanning procedure.

RESULTS

The experiment resulted in 13 elevation scans, each consisting of 409 data points. An-

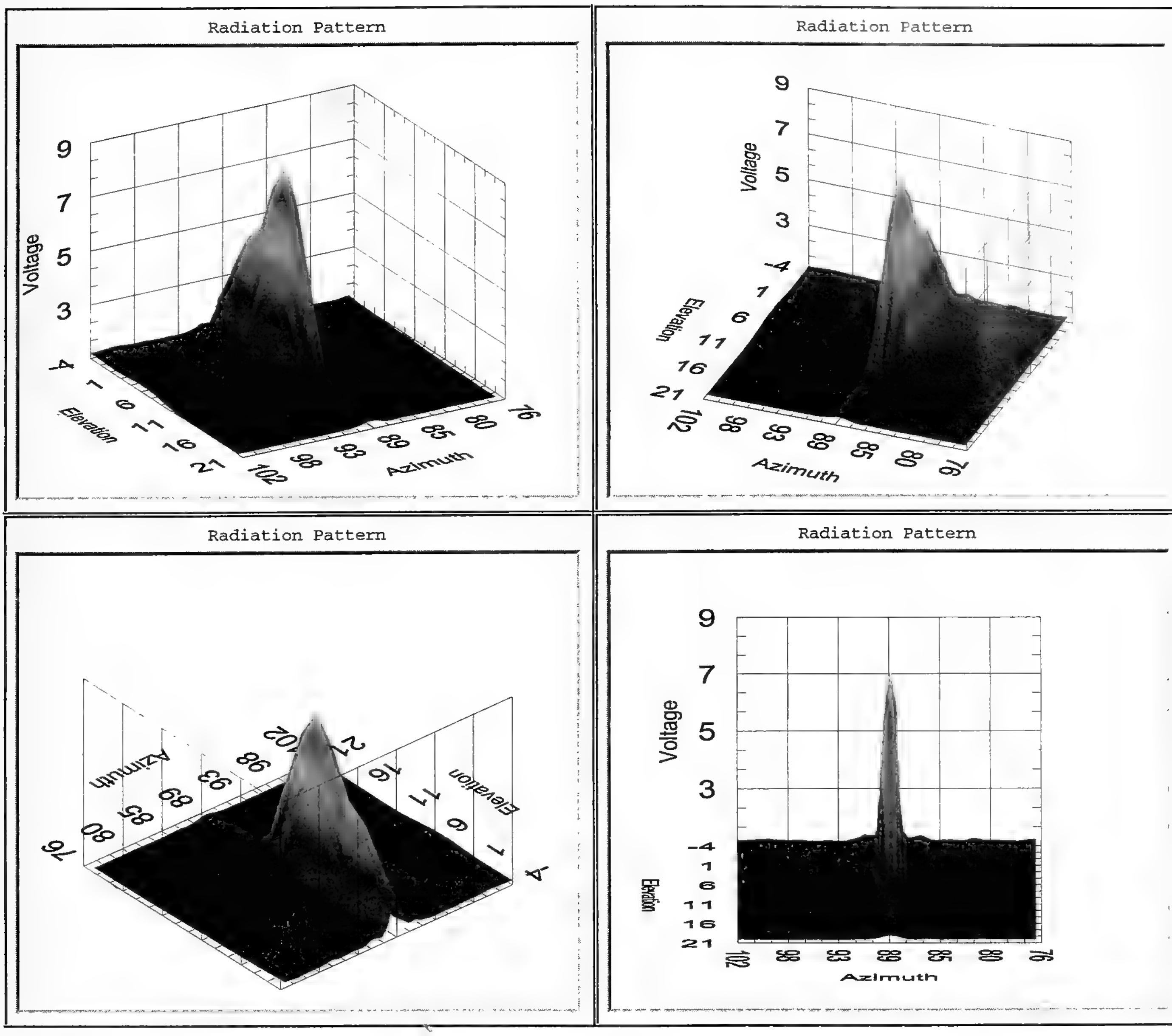

Figure 5. Morehead Radio Telescope, Morehead State University, Morehead, KY. Four perspectives of the three dimensional representation of the antenna radiation pattern.

tenna radiation pattern data are generally represented in polar coordinate systems and in Cartesian coordinates in three dimensions. A series of three-dimensional depictions of the data is presented in Figure 5. Viewing the data from different perspectives in three-dimensions lends significant insight into the geometry of the radiation pattern including the main beam and its side lobe structure. A contour map of the three-dimensional radiation pattern (Figure 6) shows that the radiation pattern is basically elliptical as expected. The radiation pattern, however, is much more complex than previously suspected, very much resembling a shark's dorsal fin whose long axis corresponds with the elevation axis of the radiation pattern. This "shark fin" feature actually makes sense in terms of the antenna's original function as one component of the two-element Nike Hercules radar system. The Nike Hercules system utilized two antennas—a 44-ft. antenna (i.e., the MRT aperture) moved in azimuth only and was used to illuminate the target and determine its precise azimuth. A smaller antenna was then pointed to the appropriate azimuth and scanned in the vertical dimension to pinpoint the target's elevation. It was desirable that the larger antenna produced a narrow beam in azimuth and a broad beam in elevation, hence its cosecant^2 cross-section. The radiation pattern measured in this experiment therefore seems very consistent with the original design purpose of the MRT aperture.

Two basic antenna measurements can be obtained from these data. First, the half-pow-

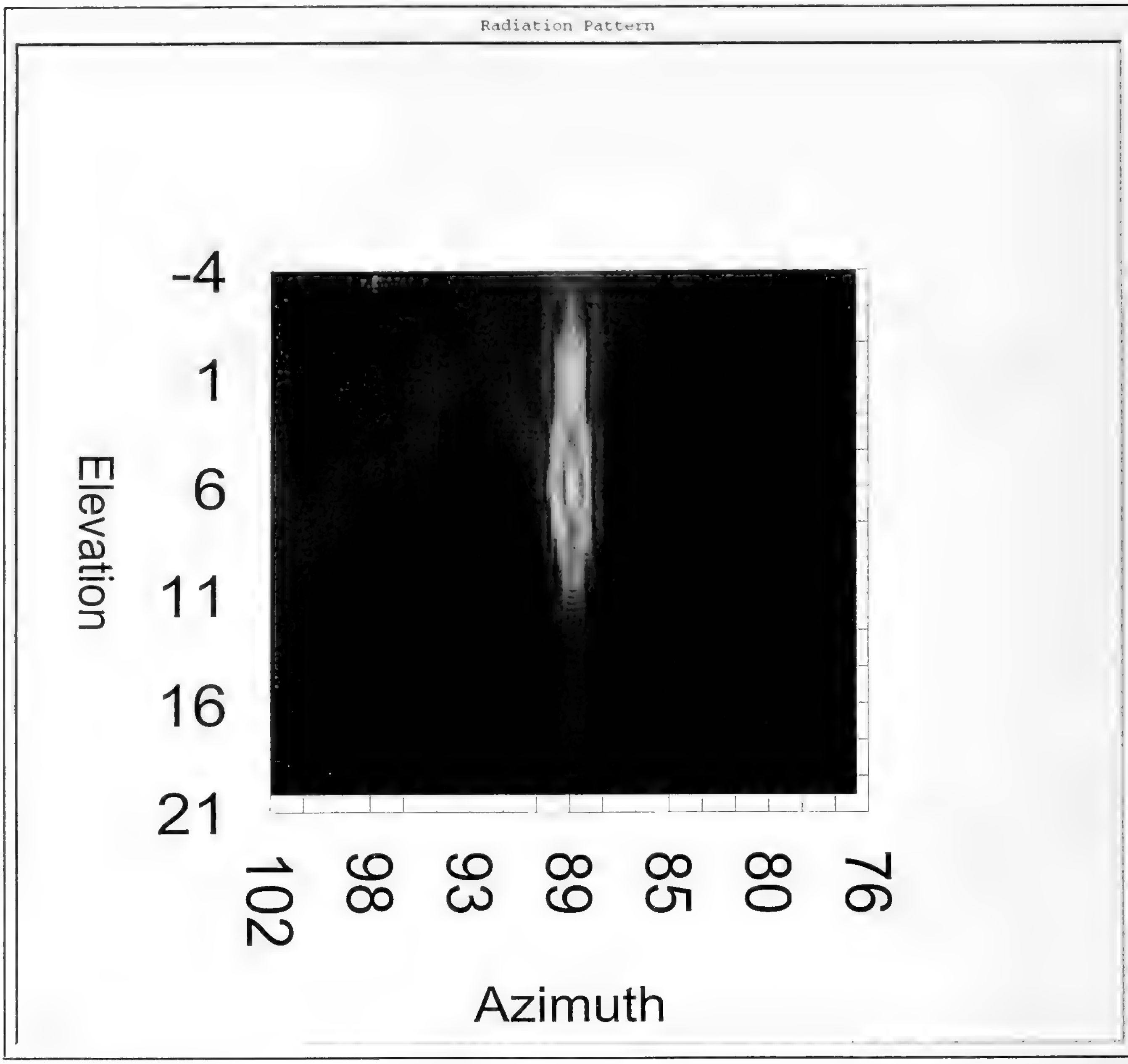

Figure 6. Morehead Radio Telescope, Morehead State University, Morehead, KY. Contour map of the antenna radiation pattern.

er beam width can be determined from the width of the voltage profile at 50% of its maximum. A peak voltage of 8.18V recorded at azimuth 89° and the width of the curve at half-maximum was found to be 1.035°. This value yields a 13% error from the theoretical HPBW for the major axis, indicating some agreement, especially given that the measured value is expected to be larger than the theoretical value. Unfortunately, given the complex shape of the beam pattern and its extent along the elevation axis, this value is not the only one of importance. Given the quasi-elliptical nature of the beam, the HPBW in elevation may be described along with the beam solid angle. The elevation HPBW is difficult to measure because of the complex geometry. Taken at exactly the half-voltage maximum, the HPBW is ca. 10°. An inclined plateau, however exists in the elevation profile. Taking the width above the profile's plateau produces a value of ca. 7°, which is in closer agreement with the theoretical value. Calculating the beam solid angle as $4/3(HPBW_{maj}*HPBW_{min})$ gives a value of 7.2 square degrees, not an unreasonable value for this size aperture. Another important value derived from this project is side-lobe height compared to the main deflection. This is found by the following equation,

$$dB = 10 \log\left(\frac{S}{S_o}\right)$$

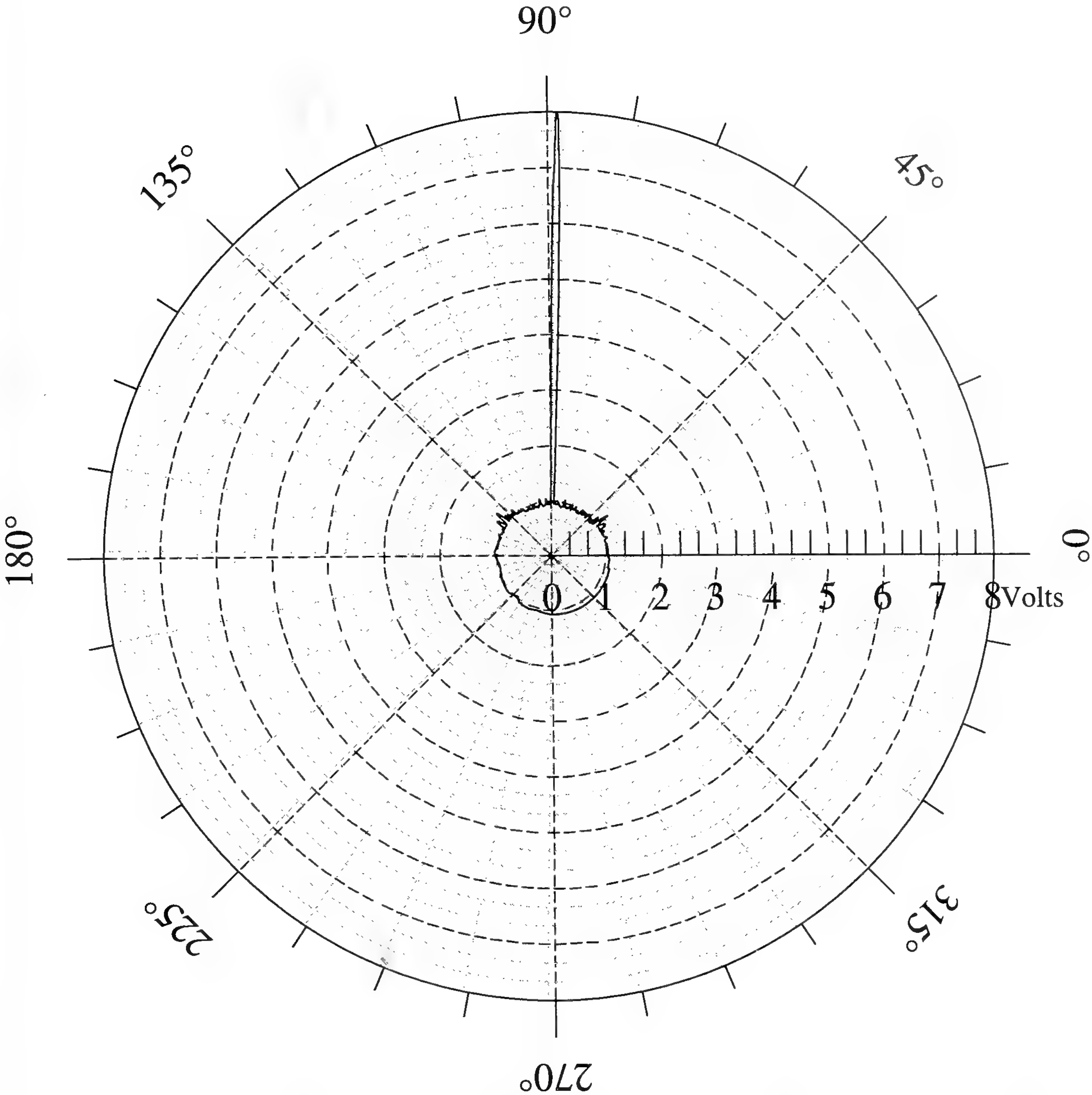

Figure 7. Morehead Radio Telescope, Morehead State University, Morehead, KY. Radiation pattern at 6.0° elevation.

where S is the side lobe height and S_o is the height of the main deflection. S was measured at 0.18v and S_o was found to be 8.18V. This yields a dB of −16.5 (ARRL Handbook).

These experimentally-produced values favorably correspond to theoretical and expected values. For a highly directional antenna, which is ideal for radio astronomy applications, the desired side lobe height is somewhat smaller. More significant, however, is the complex nature of the radiation pattern. For most astrophysical observations, a circular beam is considered ideal. In reality, however, many radio telescopes produce beams with elliptical geometries. Even synthesized beams produced with interferometry techniques such as the VLA exhibit elliptical geometries when the array points toward objects near the Southern horizon. The fact that the MRT aperture exhibits a complex elliptical geometry is therefore not completely surprising.

The significance of the 360° azimuth scan is that the HPBW can be found graphically from a polar plot of the data (Figure 7). The width of the peak at half maximum is related to the HPBW. By using $\theta = s*l^{-1}$, where θ is the HPBW in radians, s is the arc length, and l is the distance from the point at half maximum to the center of the plot. Analysis of the polar plot produces a width of the curve at half maximum of $\theta = 0.03509$ radians, which corresponds to a HPBW of 1.08°. This value implies good agreement with both the theoretical and the value based on the 3-D pattern. In theory, the two experimental values of the HPBW should be approximately the same. The empirical measurements, however, are expected to be greater than the theoretical, which cannot be achieved in reality. Possible variables for the greater empirical value include surface deformations and asymmetries in the reflecting surface, and the non-parabolic shape of the telescope.

CONCLUSIONS AND PROJECT SIGNIFICANCE

The performance characteristics of radio telescopes, specifically antenna gain, minimum detectable flux density, and spatial resolution are critical characteristics that affect the scientific results of a given research project. The primary intent in measuring the radiation pattern is to gain an invaluable diagnostic tool to determine if the antenna is functioning in a manner in which it was intended. The most important lesson to be learned from this experiment is the complex nature of the MRT antenna's radiation pattern and its exaggerated extent in elevation. Additionally, some of the features such as the inclined plateau and the symmetrical sidelobes, may imply that the electrical focus is not coincident with the antenna's mechanical focus. The inclined plateau in the "shark fin" may represent a coma lobe caused by surface deformations or a de-focused feed. This problem may potentially be ameliorated by the implementation of a traveling feed horn and waveguide system, which will allow mechanical alignment of the feed horn with the electrical focus. The same experiment can be repeated and the data compared in an iterative manner to improve the radiation pattern by empirical determination of the electrical focus. Additional measurements can be made to show the improvements that have been made to the telescope (optimization of the surface geometry, for example) and will yield new information regarding additional modifications.

Another very important aspect of the radiation pattern is that it has implications for improving image quality in mapping projects. The antenna receives signals from space that contain information from the astronomical object convolved with the antenna's radiation pattern. If the radiation pattern can be modeled by computer, it can be subtracted out to obtain very accurate "cleaned" maps of source structure in the astronomical object.

The final significance of empirical measurements of the radiation pattern is that it represents one of the most important performance characteristics of the radio telescope system. Two additional important experiments that can be executed are an empirical measurement of the antenna temperature and an empirical measurement of the antenna gain. Both of these performance characteristics will also serve as excellent diagnostic tools for the future.

ACKNOWLEDGMENTS

Funding for the MRT was provided by the National Science Foundation's Instrument and Laboratory Improvement program and by Morehead State University. Funding and assistance were provided by Dr. C. J. Whidden, chair of the Department of Physical Sciences, Dr. Gerald DeMoss, dean of the College of Science and Technology, Dr. Michael Moore, vice president of Academic Affairs, Morehead State University. Additionally, we thank Verle Pennington of ULTA-Vision, Mt. Sterling, KY, for allowing us access to an appropriate transmission site beyond the far-field limit of the telescope; and Michael Williamson, production technician, for climbing the ULTA-Vision tower on more than one occasion to mount the transmission antenna.

LITERATURE CITED

The ARRL Antenna Book. 1998. 18th ed. The American Radio Relay League, Newington, CT.

Kraus, J. D. 1986. Radio Astronomy, 2nd ed. Cygnus Quasar Publishers, Powell, OH.

Kruth, J. 1994. A receiver system for radio astronomy. Kruth Microwave Corporation, Internal Document, Hanover, MD.

Malphrus, B. K. 1996. The history of radio astronomy and the National Radio Astronomy Observatory: evolution toward big science. Krieger Publishers, Melbourne, FL.

Malphrus, B. K. 1998. The Morehead Radio Telescope: design and fabrication of a research instrument for undergraduate faculty and student research in radio frequency astrophysics. J. Kentucky Acad. Sci. 59:77–92.

Malphrus, B. K., R. Brengelman, D. Cutts, and C. Whidden. 1992. The Morehead Radio Telescope: design and fabrication of a research instrument for undergraduate faculty and student research in radio frequency astrophysics. Grant proposal submitted to the National Science Foundation. Morehead State Univ., Morehead, KY.

Napier, P. J. 1989. The primary antenna elements. Pages 39–58 in A. Perly et al. (eds). Synthesis imaging in radio astronomy. Astronomical Society of the Pacific, San Francisco, CA.

J. Ky. Acad. Sci. 60(2):124-126. 1999.

NOTE

Rare and Extirpated Plants and Animals of Kentucky: 1999 Update.—The Kentucky State Nature Preserves Commission (KSNPC) published a list of rare and extirpated plants and animals of Kentucky in 1996 (1) that was updated in 1997 (2). The list and update, developed with the assistance of many scientific authorities, were based on distributional and ecological data available as of 31 Dec 1996. KSNPC (1) committed to update the list annually so that decision makers would have current information on rare species in Kentucky, but it was not updated in 1998. Herein we provide an update based on data available through 31 Dec 1998.

The methods and status categories used herein follow KSNPC (1). Species whose conservation statuses are being changed are given in Table 1; changes in nomenclature and additions to the list are presented in Tables 2 and 3, respectively. Common names are used only when there is a nomenclature change from KSNPC (1, 2) and when a species is added to the list. Sources for plant names are Cronquist (3) and Medley (4). Sources for animal names and statuses are as follows: mollusks—Turgeon et al. (5); insects—Arnett (6), Cassie et al. (7), McCafferty (8), and Schuster (9); fishes—Etnier and Starnes (10), and Page and Burr (11); amphibians and reptiles—Carlin (12) and United States Fish and Wildlife Service (USFWS) (13); and birds—USFWS (14). We welcome questions or comments about this update or KSNPC (1, 2).

We thank the following individuals for sharing information and for their assistance: T.C. Barr Jr., Nashville, Tennessee; B.M. Burr, Southern Illinois University at Carbondale; P.A. Ceas and G.A. Schuster, Eastern Kentucky University; M.C. Compton, Kentucky Division of Water; C.V. Covell Jr., University of Louisville; P.A. Florence, Jefferson Community College; J.D. Kiser; L.E. Kornman, K.W. Prather, T. Sloan, S. Thomas, and T. Wethington, Kentucky Department of Fish and Wildlife Resources; J.R. MacGregor, United States Forest Service; W.P. McCafferty and R.P. Randolph, Purdue University; Lara Minium, The Nature Conservancy; and T.J. Timmons, Murray State University.

LITERATURE CITED. (1) Kentucky State Nature Preserves Commission. 1996. Rare and extirpated plants and animals of Kentucky. Trans. Kentucky Acad. Sci. 57: 69–91. (2) Kentucky State Nature Preserves Commission. 1997. Rare and extirpated plants and animals of Kentucky: 1997 update. Trans. Kentucky Acad. Sci. 58:96–100. (3) Cronquist, A. 1980. Vascular flora of the southeastern United States. Vol. 1. Asteraceae. Univ. North Carolina

Table 1. Conservation status changes for rare and extirpated Kentucky plants and animals.

	KSNPC[1]		US[2]	
	Old	New	Old	New
PLANTS				
Carex buxbaumii	E	H	—	—
Forestiera ligustrina	S	T	—	—
Juncus elliottii	E	H	—	—
Monarda punctata	E	H	—	—
Myriophyllum pinnatum	T	H	—	—
Silene ovata	E	T	—	—
FISHES				
Ammocrypta pellucida	S	delist	—	—
Clinostomus funduloides	S	delist	—	—
Cyprinella camura	S	E	—	—
Etheostoma lynceum	S	E	—	—
Etheostoma parvipinne	S	E	—	—
Etheostoma pyrrhogaster	S	E	—	—
Etheostoma swaini	S	E	—	—
Moxostoma poecilurum	S	E	—	—
Noturus hildebrandi	S	E	—	—
Noturus phaeus	S	E	—	—
REPTILES				
Nerodia erythrogaster neglecta	—	—	PT	—
BIRDS				
Anas discors	E	T	—	—
Haliaeetus leucocephalus	—	—	E	T

[1] S = Special Concern, T = Threatened, E = Endangered, H = Historic.
[2] PT = Proposed Threatened, T = Threatened, E = Endangered.

Table 2. Nomenclature changes for rare and extirpated Kentucky plants and animals.

Old Name	New Name
PLANTS	
Solidago caesia var. *curtisii*	*Solidago curtisii*
SNAILS	
Anguispira rugoderma	
Pine Mountain disc	Pine Mountain tigersnail
Mesodon chilhoweensis	*Appalachina chilhoweensis*
Mesodon panselenus	*Patera panselenus*
Mesodon wetherbyi	*Fumonelix wetherbyi*
Triodopsis dentifera	*Neohelix dentifera*
Triodopsis multilineata	*Webbhelix multilineata*
MUSSELS	
Fusconaia subrotunda subrotunda	
Long-solid	Longsolid
Pegias fabula	
Little-wing pearlymussel	Littlewing pearlymussel
Plethobasus cooperianus	
Orange-foot pimpleback	Orangefoot pimpleback
Pleurobema pyramidatum	*Pleurobema rubrum*
Toxolasma texasensis	*Toxolasma texasiensis*
INSECTS	
Madeophylax sp.	*Manophylax butleri*
A caddisfly (undescribed)	A limnephilid caddisfly
Pseudanophthalmus abditus	*P. horni abditus*
Pseudanophthalmus caecus	*P. horni caecus*
Pseudanophthalmus major	*P. desertus major*
FISHES	
Fundulus dispar	Northern starhead top-minnow
Starhead topminnow	
AMPHIBIANS	
Eurycea longicauda guttolineata	*E. guttolineata*

Table 3. Additions to the list of rare and extirpated Kentucky plants and animals.

	KSNPC[1]	US
PLANTS		
Agalinis auriculata Earleaf foxglove	E	—
Aster radula Low rough aster	E	—
Bouteloua curtipendula Side-oats grama	S	—
Krigia occidentalis Western dwarf dandelion	E	—
Silphium pinnatifidum Tansy rosinweed	S	—
Silphium wasiotense Appalachian rosinweed	S	—
Vaccinium erythrocarpum Highbush cranberry	E	—
INSECTS		
Callophrys irus Frosted elfin	S	—
Ephemerella inconstans An ephemerellid mayfly	H	—
Euphyes dukesi Duke's skipper	S	—
Erora laeta Early hairstreak	S	—
Polygonia faunus Green comma	H	—
Polygonia progne Gray comma	H	—
Raptoheptagenia cruentata A heptageniid mayfly	H	—
Traverella lewisi A leptophlebiid mayfly	H	—
BIRDS		
Anas clypeata Northern shoveler	E	—

[1] S = Special Concern, E = Endangered, H = Historic.

Press, Chapel Hill, NC. (4) Medley, M.E. 1989. *Silphium wasiotense* (Asteraceae), a new species from the Appalachian Plateaus in eastern Kentucky. Sida 13:286–291. (5) Turgeon, D.D., J.F. Quinn, A.E. Bogan, E.V. Coan, F.G. Hochberg, W.G. Lyons, P.M. Mikkelsen, R.J. Neves, C.F.E. Roper, G. Rosenberg, B. Roth, A. Scheltema, F.G. Thompson, M. Vecchione, and J.D. Williams. 1998. Common and scientific names of aquatic invertebrates from the United States and Canada: mollusks. 2nd ed. Am. Fish. Soc. Spec. Publ. 26. (6) Arnett, R.H., Jr. (ed). 1983. Checklist of the beetles of North and Central America and the West Indies. Flora and Fauna Publications, Gainesville, FL. (7) Cassie, B., J. Glassberg, P. Opler, R. Robbins, and G. Tudor. 1995. North American Butterfly Association (NABA) checklist and English names of North American butterflies. North American Butterfly Association, Morristown, NJ. (8) McCafferty, W.P. 1996. The Ephemeroptera species of North America and index to their complete nomenclature. Trans. Am. Entomol. Soc. 122:1–54. (9) Schuster, G.A. 1997. Description of a new species of terrestrial limnephilid caddisfly (Trichoptera) from Kentucky and West Virginia (USA). Pages 417–424 in R.W. Holzenthal and O.S. Flint Jr. (eds). Proceedings of the 8th International Symposium on Trichoptera, 1995. Ohio Biological Survey, Columbus, OH. (10) Etnier, D.A., and W.C. Starnes. 1993. The fishes of Tennessee. University Press, Knoxville, TN. (11) Page, L.M., and B.M. Burr. 1991. A field guide to freshwater fishes of North America north of Mexico. Houghton Mifflin, Boston, MA. (12) Carlin, J.L. 1997. Genetic and morphological differentiation between *Eurycea longicauda longicauda* and *E. guttolineata* (Caudata: Plethodontidae). Herpetologica 53: 206–217. (13) United States Fish and Wildlife Service. 1997. Endangered and threatened wildlife and plants; determination of threatened status for the northern population of the copperbelly water snake. Fed. Reg. 62:4183–4192. (14) United States Fish and Wildlife Service. 1995. Endangered and threatened wildlife and plants; final rule to reclassify the bald eagle from endangered to threatened in all of the lower 48 states. Fed. Reg. 60:36000–36010.—**Kentucky State Nature Preserves Commission,** 801 Schenkel Lane, Frankfort, Kentucky 40601.

List of Reviewers for Volume 60 of *Journal of the Kentucky Academy of Science*

Charles T. Bryson
David M. Brandenburg
Michael Carini
Ronald R. Cicerello
Wallace Dawson
Kenneth Embry
Richard Feist
Michael A. Flannery
Stanley Hedeen
Edmund D. Keiser
Michael J. Lacki
James O. Luken
Debra K. Pearce
Thomas C. Rambo
A. A. Reznicek
Gary Ritchison
Patrick Schultheis
James Sickel
William T. Smith
Richard Snow
Richard White

J. Ky. Acad. Sci. 60(2):127–132. 1999.

INDEX TO VOLUME 60

Compiled by Varley Wiedeman

NEWS

John Uri Lloyd: The Great American Eclectic, by Michael A. Flannery, has just been published. A hardcover book of 234 pages, this biography covers the life of an adopted son of Kentucky who rose from humble origins in Florence, Boone County, to become a pharmaceutical manufacturer and researcher of international renown. In addition, Lloyd was the leading founder of the Cincinnati-based library of botany, horticulture, and pharmacognosy that bears his name. The book, fully indexed, includes five appendices and 14 pages of illustrations. It is available from Southern Illinois University Press, P.O. Box 3697, Carbondale, IL 62902; ISBN 0-8093-2167-X; price $34.95 plus $3.50 shipping. Phone orders: (618) 453-2281.

CONTENTS

ARTICLES