Fishes, Mussels, Crayfishes, and Aquatic Habitats of the Hoosier-Shawnee Ecological Assessment Area

Brooks M. Burr, Justin T. Sipiorski, Matthew R. Thomas, Kevin S. Cummings, and Christopher A. Taylor

ABSTRACT

The Hoosier-Shawnee Ecological Assessment Area, part of the Coastal Plain and Interior Low Plateau physiographic provinces, includes 194 native fish species, 76 native mussel species, and 34 native crayfish species. Five of the subregions (e.g., Mississippi Embayment) that make up the assessment area were recently ranked as either globally or bioregionally outstanding aquatic resource areas. Fish, mussel, and crayfish diversity was analyzed for richness and density within and between the 39 hydrologic units that make up the assessment area. Species richness averaged 76 fish and 26 mussel species per hydrologic unit, and ecological units positioned as ecotones tended to be associated with primary levels of richness. At least 12 fish species are of conservation concern within the Hoosier and Shawnee National Forest boundaries; another 10 species are poorly known and need status surveys or other forms of conservation evaluation. Nearly 30 mussel species and 10 crayfish species are of conservation concern in the area, but fewer than 10 of these actually occur within national forest boundaries or would be directly affected by national forest activities. Commercial and recreational fisheries are popular in the region, and commercial exploitation of both mussels and crayfishes occurs in the assessment area. The most valuable and unique aquatic habitats in the area include springs, spring runs, karst aquifers, wetlands, swamps, mainstem large rivers, and upland, gravel-bottomed streams in both the Hoosier and Shawnee National Forests. The responsibility and challenges the USDA Forest Service shoulders in manageing and protecting the unique aquatic resources on its properties are staggering, especially in regard to the recently acknowledged global need for usable fresh water.

About the Author:

Brooks M. Burr
Professor, Department of Zoology and Center for Systematic Biology, Southern Illinois University, Carbondale, Illinois 62901-6501. Phone: 618-453-4112; e-mail: burr@zoology.siu.edu

Justin T. Sipiorski
Doctoral Graduate Assistant, Department of Zoology and Center for Systematic Biology, Southern Illinois University, Carbondale, Illinois 62901-6501

Matthew R. Thomas
Doctoral Graduate Assistant, Department of Zoology and Center for Systematic Biology, Southern Illinois University, Carbondale, Illinois 62901-6501

Kevin S. Cummings
Malacologist, Center for Biodiversity, Illinois Natural History Survey, Champaign, Illinois 61820

Christopher A. Taylor
Carcinologist, Center for Biodiversity, Illinois Natural History Survey, Champaign, Illinois 61820

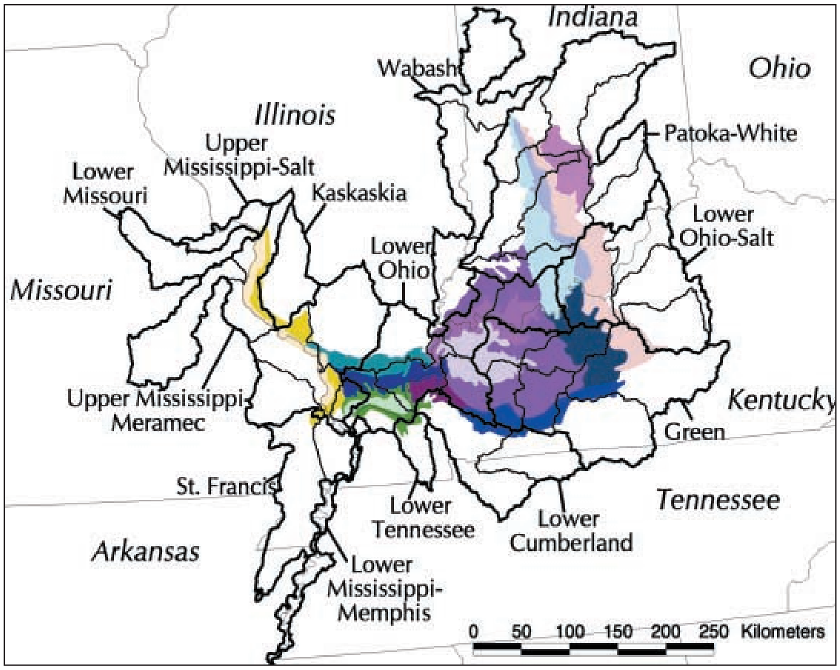

Figure 1. The 12 major river basins (divided into hydrologic units–watersheds) in the Hoosier-Shawnee Ecological Assessment Area.

We review the diversity, conservation status, and commercial significance of aquatic species and their habitats within the Hoosier-Shawnee Ecological Assessment Area. For analysis and discussion, aquatic species were restricted to three major taxonomic groups: fishes, unionid mussels, and crayfishes. Rather than use physiographic provinces as a way of analyzing patterns of distribution and diversity, we chose to use hydrological units to provide a more ecologically refined way to examine patterns across the watersheds of the assessment area (as explained in the "Data Sources and Methods of Analysis" subsections).

DIVERSITY OF FISHES, MUSSELS, AND CRAYFISHES

The fish, mussel, and crayfish fauna of the lower Ohio and middle Mississippi basins, including here portions of the Coastal Plain and Interior Low Plateau Provinces, is part of a region—the Southern and lower Midwestern United States—that harbors a significant portion of the richest temperate aquatic fauna on the North American continent (Warren et al. 2000). The combination of both upland and lowland streams and subterranean waters, along with a large river component, accounts for at least 193 native fish species, 76 native mussels, and 34 native crayfishes. These three aquatic groups represent over 24, 26, and 9 percent, respectively, of all native freshwater fishes, mussels, and crayfishes in the continental United States. The fishes alone represent over 50 percent of the native fauna of the entire Mississippi River basin and about 18 percent of all native freshwater fishes on the North American continent (Burr and Mayden 1992, Warren and Burr 1994, Warren et al. 2000). Illinois, Indiana, and Kentucky each have high to moderately high fish and mussel diversity, falling within the top eight States east of the Mississippi River and surpassing or equaling all States west of the Mississippi River except Missouri and Arkansas (Warren and Burr 1994). A major portion of that diversity is concentrated in the assessment area (Burr and Mayden 1992, Burr and Page 1986, Cummings and Mayer 1992).

The fishes, mussels, and crayfishes documented from the assessment area reside within a much larger natural region that encompasses the lower reaches of large tributaries of the Mississippi alluvial basin (e.g., Kaskaskia and Big Muddy Rivers), and all or significant portions of major drainages of the lower Ohio River basin (e.g., Green, Wabash, and Cache Rivers). It borders or encompasses parts of four ecological sections (see "Data Sources and Methods of Analysis"). Complex drainage histories beginning before the Pleistocene age set the stage for fragmentation, isolation, and mixing of faunas that in large part account for the richness and distinctiveness of the region's fishes, mussels, and crayfishes (Burr and Page 1986; Mayden 1987, 1988; Strange and Burr 1997). The region brings together two major dispersal corridors for fishes and mussels with approximately 330 river miles of the mainstem Ohio River and 165 river miles of the mainstem Mississippi River included in the assessment area.

The Forest Service's national hierarchical framework for classifying and mapping aquatic ecological units (Maxwell et al. 1995) places the Hoosier-Shawnee Ecological Assessment Area in the Arctic-Atlantic Bioregion, Mississippi Region, and Teays-Old Ohio Subregion. Small pieces of the Mississippi, Mississippi Embayment, Central Prairie, and Tennessee-Cumberland Subregions are part of the assessment area. As major rivers flow into the assessment area, most breach or border one or more major ecotones (transitional zones between ecological communities) that influence diversity and composition of fishes (Jenkins and Burkhead 1994). To the north and west, the region is bounded by the Interior Low Plateaus and Ozark Highlands, respectively, and to the south and east, by the Gulf Coastal Plain and the Appalachian Plateaus, respectively. These factors—major river systems with varied histories and ecological settings—provide the backdrop for the uniqueness and high diversity of aquatic species in the assessment area. In fact, the World Wildlife Fund's recent (Abell et al. 2000) conservation assessment of freshwater ecoregions of North America ranks three of the assessment area's subregions as globally outstanding and the remaining two as bioregionally outstanding. These two categories, globally outstanding and bioregionally outstanding, are the highest conservation rankings possible and clearly indicate the uniqueness and natural resource value of the assessment area.

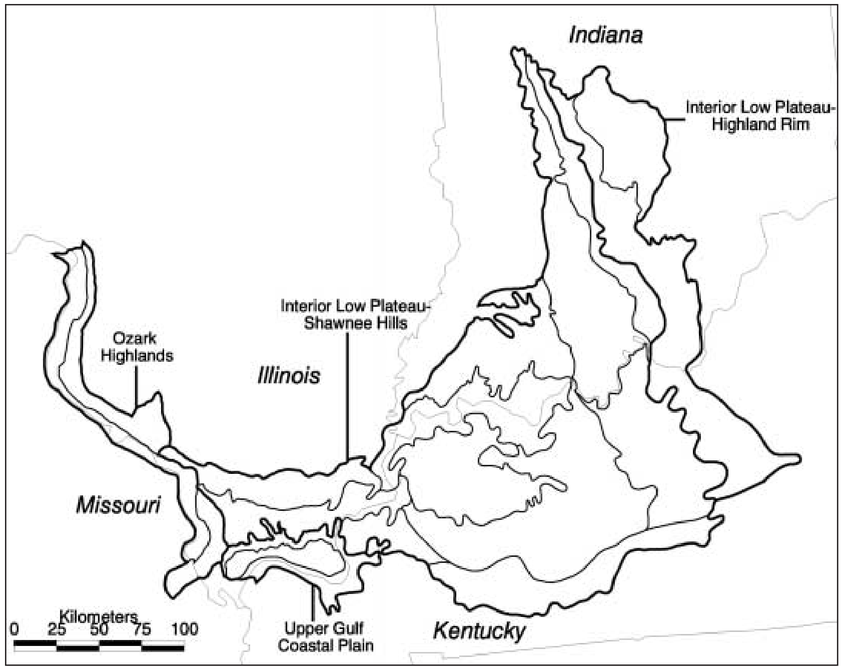

Figure 2. The four Ecological Sections of the Hoosier-Shawnee Ecological Assessment Area.

DATA SOURCES AND METHODS OF ANALYSIS

Within constraints of time and the patterns of diversity in the assessment area, we modeled our summary of aquatic diversity after the excellent chapters on *Diversity of Fishes* (Warren and Hlass 1999), *Diversity of Mussels* (Harris 1999), and *Diversity of Crayfishes* (Warren et al. 1999) as published in Ozark-Ouachita Highlands Assessments Aquatic Condition (General Technical Report SRS-33 (1999) regarding the Ozark-Ouachita Ecological Assessment in Missouri, Arkansas, Kansas, and Oklahoma). To examine the distribution of fish, mussel, and crayfish species, each of the 12 (lower Missouri, upper Mississippi-Salt, Kaskaskia, upper Mississippi-Meramec, St. Francis, lower Tennessee, lower Cumberland, Green, Wabash, Patoka-White, lower Ohio (to Mississippi River confluence), and lower Ohio (to mile 703)) major basins within the assessment area was subdivided into hydrologic units (watersheds) according to standard eight-digit hydrologic unit codes (HUCs) (fig. 1). Only 5 (Rough, Lower Green, Pond, and Tradewater) of 39 hydrologic units fell entirely within the assessment area and represented the entire area (mi^2) of their respective HUC (table 1), 16 overlapped between 13 and 99 percent of their total area, and 18 units overlapped the assessment area by 12 percent or less of their total area (fig. 1). Several of the hydrologic units also contain portions of more than one ecological subsection (figs. 1, 2) (e.g., Cache and lower Ohio units share Shawnee Hills and Gulf Coastal Plain Subsections). Only that portion of a HUC that lies within the assessment area was used for tabulation of aquatic diversity.

Table 1. Native fish species richness, density, index of relative importance, and overall rank order for watersheds of the Hoosier-Shawnee Ecological Assessment Area.

River Basin Hydrologic unit name	Watershed code (HUC)	Total area	Area of HUC in assessment	Species richness (rank order)	Species density (rank order)	Index of relative importance (sum rank orders)	Overall rank order *
		mi²	*mi²*	*no.*	*no. per mi²*		
Lower Missouri River Basin							
Lower Missouri	10300200	1,590	20.67	56 (19)	2.71 (3)	22	4
Upper Mississippi-Salt River Basins							
Peruque-Piasa	07110009	633	14.559	61 (17)	4.19 (1)	18	2
Kaskaskia River Basin							
Lower Kaskaskia	07140204	1,600	88	60 (18)	0.68 (4)	22	4
Upper Mississippi-Meramec River Basins							
Cohokia-Joachim	07140101	1,650	618.75	101 (5)	0.16 (15)	20	3(3)
Upper Mississippi-Cape Girardeau	07140105	1,690	397.15	129 (1)	0.32 (7)	8	1(1)
Big Muddy	07140106	2,350	289.05	85 (9)	0.29 (9)	18	2(2)
Whitewater	07140107	1,210	33.88	23 (27)	0.68 (4)	31	12
Cache	07140108	352	302.72	72 (13)	0.24 (12)	25	7(6)
St. Francis River Basin							
New Madrid-St. Johns	08020201	703	7.03	2 (33)	0.28 (10)	43	18
Little River Ditches	08020204	2,620	36.68	25 (25)	0.68 (4)	29	10
Lower Tennessee River Basin							
Lower Tennessee	06040006	689	79.235	47 (22)	0.59 (5)	27	8
Lower Cumberland River Basin							
Lower Cumberland	05130205	2,300	317.4	65 (16)	0.20 (13)	29	10
Red	05130206	1,450	55.1	5 (32)	0.09	32	13
Green River Basin							
Upper Green	05110001	3,130	1,311.47	87 (8)	0.07 (20)	28	9(8)
Barren	05110002	2,230	138.26	37 (24)	0.27 (11)	35	16
Middle Green	05110003	1,010	968.59	101 (5)	0.10 (18)	23	5(4)
Rough	05110004	1,070	1,070	51 (21)	0.05 (22)	43	18(15)
Lower Green	05110005	911	911	83 (11)	0.09 (19)	30	11(10)
Pond	05110006	784	784	72 (13)	0.09 (19)	32	13(11)
Wabash River Basin							
Middle Wabash-Little Vermillion	05120108	2,230	6.69	22 (28)	3.29 (2)	30	11
Lower Wabash	05120113	1,300	202.8	76 (12)	0.37 (6)	18	14
Patoka-White River Basins							
Upper White	05120201	2,700	278.1	24 (26)	0.09 (19)	45	19(16)
Lower White	05120202	1,650	664.95	67 (15)	0.10 (18)	33	14(12)
Eel	05120203	1,200	231.6	38 (23)	0.16 (15)	38	17(14)
Driftwood	05120204	1,150	40.25	12 (30)	0.30 (8)	38	17
Upper East Fork White	05120206	806	29.016	2 (33)	0.07 (20)	53	21
Muskatatuck	05120207	1,130	14.69	0 (34)	0.00 (23)	57	22
Lower East Fork White	05120208	2,030	1,822.94	104 (3)	0.06 (21)	24	6(5)
Patoka	05120209	854	620.004	67 (15)	0.11 (17)	32	13(11)

(table continued on next page)

(table 1 continued)

River Basin Hydrologic unit name	Watershed code (HUC)	Total area	Area of HUC in assessment	Species richness (rank order)	Species density (rank order)	Index of relative importance (sum rank orders)	Overall rank order *
		mi^2	mi^2	no.	no. per mi^2		
Lower Ohio River Basin (to Miss. R. confl.)							
Lower Ohio-Little Pigeon	05140201	1,370	1370	90 (7)	0.07 (20)	27	8(7)
Highland-Pigeon	05140202	1,000	957	84 (10)	0.09 (19)	29	10(9)
Lower Ohio-Bay	05140203	1,090	1,079.10	107 (2)	0.10 (18)	20	3(3)
Saline	05140204	1,160	300.44	54 (20)	0.18 (14)	34	15(13)
Tradewater	05140205	936	936	68 (14)	0.07 (20)	34	15(13)
Lower Ohio	05140206	928	668.16	103 (4)	0.15 (16)	20	3(3)
Lower Ohio Rver Basin (to mile 703)							
Silver-Little Kentucky	05140101	1,240	12.4	0 (34)	0.00 (23)	57	22
Salt	05140102	1,450	30.45	18 (29)	0.59 (5)	34	15
Rolling Fork	05140103	1,430	105.82	11 (31)	0.10 (18)	49	20
Blue Sinking	05140104	1,880	1,757.80	94 (6)	0.05 (22)	28	9(8)

* The overall ranks in parentheses have been determined with the small Hydrologic Units (less than 12% proportion of inclusion in the assessment area) removed from the ranking procedure. Small Hydrologic Units have inflated species densities and therefore convey artificailly high indicies of relative importance. See text for further discussion.

Determination of Fish, Mussel, and Crayfish Distributions

Fishes

The distribution of fishes within a particular hydrologic unit was determined primarily from spot-distribution maps in Burr and Warren (1986), Gerking (1945), Pflieger (1997), and Smith (1979). The determination of a species occurrence within a unit depended on the temporal (time) coverage, quality, and scale of source distribution maps. Distributions from cited sources (above) were presented as drainage maps for each species with dots indicating the occurrence of a fish species at that point within the drainage. The drainage maps allowed us to make relatively unambiguous interpretations of fish distributions. An unpublished report (i.e., gray literature) on fishes of the Hoosier National Forest (McComish and Brown 1980) is the most recent comprehensive source of written information for fishes in southern Indiana, but questions of quality and sources of distributional data, and accuracy of identifications make it clear that our knowledge of Indiana fishes is inferior to both the Illinois and Kentucky databases. Nevertheless, the scale of these maps, along with textual descriptions of distributions, permitted reasonably accurate delineation of a species' occurrence in a hydrological unit. Pflieger (1997) reported known collections of fishes in Missouri from about 1905 to 1995. Smith (1979) documented fish collections in Illinois from 1876 to 1978. The fish collection database for Kentucky covered records from about 1819 to 1985, with most samples dating from post-1950 (Burr and Warren 1986). Gerking (1945) made collections of fishes in Indiana from 1940 through 1943 and used many literature records from the era of David Starr Jordan and his students (1875-1894).

Information from these primary sources was augmented with fish distributional data presented in Burr and Page (1986), Lee et al. (1980), and Page and Burr (1991). Scientific and common names of fishes generally follow Mayden et al. (1992). Distributions of species described or their distributions clarified subsequent to the previously cited works were obtained from Burr and Page (1993, frecklebelly darter), Ceas and Page (1997, Shawnee darter), Dimmick et al. (1996, rosefin shiner), Eisenhour (1997, channel shiner), Page et al. (1992, guardian darter), and Poly and Wilson (1998, fringed darter). Known but as yet undescribed species of darters that occur only in the Kentucky portion of the assessment area have been included either under orangethroat darter or speckled darter.

Fish faunal composition among drainages of the region was taken from existing works for Kentucky (Burr and Warren 1986), Kentucky and Tennessee (Warren et al. 1991), Illinois and surrounding areas (Burr and Page 1986), and Missouri (Pflieger 1971). Although methods of analysis varied among these authors, each relied on comparing distributions of native fish species and classifying the resulting similarity patterns into fish faunal regions. In a novel approach, Mayden (1988) used major river drainages as analogous to "taxonomic" units and native fish species as analogous to "characters" to produce a "phylogeny" (or evolutionary tree) of drainage units in the Central United States. The fish faunal regions or drainage units recognized by these authors are compatible and generally congruent, and we assumed that sections of drainages not included in these previous works (e.g., some parts of Indiana) are classified in the same fish faunal regions as adjacent drainages in Illinois or Kentucky.

Mussels

Specific information on mussel distributions within much of the assessment area has not been published. Approximate range maps in Cummings and Mayer (1992) for mussels in Indiana, Illinois, and Missouri do not provide the resolution needed to determine specific distributions within the assessment area. Comprehensive surveys by Baker (1906) and Parmalee (1967), along with unpublished observations of Max Matteson (former zoologist with the University of Illinois, Urbana), have provided the early foundations for mussel distributions in Illinois. A recent summary of mussel distributions in Illinois was provided by Cummings and Mayer (1997). Comprehensive distributional information for mussels in Indiana was provided by Call (1900), Daniels (1903), and Goodrich and van der Schalie (1944). Several more recent studies of mussel distributions in southern Indiana were conducted on the Wabash, White, and East Fork White Rivers (Meyer 1974) and primary tributaries of the East Fork White River (Clarke et al. 1999, Cummings et al. 1992, Harmon 1998, Taylor 1982, Weilbaker et al. 1985). Updated spot-distribution maps compiled by Cummings for mussels of Illinois and Indiana (Cummings 2001, unpublished maps) were used primarily to determine current and historical mussel distributions within the assessment area in those States. Although a considerable body of literature exists on mussels in Kentucky, Cicerello et al. (1991) provided the most recent comprehensive summary of current and historical mussel distributions statewide. Updated spot-distribution maps provided by Cicerello (Cicerello 2001, unpublished maps) for the State of Kentucky served as the primary source of information on specific distributions of mussels within the assessment area in Kentucky. For the small portion of the assessment area that penetrates Missouri, spot-distribution maps in Oesch (1984) served as the primary data source. Scientific and common names of mussels generally follow Williams et al. (1993) except that subspecies are not recognized (Cummings and Mayer 1992).

Crayfishes

Data sources used to plot historic and recent distribution data of crayfishes onto the 39 watersheds of the assessment area included the following: Page (1985), Page and Mottesi (1995), and Taylor and Anton (1999) for Illinois; Pflieger (1996) for Missouri; the Illinois Natural History Survey (INHS) database (as of August 2001) and Taylor and Schuster (2001, unpublished spot-distribution maps) for

Kentucky; and the INHS database (as of August 2001) for Indiana. The INHS data on crayfish distribution in Kentucky included historic records as well as a relatively larger body of more recent collection records to be used in a future publication. However, aside from older publications—Hay (1896) and Eberly (1955), both with inexact locality information—very little publicly available data exist on the historic or current distribution of Indiana crayfishes. There were relatively few INHS crayfish records for Indiana counties in the assessment area, and those few records were generally concentrated in the Patoka River watershed as well as direct tributaries of the lower Ohio River.

Twenty-one of the thirty-four species in the assessment area have common names that derive from a variety of sources but that have not been uniformly sanctioned by a professional society. For the sake of consistency, we coined common names for the 13 species that lack them. Most of the scientific names of crayfishes in this report agree with those presented in Taylor et al. (1996). The following are exceptions. All *Cambarus bartonii* are of the subspecies *C. b. cavatus,* not *C. b. carinirostris* or *C. b. bartonii.* The subspecies *Orconectes inermis inermis* and *O. i. testii* are both included under the name *O. inermis*. *Orconectes ronaldi* and *O. margorectus* are newly described species in Taylor (2000) and Taylor (2002), respectively. *Orconectes palmeri palmeri* is the only subspecies recorded in the assessment area (Pflieger 1996) and is referred to here as *O. palmeri.* According to Taylor et al. (1996), both *Cambarus diogenes* and *Procambarus acutus* are comprised of species complexes and warrant further study.

Analysis of Aquatic Diversity

Fish, mussel, and crayfish species were noted as present or absent within each hydrologic unit and classified as native or endemic. Aquatic species occurring in peripheral (outside the assessment area) hydrologic units were not included. The status of a fish, mussel (i.e., live individual or dead shells), or crayfish species reflects its known historical presence within a unit but does not necessarily indicate its continued present-day occurrence in a unit. Information to account for changes to the fauna is inadequately synthesized for area-wide analysis. Fishes, mussels, and crayfishes were considered native if the assessment area was within their known historical range and no evidence of their having been artificially introduced was available. Depending on scale, biologists define endemic species as those that have a restricted range within one locale (or drainage). Introduced species are defined as those that have been intentionally or accidentally released in a locale. Some species can be described as native and introduced. For example, largemouth bass initially were found in the assessment area and they also have been stocked from hatchery-produced progeny into many farm ponds, impoundments, and artificial lakes in the area. Therefore, largemouth bass occur in two categories at once. Introduced bivalves (i.e., Asian clam and zebra mussel) and sphaeriid clams were not included in our analyses.

Diversity was analyzed using native species richness and native species density. Native species richness is the number of native species (i.e., fish, mussel, or crayfish) within each hydrologic unit. Hydrological units vary in areal extent, and species richness often increases with increases in stream size or area drained. To examine the effect of areal additivity (increases in area may be accompanied by an increase in species), native species richness was divided by the number of square miles in a given hydrologic unit (or partial unit) to produce native species density values for each HUC. In addition, the log of native species richness was regressed on the log area of hydrologic units to examine the relationship between species richness and unit size. Native species richness and a ranked sum of richness and density were plotted on separate hydrologic unit

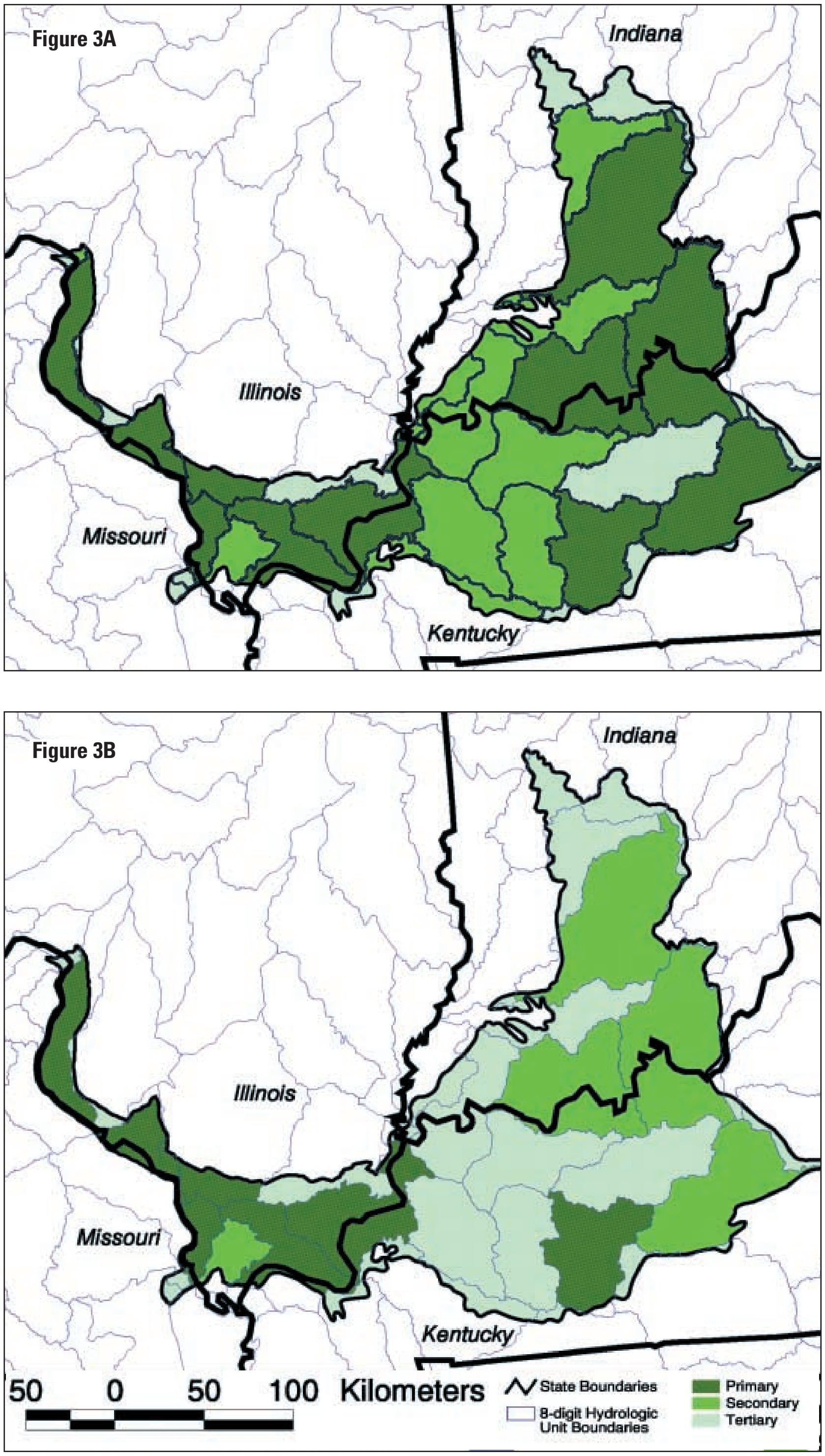

Figure 3. Levels of fish species richness (A) and fish species rank of overall importance (B) by watershed in the Hoosier-Shawnee Ecological Assessment Area.

maps. Rank values of species richness in all hydrologic units and ranks of overall importance in hydrologic units with 12 percent or more of their area in the assessment area were divided into quartiles. Three levels of relative richness were recognized among hydrologic units: primary, secondary, and tertiary. Primary levels were assigned to the 9-10 units (depending on tied scores) with the highest values, secondary levels were assigned to the next highest 8-10 units, and tertiary levels were assigned to the remaining units. Hence, primary levels approximate values in the fourth quartile or top 25 percent, secondary levels approximate values in the third quartile or second 25 percent, and tertiary levels approximate values in the first and second quartiles or bottom 50 percent.

Watersheds with less than 12 percent of their total area in the assessment area had artificially high species density values. Therefore, species richness was considered a “real” descriptor of non-random distribution that was not as heavily burdened by watershed size as was species density. For this reason, no figure of species density was included, even though species density values were used in calculating the index of overall importance (but only for watersheds with 12 percent or more of their area in the assessment area).

Individual rank orders of the hydrologic units for native species richness and native species density were summed to create an index of overall relative importance of hydrologic units as freshwater habitats in the assessment area. Species richness and ranked sum of richness and density were plotted on separate hydrologic unit maps to show patterns of richness and relative overall importance (figs. 3-5). All ranking procedures used integer values. The hydrologic units or partial units with lowest ranks were considered the most important with regard to either richness, density, or overall rank. All tied calculated values received the same rank value.

PATTERNS AND TRENDS

Composition of Native Freshwater Fishes

Native fish diversity is divided unevenly among families in the assessment area. In the region, 194 native fish species placed in 24 families are represented (table 2). The five richest families—minnows (58 native species), perches (42), suckers (18), sunfishes and basses (16), and bullhead catfishes (14),—account for about 76 percent of the fish fauna. Just over 50 percent of the native fish fauna is made up of minnows (Cyprinidae) and darters (Percidae, perch family). Ten families have only one species represented in the assessment area, and other families support a significant number of North American species. For example, 50 percent of all cavefishes (Amblyopsidae) and about 25 percent of lampreys (Petromyzontidae) are recorded from the assessment area (Mayden et al. 1992).

Fish faunal composition has been independently analyzed for Missouri (Pflieger 1971), Kentucky (Burr and Warren 1986), Kentucky and Tennessee (Warren et al. 1991), and Illinois and surrounding areas (Burr and Page 1986). All of these analyses used different units of scale, generally larger drainage units than the eight-digit hydrologic units used here. Three of these studies also were limited to the political boundaries of their respective states and varied in the level of classification achieved. The primary findings relevant to the assessment area are summarized here; for details, the reader is referred to the original studies.

Pflieger (1971) recognized four primary faunal regions in Missouri: Ozark, lowland, prairie, and big river. The Ozark fish faunal region was restricted primarily to the Ozark Highlands or about the southern half of the State. Fish communities here are distinctively fluvial and unique, especially considering the high degree of endemism in the region. Noteworthy are the numbers of geminate pairs of fishes that occur in the Ozark Highlands and that have their next closest relatives occurring in the Appalachian Highlands (Burr and Page 1986). The lowland fish faunal region is a community of fishes restricted primarily to the southeastern corner of Missouri in the "bootheel" of the State. The species and habitats identified for this community in Missouri are similar to what is found in the assessment area in southern Illinois south of the Shawnee Hills continuing through the lower Cumberland-Tennessee region and including the lower Green River drainage. The prairie fish faunal region dominates the northern half of Missouri and is similar to the fish communities recognized in the assessment area in those hydrological units bordering the Mississippi and lower Missouri Rivers. The fourth and final fish faunal region recognized, the big river, includes primarily the mainstem channels of the Mississippi and Missouri Rivers. The assessment area includes about 165 miles of the mainstem Mississippi River and only a few miles of the extreme lower reaches of the Missouri River. The lower Ohio River is different in character (i.e., lower turbidity, narrower unbraided channel, less fluctuation in flow) from the Mississippi and lower Missouri Rivers but is more similar faunistically to the big river faunal region than any of the others recognized.

Burr and Warren (1986) analyzed fish diversity in Kentucky in two ways: 1) on the basis of 28 faunal or watershed units and 2) on the basis of 25 previously recognized physiographic units. Faunal similarity among watershed units was influenced by size, geographic proximity, geological history, and physical and biological characteristics of the units themselves. Three basic faunal groupings were formed: 1) a big river/lowland fauna, 2) an upland fauna, and 3) Terrapin Creek. The first two groupings are relevant to the assessment area and overlap in fish composition with the similar groupings in Missouri. Characteristic of the big river group are the shovelnose sturgeon, paddlefish, skipjack herring, goldeye, river shiner, silverband shiner, flathead chub, and blue sucker. At least four species, pallid sturgeon, sturgeon chub, sicklefin chub, and plains minnow, occur only in the mainstem Mississippi River in the assessment area.

The group most closely associated with the big river assemblage was the lowlands, including the Coastal Plain proper and environmentally similar areas of the lower Green and Tradewater

Table 2. Conservation ranks of native fishes of the Hoosier-Shawnee Ecological Assessment Area.

			Occurrence		Conservation ranks										
Family	**Species**	**Common name**	**SNF**	**HNF**	**Global**	**Federal**	**AFS**	**HNF**	**SNF**	**MIS HNF**	**MIS SNF**	**IL**	**IN**	**KY**	**MO**
Acipenseridae	*Acipenser fulvescens*	Lake sturgeon	X	X	G3		T	R				E	E	E	S1
Acipenseridae	*Scaphirhynchus albus*	Pallid sturgeon	X		G1G2	E	E					E		E	S1
Acipenseridae	*Scaphirhynchus platorynchus*	Shovelnose sturgeon	X	X	G4										
Amblyopsidae	*Amblyopsis spelaea*	Northern cavefish		X	G3	T	T	R					E	S	
Amblyopsidae	*Forbesichthys agassizi*	Spring cavefish	X		G4G5										S1
Amblyopsidae	*Typhlichthys subterraneus*	Southern cavefish		X	G4		V						E	S	S2,S3
Amiidae	*Amia calva*	Bowfin	X	X	G5										
Anguillidae	*Anguilla rostrata*	American eel	X	X	G5										
Aphredoderidae	*Aphredoderus sayanus*	Pirate perch	X	X	G5										
Atherinopsidae	*Labidesthes sicculus*	Brook silverside	X	X	G5										
Atherinopsidae	*Menidia beryllina*	Inland silverside	X		G5									T	
Catostomidae	*Carpiodes carpio*	River carpsucker	X	X	G5										
Catostomidae	*Carpiodes cyprinus*	Quillback	X		G5										
Catostomidae	*Carpiodes velifer*	Highfin carpsucker	X	X	G4G5										S2
Catostomidae	*Catostomus commersoni*	White sucker	X	X	G5										
Catostomidae	*Cycleptus elongatus*	Blue sucker	X	X	G3G4		V						S		S3
Catostomidae	*Erimyzon oblongus*	Creek chubsucker	X	X	G5										
Catostomidae	*Erimyzon sucetta*	Lake chubsucker	X	X	G5									T	
Catostomidae	*Hypentelium nigricans*	Northern hog sucker	X	X	G5										
Catostomidae	*Ictiobus bubalus*	Smallmouth buffalo	X	X	G5										
Catostomidae	*Ictiobus cyprinellus*	Bigmouth buffalo	X	X	G5										
Catostomidae	*Ictiobus niger*	Black buffalo	X		G5									S	
Catostomidae	*Minytrema melanops*	Spotted sucker	X	X	G5										
Catostomidae	*Moxostoma anisurum*	Silver redhorse		X	G5										
Catostomidae	*Moxostoma carinatum*	River redhorse		X	G4							T	S		
Catostomidae	*Moxostoma duquesnei*	Black redhorse	X	X	G5										
Catostomidae	*Moxostoma erythrurum*	Golden redhorse	X	X	G5T4										
Catostomidae	*Moxostoma macrolepidotum*	Shorthead redhorse	X	X	G5T?										
Centrarchidae	*Ambloplites rupestris*	Rock bass	X	X	G5					M					
Centrarchidae	*Centrarchus macropterus*	Flier	X	X	G5										S3
Centrarchidae	*Lepomis auritus*	Redbreast sunfish			G5										
Centrarchidae	*Lepomis cyanellus*	Green sunfish	X	X	G5										
Centrarchidae	*Lepomis gulosus*	Warmouth	X	X	G5										
Centrarchidae	*Lepomis humilis*	Orangespotted sunfish	X	X	G5										
Centrarchidae	*Lepomis macrochirus*	Bluegill	X	X	G5					M					
Centrarchidae	*Lepomis megalotis*	Longear sunfish	X	X	G5										
Centrarchidae	*Lepomis microlophus*	Redear sunfish	X	X	G5										
Centrarchidae	*Lepomis miniatus*	Redspotted sunfish	X		G5							T		T	
Centrarchidae	*Lepomis symmetricus*	Bantam sunfish	X		G5				R			T	S		S2
Centrarchidae	*Micropterus dolomieu*	Smallmouth bass	X	X	G5					M					
Centrarchidae	*Micropterus punctulatus*	Spotted bass	X	X	G5										

(table continued on next page)

(table 2 continued)

			Occurrence		Conservation ranks										
Family	Species	Common name	SNF	HNF	Global	Federal	AFS	HNF	SNF	MIS HNF	MIS SNF	IL	IN	KY	MO
Centrarchidae	*Micropterus salmoides*	Largemouth bass	X	X	G5					M					
Centrarchidae	*Pomoxis annularis*	White crappie	X	X	G5										
Centrarchidae	*Pomoxis nigromaculatus*	Black crappie	X	X	G5										
Clupeidae	*Alosa alabamae*	Alabama shad			G3	C	V						Ex	E	S2
Clupeidae	*Alosa chrysochloris*	Skipjack herring	X	X	G5										
Clupeidae	*Dorosoma cepedianum*	Gizzard shad	X	X	G5										
Clupeidae	*Dorosoma petenense*	Threadfin shad	X	X	G5										
Cottidae	*Cottus bairdi*	Mottled sculpin		X	G5T?										
Cottidae	*Cottus carolinae*	Banded sculpin	X	X	G5										
Cyprinidae	*Campostoma anomalum*	Central stoneroller	X	X	G5										
Cyprinidae	*Campostoma pullum*	Mississippi stoneroller		X	G5										
Cyprinidae	*Campostoma oligolepis*	Largescale stoneroller			G5										
Cyprinidae	*Cyprinella lutrensis*	Red shiner	X		G5										
Cyprinidae	*Cyprinella spiloptera*	Spotfin shiner	X	X	G5										
Cyprinidae	*Cyprinella venusta*	Blacktail shiner	X		G5									S	
Cyprinidae	*Cyprinella whipplei*	Steelcolor shiner	X	X	G5										
Cyprinidae	*Ericymba buccata*	Silverjaw minnow	X	X	G5										
Cyprinidae	*Erimystax dissimilis*	Streamline chub			G4										
Cyprinidae	*Erimystax x-punctatus*	Gravel chub		X	G4									Ex	
Cyprinidae	*Hybognathus argyritis*	Western silvery minnow	X		G4										S2
Cyprinidae	*Hybognathus hayi*	Cypress minnow	X	X	G5							E		E	S1
Cyprinidae	*Hybognathus nuchalis*	Mississippi silvery minnow	X	X	G5										S3,S4
Cyprinidae	*Hybognathus placitus*	Plains minnow	X		G4									S	S2
Cyprinidae	*Hybopsis amblops*	Bigeye chub	X	X	G5							E			
Cyprinidae	*Hybopsis amnis*	Pallid shiner	X	X	G4		V					E		H	SX
Cyprinidae	*Luxilus chrysocephalus*	Striped shiner	X	X	G5										
Cyprinidae	*Luxilus cornutus*	Common shiner		X	G5										
Cyprinidae	*Luxilus zonatus*	Bleeding shiner			G5										
Cyprinidae	*Lythrurus fasciolaris*	Scarletfin shiner	X	X	G5										
Cyprinidae	*Lythrurus fumeus*	Ribbon shiner	X	X	G5										
Cyprinidae	*Lythrurus umbratilis*	Redfin shiner	X	X	G5					M					
Cyprinidae	*Macrhybopsis gelida*	Sturgeon chub	X		G2	C	V					E		H	S3
Cyprinidae	*Macrhybopsis hyostoma*	Speckled chub	X	X	G5										
Cyprinidae	*Macrhybopsis meeki*	Sicklefin chub	X		G3	C	V							H	S3
Cyprinidae	*Macrhybopsis storeriana*	Silver chub	X	X	G5										S3
Cyprinidae	*Nocomis biguttatus*	Hornyhead chub	X	X	G5									S	
Cyprinidae	*Nocomis effusus*	Redtail chub			G4										
Cyprinidae	*Notemigonus crysoleucas*	Golden shiner	X	X	G5										
Cyprinidae	*Notropis ariommus*	Popeye shiner		X	G3		V						Ex		
Cyprinidae	*Notropis atherinoides*	Emerald shiner	X	X	G5										
Cyprinidae	*Notropis blennius*	River shiner	X	X	G5										

(table continued on next page)

(table 2 continued)

			Occurrence		Conservation ranks										
Family	Species	Common name	SNF	HNF	Global	Federal	AFS	HNF	SNF	MIS HNF	MIS SNF	IL	IN	KY	MO
Cyprinidae	*Notropis boops*	Bigeye shiner	X	X	G5							E			
Cyprinidae	*Notropis buchanani*	Ghost shiner	X	X	G5										S2
Cyprinidae	*Notropis chalybaeus*	Ironcolor shiner		X	G5		V					T			S1
Cyprinidae	*Notropis dorsalis*	Bigmouth shiner	X		G5										
Cyprinidae	*Notropis hudsonius*	Spottail shiner	X		G5									S	
Cyprinidae	*Notropis ludibundus*	Sand shiner	X	X	G5										
Cyprinidae	*Notropis maculatus*	Taillight shiner	X	X	G5							E		T	S1
Cyprinidae	*Notropis nubilus*	Ozark minnow	X		G5										
Cyprinidae	*Notropis photogenis*	Silver shiner		X	G5										
Cyprinidae	*Notropis rubellus*	Rosyface shiner		X	G5										
Cyprinidae	*Notropis shumardi*	Silverband shiner	X	X	G5										
Cyprinidae	*Notropis texanus*	Weed shiner			G5							E			
Cyprinidae	*Notropis volucellus*	Mimic shiner	X	X	G5										
Cyprinidae	*Notropis wickliffi*	Channel shiner	X	X	G5										
Cyprinidae	*Opsopoeodus emiliae*	Pugnose minnow	X	X	G5					M					S4
Cyprinidae	*Phenacobius mirabilis*	Suckermouth minnow	X	X	G5										
Cyprinidae	*Phenacobius uranops*	Stargazing minnow			G4									S	
Cyprinidae	*Phoxinus erythrogaster*	Southern redbelly dace	X	X	G5					M					
Cyprinidae	*Pimephales notatus*	Bluntnose minnow	X	X	G5										
Cyprinidae	*Pimephales promelas*	Fathead minnow	X	X	G5										
Cyprinidae	*Pimephales vigilax*	Bullhead minnow	X	X	G5										
Cyprinidae	*Platygobio gracilis*	Flathead chub	X		G5		V					E		S	S1
Cyprinidae	*Pteronotropis hubbsi*	Bluehead shiner	X		G3		V		R			E			
Cyprinidae	*Rhinichthys atratulus*	Blacknose dace	X	X	G5										
Cyprinidae	*Rhinichthys cataractae*	Longnose dace	X		G5										
Cyprinidae	*Semotilus atromaculatus*	Creek chub	X	X	G5										
Elassomatidae	*Elassoma zonatum*	Banded pygmy sunfish	X		G5										
Esocidae	*Esox americanus*	Grass pickerel	X	X	G5					M					
Esocidae	*Esox lucius*	Northern pike	X	X	G5										
Esocidae	*Esox masquinongy*	Muskellunge		X	G5								S		
Esocidae	*Esox niger*	Chain pickerel			G5									S	
Fundulidae	*Fundulus catenatus*	Northern studfish	X		G5								S		
Fundulidae	*Fundulus dispar*	Starhead topminnow	X		G4									E	S2
Fundulidae	*Fundulus notatus*	Blackstripe topminnow	X	X	G5										
Fundulidae	*Fundulus olivaceus*	Blackspotted topminnow	X		G5										
Gadidae	*Lota lota*	Burbot			G5									S	
Hiodontidae	*Hiodon alosoides*	Goldeye	X		G5										
Hiodontidae	*Hiodon tergisus*	Mooneye	X	X	G5										S3
Ictaluridae	*Ameiurus melas*	Black bullhead	X	X	G5										
Ictaluridae	*Ameiurus natalis*	Yellow bullhead	X	X	G5										
Ictaluridae	*Ameiurus nebulosus*	Brown bullhead	X	X	G5										S3?

(table continued on next page)

(table 2 continued)

Family	Species	Common name	Occurrence		Conservation ranks											
			SNF	HNF	Global	Federal	AFS	HNF	SNF	MIS HNF	MIS SNF	IL	IN	KY	MO
Ictaluridae	*Ictalurus furcatus*	Blue catfish	X		G5										
Ictaluridae	*Ictalurus punctatus*	Channel catfish	X	X	G5										
Ictaluridae	*Noturus elegans*	Elegant madtom			G4										
Ictaluridae	*Noturus eleutherus*	Mountain madtom		X	G4										S1,S2
Ictaluridae	*Noturus exilis*	Slender madtom	X		G5									E	
Ictaluridae	*Noturus flavus*	Stonecat	X	X	G5										
Ictaluridae	*Noturus gyrinus*	Tadpole madtom	X	X	G5										
Ictaluridae	*Noturus miurus*	Brindled madtom	X	X	G5										
Ictaluridae	*Noturus nocturnus*	Freckled madtom	X	X	G5										
Ictaluridae	*Noturus stigmosus*	Northern madtom		X	G3		V					E		S	
Ictaluridae	*Pylodictis olivaris*	Flathead catfish	X	X	G5										
Lepisosteidae	*Atractosteus spatula*	Alligator gar	X		G5		V					Ex		E	SX
Lepisosteidae	*Lepisosteus oculatus*	Spotted gar	X		G5										
Lepisosteidae	*Lepisosteus osseus*	Longnose gar	X	X	G5										
Lepisosteidae	*Lepisosteus platostomus*	Shortnose gar	X	X	G5										
Moronidae	*Morone chrysops*	White bass	X		G5										
Moronidae	*Morone mississippiensis*	Yellow bass	X	X	G5										
Percidae	*Ammocrypta clara*	Western sand darter	X		G3		V					E			S2,S3
Percidae	*Ammocrypta pellucida*	Eastern sand darter		X	G3		V	R				T			
Percidae	*Crystallaria asprella*	Crystal darter			G3		V					Ex			S1
Percidae	*Etheostoma asprigene*	Mud darter	X		G4 G5										
Percidae	*Etheostoma barbouri*	Teardrop darter			G4 G5										
Percidae	*Etheostoma bellum*	Orangefin darter			G4 G5										
Percidae	*Etheostoma blennioides*	Greenside darter		X	G5										
Percidae	*Etheostoma caeruleum*	Rainbow darter	X	X	G5						M				
Percidae	*Etheostoma camurum*	Bluebreast darter		X	G4					FSOC		E			
Percidae	*Etheostoma chlorosoma*	Bluntnose darter	X	X	G5										
Percidae	*Etheostoma crossopterum*	Fringed darter			G4										
Percidae	*Etheostoma flabellare*	Fantail darter	X	X	G5										
Percidae	*Etheostoma flavum*	Saffron darter			G4										
Percidae	*Etheostoma gracile*	Slough darter	X	X	G5										
Percidae	*Etheostoma histrio*	Harlequin darter			G4							E			S2
Percidae	*Etheostoma kennicotti*	Stripetail darter	X		G4 G5										
Percidae	*Etheostoma maculatum*	Spotted darter			G2		V								
Percidae	*Etheostoma nigrum*	Johnny darter	X	X	G5										
Percidae	*Etheostoma oophylax*	Guardian darter			G4 G5										
Percidae	*Etheostoma proeliare*	Cypress darter	X		G5										
Percidae	*Etheostoma rafinesquei*	Kentucky darter													
Percidae	*Etheostoma smithi*	Slabrock darter			G4										
Percidae	*Etheostoma spectabile*	Orangethroat darter	X	X	G5										
Percidae	*Etheostoma squamiceps*	Spottail darter	X		G4 G5										

(table continued on next page)

(table 2 continued)

			Occurrence		Conservation ranks											
Family	Species	Common name	SNF	HNF	Global	Federal	AFS	HNF	SNF	MIS HNF	MIS SNF	IL	IN	KY	MO
Percidae	*Etheostoma stigmaeum*	Speckled darter			G5										
Percidae	*Etheostoma tecumsehi*	Shawnee darter			G1		T								
Percidae	*Etheostoma tippecanoe*	Tippecanoe darter		X	G3		V	Ex							
Percidae	*Etheostoma variatum*	Variegate darter		X	G5										
Percidae	*Etheostoma virgatum*	Striped darter			G4										
Percidae	*Etheostoma zonale*	Banded darter		X	G5										
Percidae	*Perca flavescens*	Yellow perch		X	G5										
Percidae	*Percina caprodes*	Logperch	X	X	G5										
Percidae	*Percina copelandi*	Channel darter		X	G4										S3
Percidae	*Percina evides*	Gilt darter			G4										
Percidae	*Percina maculata*	Blackside darter	X	X	G5										
Percidae	*Percina phoxocephala*	Slenderhead darter	X	X	G5										
Percidae	*Percina sciera*	Dusky darter	X	X	G5										
Percidae	*Percina shumardi*	River darter	X	X	G5										S3
Percidae	*Percina stictogaster*	Frecklebelly darter			G4 G5										
Percidae	*Percina vigil*	Saddleback darter			G5										
Percidae	*Stizostedion canadense*	Sauger	X	X	G5										
Percidae	*Stizostedion vitreum*	Walleye	X		G5										
Percopsidae	*Percopsis omiscomaycus*	Trout-perch	X	X	G5		V								S1?
Petromyzontidae	*Ichthyomyzon bdellium*	Ohio lamprey		X	G5										
Petromyzontidae	*Ichthyomyzon castaneus*	Chestnut lamprey	X	X	G3 G4										
Petromyzontidae	*Ichthyomyzon fossor*	Northern brook lamprey		X	G4							E			
Petromyzontidae	*Ichthyomyzon unicuspis*	Silver lamprey	X	X	G5										
Petromyzontidae	*Lampetra aepyptera*	Least brook lamprey	X	X	G5							T			
Petromyzontidae	*Lampetra appendix*	American brook lamprey			G4										S2
Poeciliidae	*Gambusia affinis*	Western mosquitofish	X		G5										
Polyodontidae	*Polyodon spathula*	Paddlefish	X		G4		V								S3
Sciaenidae	*Aplodinotus grunniens*	Freshwater drum	X	X	G5										
Umbridae	*Umbra limi*	Central mudminnow	X	X	G5										S1

E = Endangered
T = Threatened
S = Special concern
V = Vulnerable (American Fisheries Society)
Ex = Extirpated from the area/state in question
C = Candidate for listing federally
G1 = Critically imperiled globally (typically occurs in 5 or fewer counties)
G2 = Imperiled globally (typically occurs in 6 to 20 counties)
G3 = Very rare and local throughout range or found locally in a restricted range
G4 = Widespread, abundant, and apparently secure globally
G5 = Demonstrably widespread, abundant, and secure globally
T4 = Taxonomic subdivision: widespread, abundant, and apparently secure globally
S1 = Missouri-Critically imperiled in the State (typically 5 or fewer occurrences)
S2 = Missouri-Imperiled in the State (typically 6 to 20 occurrences)
S3 = Missouri-Rare and uncommon in the State (21 to 100 occurrences)
S4 = Missouri-Widespread and abundant but of long-term concern
SX = Missouri-Extirpated
H = Historic (Extirpated-Kentucky)
? = Inexact or uncertain
R= Rare within a national forest
FSOC = Forest Species of Concern
M = Management Indicator Species in the national forest
SNF = Shawnee National Forest
HNF = Hoosier National Forest
AFS = American Fisheries Society
MIS = Management Indicator Species

Rivers. Indicative of the lowlands are the spotted gar, cypress minnow, pugnose minnow, ribbon shiner, lake chubsucker, pirate perch, flier, redspotted sunfish, banded pygmy sunfish, mud darter, bluntnose darter, and slough darter. Species more characteristic of the Coastal Plain include the chain pickerel, central mudminnow, blacktail shiner, taillight shiner, bantam sunfish, and cypress darter. The distribution of lowland fishes is strongly associated with a lack of topographic relief and low stream gradients. As a group they inhabit standing waters or sluggish streams and ditches with sand or mud bottoms. Many are also found among or near debris or dense growths of submerged aquatic vegetation. Because parts of the Interior Low Plateaus have aquatic habitats similar to those on the Coastal Plain, especially the floodplains of large streams and rivers, many species primarily distributed on the Gulf Coastal Plain have dispersed to areas far beyond the Mississippi Embayment.

A number of streams in the Ohio basin are representative of fish communities inhabiting upland habitats. Burr and Page (1986) referred to this upland cluster as the “Ohio River Uplands group.” Among the most characteristic fishes of this group are the streamline chub, popeye shiner, silver shiner, rosyface shiner, stonecat, Tippecanoe darter, spotted darter, variegate darter, and gilt darter. As a group the upland fauna seems to be intolerant of continuous turbidity and siltation and requires streams with permanent flow, high gradients, and coarse gravel or rock bottoms. The distinctiveness of the upland fauna is probably related to topographic and habitat diversity, a relatively long history of drainage stability, constant base flows, and the isolation associated with inhabiting small streams and rivers. The upland faunal group emphasizes that faunal similarity among the drainages is influenced by geographic propinquity and major drainage basin. These findings are similar to those using physiographic units and others that relied almost exclusively on drainage units (e.g., Burr and Page [1986] for Illinois and surrounding areas, Warren et al. [1991] for Kentucky and Tennessee).

In Mayden’s (1988) unique approach to fish faunal assemblages in the assessment area, he used 34 major drainages (e.g., Wabash, Green, Big Muddy Rivers) as analogous to “taxonomic units” and used fish species as the “characters” supporting the branching patterns of the “phylogeny” (estimate of evolutionary history) of the drainage units. His study derived a phylogeny consistent with the known pre-Pleistocene geological history of eastern North American rivers and supported the hypothesis of an ancient ichthyofauna in the Central Highlands region (including the Ouachita, Ozark, and Appalachian Highlands). Among the more intriguing findings of this study and others is that some endemic fish species in the Ozark Highlands have their closest relatives in the Ouachita Highlands, and these two regions together have their next closest relatives in the Appalachian Highlands of eastern Kentucky. For further details on geological and drainage history of the assessment area, see Burr and Page (1986), Burr and Warren 1986), Mayden (1988), Strange and Burr (1997), and Wiley and Mayden (1985).

Native fish species richness and density

The number of native fish species is not evenly distributed among the hydrologic units (fig. 3A), nor is it oriented to a simple geographic axis or compass point. Species richness averaged 76 fish species per hydrologic unit (after removal of HUCs that have only a small proportion of their area in the assessment area) and ranged from 37 to 129 species. Most units, however, displayed diverse fish faunas; 21 of the 27 units in the assessment area had more than 60 species.

Two separate geographical centers with primary levels of fish species richness (85 to 129 species) are apparent (fig. 3A). One occurs along the southwestern and southern edge of Illinois and the other occurs primarily along the eastern border of the assessment area. The southwestern-southern center is comprised of units within the Mississippi-lower Ohio drainage (Cahokia-Joachim, upper Mississippi-Cape Girardeau, Big Muddy, lower Ohio, and lower Ohio-Bay). The eastern center is comprised of units within the Green, Ohio and Wabash River drainages (lower East Fork White, Blue-Sinking, lower Ohio-Little Pigeon, upper Green, and Pond).

Units with secondary levels of fish species richness (61 to 84 species) are located in the extreme southwest (Cache unit), and the central units (Tradewater, middle Green, lower Green, Highland Pigeon, lower Wabash, Patoka, and lower White) of the assessment area (fig. 3A). Minor secondary units with little space in the assessment area include the lower Cumberland and Piasa (fig. 3A). Those units with tertiary levels (60 or fewer species) were primarily narrow strips of area or incomplete border units. The one exception to this pattern is the Rough unit in the Green River drainage with only 51 recorded species.

Ecological units positioned as ecotones tended to be associated with primary levels of richness. The cluster of hydrological units in the west and south reflects their ecotonal position between the uplands of the Shawnee Hills (in Illinois not Kentucky) and the lowlands of both the Gulf Coastal Plain and the Mississippi Alluvial Plain. These units are enriched by having representatives of both upland and lowland fish communities and the uniqueness of the mainstem Mississippi River's "big river" fauna (Burr and Page 1986, Burr and Warren 1986, Pflieger 1971). The primary richness levels along the eastern edge of the assessment area reflect a dominance of upland habitat, close proximity to the high number of endemic fishes in the Ohio basin, and perhaps an artifact of more thorough sampling efforts in these units. The aggregate of units in the central portion of the assessment area with secondary levels of fish species richness are situated primarily in the lowlands of the lower Green and Tradewater Rivers. Much of this region has been subjected to extensive strip mining, stream channelization, and outdated land-use practices. These kinds of habitat changes and degradation have resulted in a more depauperate fish fauna when compared to surrounding units. The fish fauna in these units is not enriched to the extent of other units that are positioned as ecotones, although as noted this may be an artifact of more extensive historical changes in that region.

The density of native fish species (number of fishes per unit area) was highly variable throughout the assessment area, and small HUCs had inflated species densities that do not accurately reflect density patterns recorded for larger HUCs. We therefore summed the rank order for both richness and density per hydrologic unit and arrived at an overall rank order of importance (table 1, fig. 3B). The overall rank order of importance was identical to native fish species richness in the southwestern and southern units of Illinois. The eastern units that ranked high in richness mostly dropped to secondary levels of overall rank order of importance, except that the middle Green unit maintained its status of primary importance. The number of tertiary units increased in the eastern half of the assessment area.

Small hydrologic units in the assessment area may show high native fish species densities because these units are influenced by the fish fauna of surrounding units. If these units were isolated from their respective surrounding units, we predict that species density would decline. The log of native fish species density in a unit was correlated negatively with the log of unit area ($P < 0.0005$). Regression of the log of native fish species richness with the log of square miles in units was positive and statistically significant (P <0.005). Thus, areal additivity is a factor in consideration of species richness and area, but richness approaches some asymptotic value as area increases. Nevertheless, units with primary and secondary levels of richness and overall rank importance should be considered exceptional areas of fish diversity in the assessment area.

Endemic fishes

In the strictest sense, only one fish species, the Shawnee darter, is endemic to the assessment area. Its entire range is found in the upper Pond River (Ceas and Page 1997) and the hydrologic unit of the same name. Some 11 additional species are narrow range endemics that in six cases have significant portions of their ranges in the assessment area. Additionally, ongoing studies indicate that several currently recognized species are, in fact, two or more distinct species. For example, Layman (1994) demonstrated that at least two distinct species now masquerading under the name speckled darter have narrow ranges that include the assessment area. Likewise, the orangethroat darter consists of additional distinct, but not yet formally described, species (Ceas 1997) whose ranges fall partially within the assessment area. Several other subspecies of fishes in the area likely will be recognized as distinct endemic species after further study (Mayden et al. 1992, Warren et al. 2000).

Endemic fishes within the assessment area represent four families: the perches, minnows, catfishes, and cavefishes. The perches (darters) have the highest number of endemic species with 9, or 23 percent of all darters recorded in the area. In addition, the assessment area harbors one endemic minnow (Ozark minnow), one endemic madtom catfish (elegant madtom), and one endemic cavefish (northern cavefish).

The primary region of endemicity in the assessment area is the upper Green River and its major tributaries (i.e., Rough, Barren, and Pond Rivers). Four endemics (Kentucky darter, teardrop darter, orangefin darter, and elegant madtom) occur in this region including some combination of the upper Green, Rough, and middle Green hydrologic units. One species (striped darter) is restricted to the Cumberland River including the Red hydrologic unit. Two species (saffron darter, slabrock darter) are restricted range endemics in the Cumberland and Tennessee drainages and found only in the lower Cumberland hydrologic unit in the assessment area. The frecklebelly darter, the only fish species exclusively shared by the Green and Kentucky River drainages in Kentucky and Tennessee, occupies the upper Green and Rough hydrologic units. The guardian darter occurs in tributaries of the lower Tennessee River, including only the lower Tennessee hydrologic unit in the assessment area. The Ozark minnow, an Ozark Highlands-Driftless Area endemic, barely ranges into the assessment area and is found only in the narrow eastern border referred to here as the Cahokia-Joachim and upper Mississippi-Cape Girardeau hydrologic units. Additionally, the cavefish family has three representatives in the assessment area that occupy subterranean waters or surface springs closely connected to karst environments. One of these, the northern cavefish, has nearly its entire hypogean range within the assessment area where it has been recorded in the lower East Fork White, Blue-Sinking, Rough, and upper Green hydrologic units.

On a larger scale the assessment area captures portions of the ranges of big river endemics including the pallid sturgeon, sturgeon chub, and sicklefin chub. All three of these species are found only in the mainstem of the Missouri River and the Mississippi River below the mouth of the Missouri River. None of these species occupy the main channel of the Ohio

River. About 165 river miles of the ranges of these three species are included in the assessment area. No endemic fishes are known in either the Shawnee or Hoosier National Forests, but stable populations of the spring cavefish and northern cavefish occur on Forest Service properties and present unique opportunities for study and protection.

Composition of Native Mussel Species

Freshwater mussels of the families Unionidae and Margaritiferidae (commonly called naiads, unionids, bivalves, or clams) are found worldwide but achieve their greatest diversity in eastern North America with approximately 297 taxa (281 species and 16 subspecies) currently recognized (Williams et al. 1993). Seventy-six species have been recorded within the boundaries of the assessment area, representing 26 percent of the North American fauna. This includes 92 percent of the species reported to occur or to have occurred in Illinois (Cummings 2001, unpublished data); 97 percent of the species reported in Indiana (Cummings 2001, unpublished data); 71 percent of the species reported in Kentucky (Cicerello 2001, unpublished data); and 39 percent of the species and subspecies reported in Missouri (Oesch 1984).

Many of the mussel species occurring in the assessment area are widely dispersed throughout the Mississippi and Ohio River drainages, whereas others are restricted to a specific stream type (e.g., headwaters and small creeks). Large river drainages traverse different physiographic provinces (ecological subregions) within the assessment area, providing conditions suitable for different aquatic faunal groups, including mussels and fishes. Most mussel species rely on fishes as hosts during the parasitic larval (glochidial) stage of their life cycle. This temporary attachment of the glochidia onto passing fish serves as the means for their dispersal. Pliocene and Pleistocene events affecting zoogeography of fishes in the lower Ohio-upper Mississippi basin have similarly played an important role in the distribution and diversification of freshwater mussels. Mussel species richness (table 3) within the assessment area has resulted from complex drainage histories and varied aquatic habitats, and complex co-evolutionary histories with fish hosts.

The 76 native freshwater mussel species in the assessment area are placed in 36 genera (table 4). The most species-rich genera include *Epioblasma* (8 native species), *Quadrula* (6 species) and *Lampsilis* (6 species). Nineteen genera (25 percent) are represented by a single species. Of the three subfamilies in the Unionidae, 39 lampsilines, 26 amblemines, and 11 anodontines occur within the assessment area. The second family, Margaritiferidae, is represented by a single species *Cumberlandia monodonta* (table 4).

Species richness for hydrologic units within 12 major river basins ranged from a high of 48 in the lower Tennessee to being entirely absent from units in the St. Francis and lower Missouri River basins (table 3). In descending order, average species richness for the remaining nine major river basins was as follows: lower Ohio River (to Mississippi River confluence) (34), Green River (31), lower Cumberland River (19), lower Ohio (to mile 703) (14), Kaskaskia River (13), Patoka-White River (13), upper Mississippi-Meramec River (9), upper Mississippi-Salt River (6), and Wabash River (1).

Roughly half of the native mussel species occurring within the assessment area are representative of a ubiquitous fauna widely dispersed in both the Mississippi and Ohio Rivers (Cummings and Mayer 1992, Johnson 1980). Twenty species are widespread and common within the assessment area—threeridge, Wabash pigtoe, pimpleback, mapleleaf, cylindrical papershell, white heelsplitter, giant floater, creeper, pond papershell, mucket, pocketbook,

Table 3. Native fish species richness, density, index of relative importance, and overall rank order for watersheds of the Hoosier-Shawnee Ecological Assessment Area.

River Basin Hydrologic unit name	Watershed code (HUC)	Total area	Area of HUC in assessment	Species richness (rank order)	Species density (rank order)	Index of relative importance (sum rank orders)	Overall rank order *
		mi²	*mi²*	*no.*	*no. per mi²*		
Lower Missouri River Basin							
Lower Missouri	10300200	1,590	20.67	0 (24)	0.000 (28)	52	21
Upper Mississippi-Salt River Basins							
Peruque-Piasa	07110009	633	14.559	6 (19)	0.412 (2)	21	8
Kaskaskia River Basin							
Lower Kaskaskia	07140204	1,600	88	13 (17)	0.148 (5)	22	9
Upper Mississippi-Meramec River Basins							
Cohokia-Joachim	07140101	1,650	618.75	12 (18)	0.019 (23)	41	17(13)
Upper Mississippi-Cape Girardeau	07140105	1,690	397.15	18 (14)	0.045 (11)	25	11(7)
Big Muddy	07140106	2,350	289.05	2 (22)	0.007 (25)	47	20(16)
Whitewater	07140107	1,210	33.88	0 (24)	0.000 (28)	52	21
Cache	07140108	352	302.72	13 (17)	0.043 (13)	30	15(11)
St. Francis River Basin							
New Madrid-St. Johns	08020201	703	7.03	0 (24)	0.000 (28)	52	21
Little River Ditches	08020204	2,620	36.68	0 (24)	0.000 (28)	52	21
Lower Tennessee River Basin							
Lower Tennessee	06040006	689	79.235	48 (2)	0.606 (1)	3	1(1)
Lower Cumberland River Basin							
Lower Cumberland	05130205	2,300	317.4	37 (5)	0.117 (7)	12	3(3)
Red	05130206	1,450	55.1	0 (24)	0.000 (28)	52	21
Green River Basin							
Upper Green	05110001	3,130	1,311.47	58 (1)	0.044 (12)	13	4(4)
Barren	05110002	2,230	138.26	20 (13)	0.145 (6)	19	6
Middle Green	05110003	1,010	968.59	37 (5)	0.038 (14)	19	6(5)
Rough	05110004	1,070	1,070	30 (7)	0.028 (19)	26	12(8)
Lower Green	05110005	911	911	25 (10)	0.027 (20)	30	15(11)
Pond	05110006	784	784	16 (15)	0.020 (22)	37	16(12)
Wabash River Basin							
Middle Wabash-Little Vermillion	05120108	2,230	6.69	0 (24)	0.000 (28)	52	21
Lower Wabash	05120113	1,300	202.8	1 (23)	0.005	23	10
Patoka-White River Basins							
Upper White	05120201	2,700	278.1	3 (21)	0.011 (24)	45	18(14)
Lower White	05120202	1,650	664.95	21 (12)	0.032 (17)	29	14(10)
Eel	05120203	1,200	231.6	14 (16)	0.060 (9)	25	11(6)
Driftwood	05120204	1,150	40.25	13 (17)	0.323 (3)	20	7
Upper East Fork White	05120206	806	29.016	0 (24)	0.000 (28)	52	21
Muskatatuck	05120207	1,130	14.69	0 (24)	0.000 (28)	52	21
Lower East Fork White	05120208	2,030	1,822.94	48 (2)	0.026 (21)	23	10(6)
Patoka	05120209	854	620.004	4 (20)	0.006 (26)	46	19(14)

(table continued on next page)

(table 3 continued)

River Basin Hydrologic unit name	Watershed code (HUC)	Total area	Area of HUC in assessment	Species richness (rank order)	Species density (rank order)	Index of relative importance (sum rank orders)	Overall rank order *
		m²	*m²*	*no.*	*no. per m²*		
Lower Ohio River Basin (to Miss. R. confl.)							
Lower Ohio-Little Pigeon	05140201	1,370	1370	46 (3)	0.034 (16)	19	6(5)
Highland-Pigeon	05140202	1,000	957	29 (8)	0.030 (18)	26	12(8)
Lower Ohio-Bay	05140203	1,090	1,079.10	40 (4)	0.037 (15)	19	6(5)
Saline	05140204	1,160	300.44	14 (16)	0.047 (10)	26	12(8)
Tradewater	05140205	936	936	26 (9)	0.028 (19)	28	13(9)
Lower Ohio	05140206	928	668.16	48 (2)	0.072 (8)	10	2(2)
Lower Ohio Rver Basin (to mile 703)							
Silver-Little Kentucky	05140101	1,240	12.4	0 (24)	0.00 (28)	52	21
Salt	05140102	1,450	30.45	0 (24)	0.00 (28)	52	21
Rolling Fork	05140103	1,430	105.82	24 (11)	0.23 (4)	15	5
Blue Sinking	05140104	1,880	1,757.80	31 (6)	0.02 (22)	28	13(9)

* The overall ranks in parentheses have been determined with the small Hydrologic Units (less than 12% proportion of inclusion in the assessment area) removed from the ranking procedure. Small Hydrologic Units have inflated species densities and therefore convey artificailly high indicies of relativeimportance. See text for further discussion.

fatmucket, fragile papershell, threehorn wartyback, hickorynut, pink heelsplitter, pink papershell, lilliput, fawnsfoot, and deertoe. Although many species have broad distributions, several of these are uncommon or sporadically distributed throughout their range, due to either human-related impacts or specific habitat restrictions (Cummings and Mayer 1992). Eighteen species are broadly distributed but are uncommon or sporadic within the assessment area—purple wartyback, elephant ear, spike, round pigtoe, Ohio pigtoe, pyramid pigtoe, pistolgrip, pondhorn, elktoe, fluted shell, butterfly, wavy-rayed lampmussel, yellow sandshell, black sandshell, round hickorynut, kidneyshell, rainbow, and little spectaclecase. Another 16 species are rare within the assessment area or have been recorded in less than 10 percent of the hydrologic units—crackling pearlymussel, orangefoot pimpleback, clubshell, rough pigtoe, sugarspoon, leafshell, catspaw, Tennessee riffleshell, northern riffleshell, Wabash riffleshell, tubercled blossom, snuffbox, bleufer, purple lilliput, rayed bean, and Kentucky creekshell.

The majority of the native freshwater mussel species within the assessment area are representatives of the rich Interior Basin fauna, which encompasses the entire Mississippi River basin, excluding the Ozarkian and Cumberlandian faunal areas (Parmalee and Bogan 1998, van der Schalie and van der Schalie 1950). One Cumberlandian species (sugarspoon) has been reported to have occurred in the lower Tennessee River (lower Tennessee hydrologic unit), based on an archaeological record (Cicerello et al. 1991). Johnson (1980) subdivided the Interior Basin into Ohioan, Mississippian, and Gulf Coastal regions, based on several species unique to each area. Thus defined, 7 species within the assessment area are characteristic of the Mississippian region and 20 are characteristic of the Ohioan region. Two Gulf coastal species (bleufer and Texas lilliput) reaching the northern limits of their range are represented in only 10 percent of the hydrologic units along the Mississippi and lower Ohio Rivers. The remaining 47 species are uniformly distributed in both the Mississippian and Ohioan regions.

Table 4. Conservation ranks of native freshwater mussels of the Hoosier-Shawnee Ecological Assessment Area.

Family			Occurrence		Conservation ranks										
Subfamily	Species	Common name	SNF	HNF	Global	Federal	AFS	HNF	SNF	MIS HNF	MIS SNF	IL	IN	KY	MO
Margaretiferidae	*Cumberlandia monodonta*	Spectaclecase	X		G2G3		T					E	EX	E	S3
Unionidae															
Ambleminae	*Amblema plicata*	Threeridge	X	X	G5			R							
Ambleminae	*Cyclonaias tuberculata*	Purple wartyback	X	X	G5		SC					T			
Ambleminae	*Elliptio crassidens*	Elephant ear	X	X	G5							T			
Ambleminae	*Elliptio dilatata*	Spike	X	X	G5			R				T			
Ambleminae	*Fusconaia ebena*	Ebonyshell	X	X	G4G5							T			E
Ambleminae	*Fusconaia flava*	Wabash pigtoe	X	X	G5										
Ambleminae	*Fusconaia subrotunda*	Long-solid		X	G3		SC						E	SC	
Ambleminae	*Hemistena lata*	Cracking pearlymussel			G1		E						EX		
Ambleminae	*Megalonaias nervosa*	Washboard	X	X	G5										
Ambleminae	*Plethobasus cicatricosus*	White wartyback			G1		E						E		
Ambleminae	*Plethobasus cooperianus*	Orange-foot pimpleback	X	X	G1	E	E					E	E	E	
Ambleminae	*Plethobasus cyphyus*	Sheepnose	X	X	G3		T					E	E	SC	E
Ambleminae	*Pleurobema clava*	Clubshell		X	G2	E	E						E	E	
Ambleminae	*Pleurobema sintoxia*	Round pigtoe		X	G3										
Ambleminae	*Pleurobema cordatum*	Ohio pigtoe	X	X	G3		SC					E	T		
Ambleminae	*Pleurobema plenum*	Rough pigtoe		X	G1	E	E						E	E	
Ambleminae	*Pleurobema rubrum*	Pyramid pigtoe		X	G2		T					E	E	E	
Ambleminae	*Quadrula nobilis*	Southern mapleleaf			G5										
Ambleminae	*Quadrula cylindrica*	Rabbitsfoot	X	X	G3T3		T					E	E	T	S1
Ambleminae	*Qudrula metanevra*	Monkeyface	X	X	G4										
Ambleminae	*Quadrula nodulata*	Wartyback	X		G4										S3
Ambleminae	*Quadrula pustulosa*	Pimpleback	X	X	G5										
Ambleminae	*Quadrula quadrula*	Mapleleaf	X	X	G5										
Ambleminae	*Tritogonia verrucosa*	Pistolgrip	X	X	G4										
Ambleminae	*Uniomerus tetralasmus*	Pondhorn	X	X	G4										
Anodontinae	*Alasmidonta marginata*	Elktoe			G5		SC							T	S2?
Anodontinae	*Alasmidonta viridis*	Slippershell			G4G5		SC					T			
Anodontinae	*Anodonta suborbiculata*	Flat floater	X	X	G5										S2
Anodontinae	*Anodontoides ferussacianus*	Cylindrical papershell		X	G5					M					S1?
Anodontinae	*Arcidens confragosus*	Rock-pocketbook	X	X	G4										S3
Anodontinae	*Lasmigona complanata*	White heelsplitter	X	X	G5										
Anodontinae	*Lasmigona costata*	Fluted shell		X	G5										
Anodontinae	*Pyganodon grandis*	Giant floater	X	X	G5										
Anodontinae	*Simpsonaias ambigua*	Salamander mussel		X	G3		SC					E	T	T	S1
Anodontinae	*Strophitus undulatus*	Squawfoot		X	G5					M					
Anodontinae	*Utterbackia imbecillis*	Paper pondshell		X	G5										
Lampsilinae	*Actinonaias ligamentina*	Mucket	X	X	G5										
Lampsilinae	*Cyprogenia stegaria*	Fanshell		X	G1	E	E		R			E	E	E	
Lampsilinae	*Ellipsaria lineolata*	Butterfly	X	X	G4					M		T			
Lampsilinae	*Epioblasma archaeformis*	Sugarspoon			GX		E*								
Lampsilinae	*Epioblasma flexuosa*	Leafshell			GX		E*			M			EX		
Lampsilinae	*Epioblasma obliquata*	Catspaw			G1	E	E						E	E	
Lampsilinae	*Epioblasma propinqua*	Tennessee riffleshell		X	GX		E*						EX		
Lampsilinae	*Epioblasma rangiana*	Northern riffleshell		X	G2T2		E						E	E	

(table continued on next page)

(table 4 continued)

Family Subfamily	Species	Common name	Occurrence SNF	Occurrence HNF	Conservation ranks Global	Federal	AFS	HNF	SNF	MIS HNF	MIS SNF	IL	IN	KY	MO
Lampsilinae	*Epioblasma sampsonii*	Wabash riffleshell			GX		E*						EX		
Lampsilinae	*Epioblasma torulosa*	Tubercled blossom		X	G2T2	E	E						E		
Lampsilinae	*Epioblasma triquetra*	Snuffbox		X	G3		T					E	E	SC	S1
Unionidae															
Lampsilinae	*Lampsilis abrupta*	Pink mucket	X		G2	E	E					E	E	E	E
Lampsilinae	*Lampsilis cardium*	Pocketbook	X	X	G5		SC								
Lampsilinae	*Lampsilis fasciola*	Wavy-rayed lampmussel		X	G4							E	T		
Lampsilinae	*Lampsilis ovata*	Pocketbook	X		G1		SC							E	
Lampsilinae	*Lampsilis siliquoidea*	Fatmucket	X	X	G5										
Lampsilinae	*Lampsilis teres*	Yellow sandshell	X	X	G5										
Lampsilinae	Leptodea fragilis	Fragile papershell	X	X	G5										
Lampsilinae	*Ligumia recta*	Black sandshell	X	X	G5		SC					T			S1S2
Lampsilinae	*Ligumia subrostrata*	Pondmussel	X		G4G5										
Lampsilinae	*Obliquaria reflexa*	Threehorn wartyback	X	X	G5										
Lampsilinae	*Obovaria olivaria*	Hickorynut	X	X	G4										S2S3
Lampsilinae	*Obovaria retusa*	Ring pink	X		G1	E	E						EX	E	
Lampsilinae	*Obovaria subrotunda*	Round hickorynut	X	X	G4		SC					E	T		
Lampsilinae	*Potamilus alatus*	Pink heelsplitter	X	X	G5										
Lampsilinae	*Potamilus capax*	Fat pocketbook	X	X	G1	E	E					E	E	E	E
Lampsilinae	*Potamilus ohiensis*	Pink papershell	X	X	G5										
Lampsilinae	*Potamilus purpuratus*	Bleufer	X		G5									E	
Lampsilinae	*Ptychobranchus fasciolaris*	Kidneyshell	X	X	G4G5							E	T		
Lampsilinae	*Toxolasma lividus*	Purple lilliput			G2		SC					E	T	E	S2
Lampsilinae	*Toxolasma parvus*	Lilliput			G5										
Lampsilinae	*Toxolasma texasensis*	Texas lilliput	X		G4					M				E	S3
Lampsilinae	*Truncilla donaciformis*	Fawnsfoot	X	X	G5										
Lampsilinae	*Truncilla truncata*	Deertoe	X	X	G5										
Lampsilinae	*Villosa fabalis*	Rayed bean			G1G2		SC					E	T	E	
Lampsilinae	*Villosa iris*	Rainbow			G5							E			
Lampsilinae	*Villosa lienosa*	Little spectaclecase		X	G5							E	T	SC	
Lampsilinae	*Villosa ortmanni*	Kentucky creekshell			G2		SC							T	
Unioninae	*Plectomerus dombeyanus*	Bankclimber			G4G5										S3

E* = possibly extinct
EX = extirpated from the study area
G1 = Critically imperiled globally (typically 5 or fewer occurrences)
G2 = Imperiled globally (typically 6 to 20 occurrences)
G3 = Very rare and local throughout range or found locally in a restricted range
G4 = Widespread, abundant, and apparently secure globally
G5 = Demonstrably widespread, abundant, and secure globally
T2 = Taxonomic subdivision; imperiled globally (typically 6 to 20 occurrences)
T3 = Taxonomic subdivision; very rare and local throughout range or found locally in a restricted range
S1 = Critically imperiled in the State (typically 5 or fewer occurrences)
S2 = Imperiled in the State (typically 6 to 20 occurrences)
S3 = Rare and uncommon in the State (21 to 100 occurrences)
? = Inexact or uncertain
SC = Species of special concern
E = Endangered
T = Threatened

R= Rare within a national forest
M = Management Indicator Species in the national forest
SNF = Shawnee National Forest
HNF = Hoosier National Forest
AFS = American Fisheries Society
MIS = Management Indicator Species
IL (Herckert 1992)
KY (KSNPC 1996)
IN (www.in.gov/dnr/fishwild 2001)
MO (www.conservation.state.mo.us 2001)

Native mussel species richness and density

Several of the hydrologic units within the assessment area occupied less than 3 percent of the area of their respective HUCs native freshwater mussels are absent from these units either because it was impossible to determine whether species records fell within the unit boundaries or because the units contained no streams or bodies of water large enough to support freshwater mussels. Species richness averaged 26 species per hydrologic unit (following removal of hydrologic units having only a small proportion of their area in the HUC), but varied considerably between and within major river basins (table 3). For example, within the Patoka-White River basin, only 4 species are known from the Patoka hydrologic unit, whereas 48 are known from the lower East Fork White unit. Primary levels of species richness (31 to 58 species) are concentrated in the southwestern-central (lower Ohio and lower Ohio Bay) units and in the eastern (lower Ohio-Little Pigeon, Blue-Sinking, lower East Fork White, middle Green, and upper Green) units (fig. 4A). Minor primary units having little space within the assessment area include the lower Cumberland and lower Tennessee. Units with secondary levels of mussel species richness (21 to 30 species) are located in the central (Tradewater, Highland-Pigeon, and lower Green) units and in the eastern (Rough, lower White, and Rolling Fork) units. Units with tertiary levels of species richness (20 or fewer species) were primarily those distributed along the borders of the assessment area occupying a small portion of their respective HUCs (fig. 4A).

Hydrologic units in areas that permit a mixture of faunal elements tended to be associated with primary levels of species richness. For example, the southwestern-central units (including the lower Tennessee and lower Cumberland) are enriched by Interior Basin and Cumberlandian species (or Interior Basin species having a Cumberlandian origin) (van der Schalie and van der Schalie 1950). Species-rich units in the Green River basin (middle Green and upper Green) are part of what is recognized to be an important refugium for Ohioan species that repopulated other Ohio River basin tributaries subsequent to Pleistocene glacial events (Johnson 1980). Other hydrologic units (Ohio-Little Pigeon, Blue-Sinking, and lower East Fork

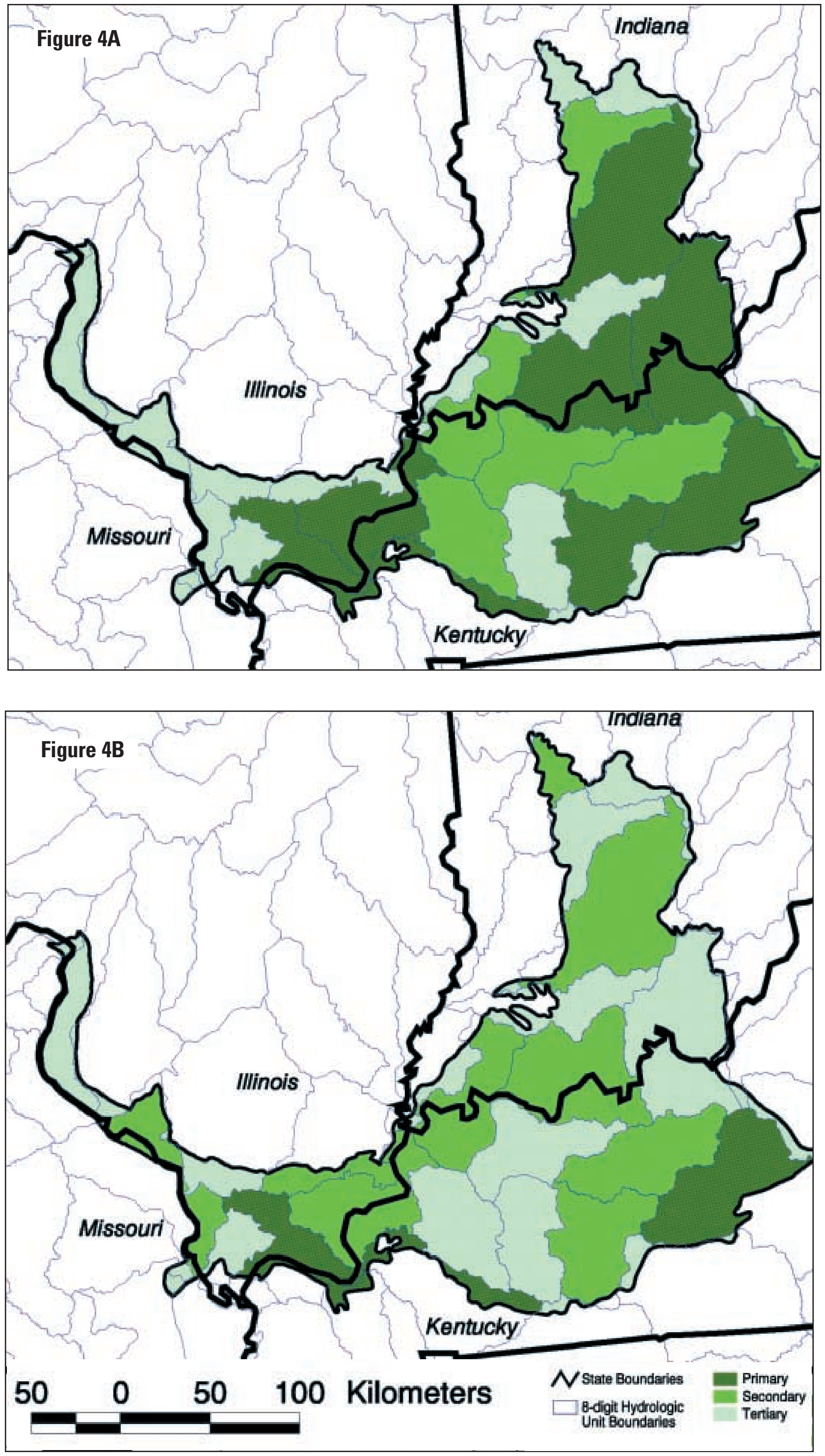

Figure 4. Levels of mussel species richness (A) and mussel species rank of overall importance (B) by watershed in the Hoosier-Shawnee Ecological Assessment Area.

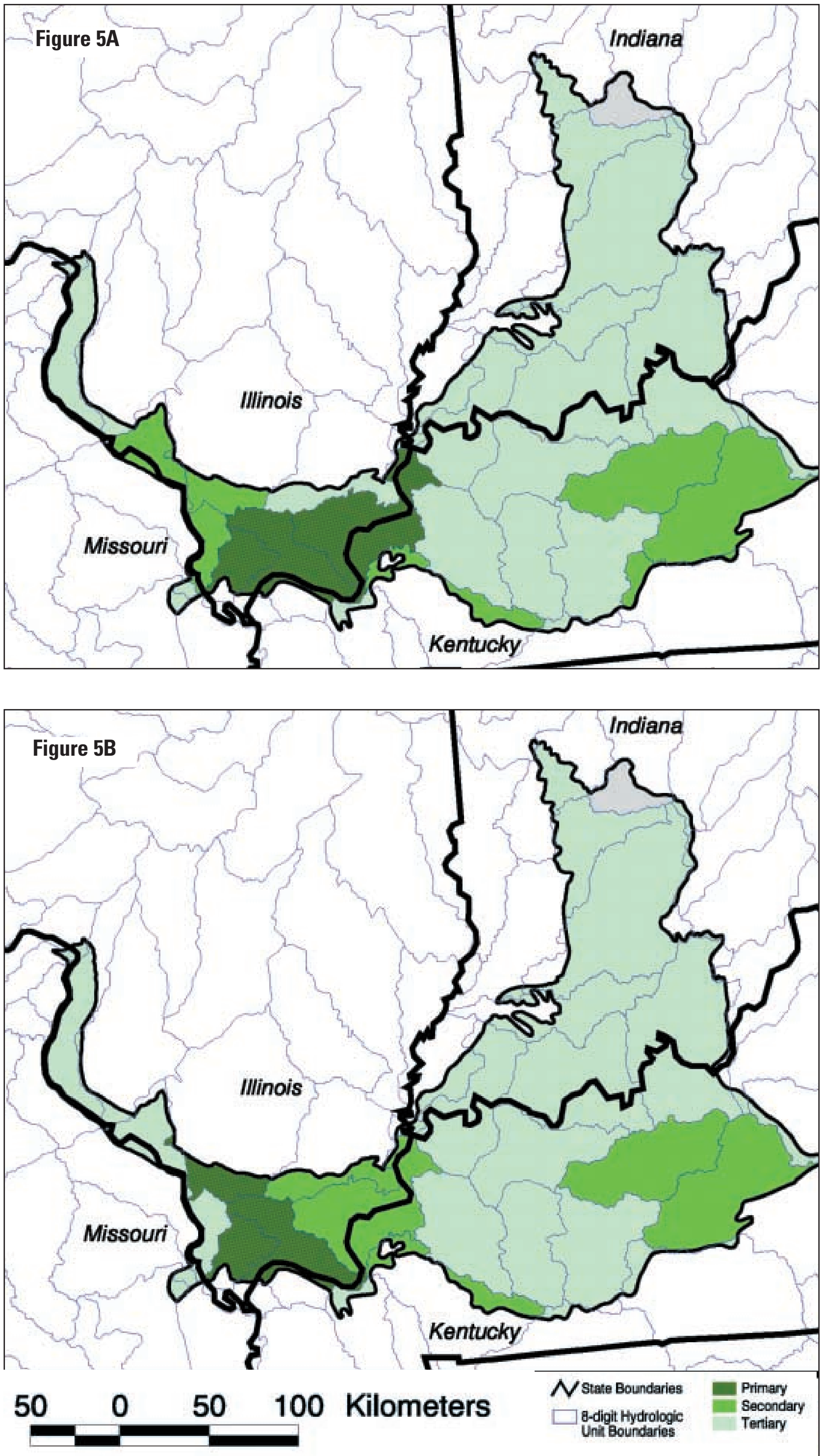

Figure 5. Levels of crayfish species richness (A) and crayfish species rank of overall importance (B) by watershed in the Hoosier-Shawnee Ecological Assessment Area.

White) are positioned on ecotones between uplands of the Interior Low Plateau and lowlands of the lower Ohio-Cache-Wabash Alluvial Plains. These units contained species characteristic of both tributaries and larger rivers and thus exhibited higher species richness.

Native mussel species density (number of species per square mile) was highly variable among hydrologic units, ranging from 0.007 to 0.6; average mussel species density was 0.07 species per mi^2. Regression of species richness with unit area was significant ($P < 0.05$), but the relationship between species density and unit area was not significant ($P \sim 0.2$). In mussels, therefore, richness increases at a constant rate as area increases at a constant rate (i.e., a linear relationship). Those hydrologic units representing a small portion of the HUCs (peripheral units) had inflated species densities that do not accurately reflect density patterns recorded for larger units. We therefore summed rank order values for species richness and density for each hydrologic unit to give an "index of relative importance" (table 3, fig. 4B). Hydrologic units having primary levels of species richness that also maintained primary rank orders of overall importance were the upper Green and lower Ohio. Eastern units (lower East Fork White, lower Ohio-Little Pigeon, Blue-Sinking, and Pond) ranking high in species richness mostly dropped to secondary levels of overall rank of importance, except that the Blue-Sinking unit dropped to a tertiary level of importance. All peripheral hydrologic units, or those with very small proportions in a particular HUC, were relegated to tertiary importance. The lower Tennessee and lower Cumberland units maintained ranks of primary importance because of their exceptional species richness. Although these units represent small portions of their respective HUCs, species density problems did not inflate their overall ranks. Four hydrologic units were assigned primary levels of relative importance—lower Tennessee, lower Ohio, lower Cumberland, and upper Green. Of these units, the lower Tennessee ranked first in species density (0.6 species per mi^2) and the Green ranked first in species richness (58 species). All 10 species federally listed as endangered have been reported from at least one of the units assigned primary levels of relative importance. The upper Green hydrologic unit contains the largest number of species federally listed as endangered—clubshell, rough pigtoe, fanshell, catspaw, northern riffleshell, pink mucket, and ring pink.

Composition of Native Crayfish Species

Approximately 390 species and subspecies of crayfish are endemic to North America (Lodge et al. 2000a, Taylor et al. 1996). The diversity of crayfish species in the assessment area represents only a small portion of North American diversity, although crayfishes nevertheless are a conspicuous and moderately diverse component of the local aquatic fauna. There are 34 species of crayfish in the assessment area (table 5) and all are members of the family Cambaridae. There are two dwarf species in the genus *Cambarellus*, subfamily Cambarellinae. Otherwise, the assessment area is host to five genera of crayfish all in the subfamily Cambarinae: *Barbicambarus, Cambarus, Fallicambarus, Orconectes,* and *Procambarus*. The largest genus, *Orconectes*, with 19 species, makes up almost 56 percent of the crayfish fauna in the assessment area. The genus *Cambarus* is represented by six species, *Procambarus* by four species, and *Barbicambarus* and *Fallicambarus* each by a single species.

Even though the relative diversity of crayfish species in the assessment area is low compared to other Forest Service assessment areas (e.g., Warren et al. 1999), crayfishes in the region play a significant ecological role and serve as an integral food source for recreationally and commercially important fishes (Lodge et al. 2000a, Taylor et al. 1996). Crayfishes can make up a large portion of the biomass in freshwater ecosystems and may be the largest individual invertebrates present there (Lodge et al. 2000a). Lodge et al. (2000a) also noted that, "Crayfishes are often a central part of freshwater foodwebs and ecosystems. They are dominant consumers of benthic invertebrates, detritus, macrophytes, and algae in streams and lakes, and are themselves important forage for fishes . . . Thus, additions or removals of crayfish species often lead to large ecosystem effects, in addition to changes in fish populations, and losses of biodiversity."

The high numbers of crayfish species supported by the Tennessee-Cumberland and Mississippi Embayment ecoregions are considered globally outstanding by Abell et al. (2000), and the Teays-Ohio and Central Prairie ecoregions also support fairly high numbers of crayfish species. The Tennessee-Cumberland and Mississippi Embayment ecoregions also support the highest number of endemic crayfishes of all North American ecoregions. These major ecoregions and their varied habitats and complexity are primary factors responsible for the crayfish diversity recorded from the assessment area.

Native crayfish species richness and density

Crayfish species richness, species density, index of relative importance, and rank of overall importance are reported for each hydrologic unit in the assessment area (table 6). Watersheds in the assessment area exhibiting primary, secondary, and tertiary levels of crayfish species richness are shown in figure 5A. The center of primary crayfish species richness occurs in the lower Ohio drainage, from roughly its confluence with the Wabash River to approximately its confluence with the Mississippi River. Nearly the entire Cache River drainage is included in the center of primary richness. There are two centers of secondary crayfish species richness: 1) the entire catchment of the Rough River, the approximately lower half of the upper Green River watershed, and the lower 6 percent of the Barren River watershed; and 2) the lower Mississippi River and its direct Illinois tributaries, from its confluence with the Kaskaskia River to roughly its confluence with the Cache River, and including the lower 12 percent of the Big Muddy River watershed. Secondary richness status also was achieved in two small portions of the lower Cumberland River drainage and its direct tributaries below Lake Barkley, as well as some of its headwater tributaries bordering the Pond and Tradewater River watersheds. No crayfish distribution data were available for the portions of the upper White River and middle White-Little Vermillion watersheds in Indiana. This pattern of species richness has implications for the Shawnee National Forest because all the watersheds making up the assessment area's center of primary species richness either underlie or border the Shawnee.

Watersheds in the assessment area exhibiting primary, secondary, and tertiary ranks of overall importance are shown in figure 5B. The area of primary rank of overall importance includes portions of three watersheds: the lower 12 percent of the Big Muddy River watershed, most of the Cache River watershed, and the lower Ohio River drainage from downstream of Ledbetter, Kentucky, to its approximate confluence with the Mississippi River. There are two centers of secondary overall importance: 1) the lower half of the upper Green and the entire Rough River watershed; and 2) portions of three watersheds including the lower Cumberland River and its direct tributaries below Lake Barkley, as well as some headwater tributaries bordering the Pond and Tradewater River watersheds; the lower Ohio River drainage from its confluence with the Wabash River to Ledbetter, Kentucky; and the southern 26 percent of the Saline River watershed. No distribution data were available for the portions of the upper White River and middle White-Little Vermillion watersheds in Indiana.

Endemic crayfishes

Six crayfish species are endemic to the assessment area: the Illinois crayfish (*Orconectes illinoisensis*) (Page 1985), the Indiana crayfish (*O. indianensis*) (Page 1985), the Kentucky crayfish (*O. kentuckiensis)* (Page 1985), the Crittenden crayfish (*O. bisectus*) (Taylor and Schuster 2001, unpublished spot-distribution maps), Rafinesque's crayfish (*O. rafinesquei*) (Taylor and Schuster 2001, unpublished spot-distribution maps), and Cobble crayfish (*O. margorectus*) (Taylor 2002).

The range of *O. illinoisensis* is completely contained within Illinois and for the most part coincides with the boundaries of the Shawnee National Forest, except that it also occurs in several rocky, Coastal Plain tributaries of the lower Ohio River. It is considered to be currently stable in the state, is common throughout its range, and can be locally abundant. Although *O. indianensis* is considered endemic to the assessment area, its historic range extends beyond the assessment boundaries, mainly via the North Branch of the Saline River in Illinois and via direct tributaries of the Wabash River north of Greathouse Island to almost its confluence with the White River. Although formerly more widespread in Illinois, the current distribution of *O. indianensis* falls within the assessment area. It is listed as endangered in Illinois (table 5). Except for one collection locality—14 specimens (INHS 112, 4568)—recent collections of *O. indianensis* in Indiana have been within the assessment area, and most of those collections have come from within the Hoosier National Forest. This crayfish species is presumed to be currently stable in Indiana (table 5). Nearly the entire range of *O. kentuckiensis* falls within the assessment area except for a small reach of the lower Cumberland River and its direct tributaries below Lake Barkley. It is listed as endangered in Illinois, occurring only in a few rocky, direct tributaries of the Ohio River in southeastern Illinois. In Kentucky, it occurs in several direct tributaries of the Ohio River in three counties—Crittenden, Livingston, and Union—and is considered to be currently stable.

Orconectes bisectus has the most limited range of the six crayfish species endemic to the assessment area. It is found only in Camp and Crooked Creeks, direct tributaries of the Ohio River, in Crittenden County, Kentucky. It is listed as threatened in Kentucky. *Orconectes margorectus*

Table 5. Conservation ranks of native freshwater crayfishes of the Hoosier-Shawnee Ecological Assessment Area.

			Occurrence		Conservation ranks										
Family Subfamily	Species	Common name	SNF	HNF	Global	Federal	AFS	HNF	SNF	MIS HNF	MIS SNF	IL	IN	KY	MO
Cambaridae															
Cambarellinae	*Cambarellus puer*	Cajun dwarf crayfish	X		G4G5									E	S3?
Cambarellinae	*Cambarellus shufeldtii*	Shufeldt's dwarf crayfish	X		G5									S	S3?
Cambarinae	*Barbicambarus cornutus*	Bottlebrush crayfish			G3G4									S	
Cambarinae	*Cambarus bartonii*	Appalachian brook crayfish			G5										
Cambarinae	*Cambarus diogenes*	Devil crayfish	X	X	G5										
Cambarinae	*Cambarus graysoni*	Nashville crayfish			G5										
Cambarinae	*Cambarus ortmanni*	Lentic crayfish			G4G5										
Cambarinae	*Cambarus rusticiformis*	Riffle crayfish	X		G4G5										
Cambarinae	*Cambarus tenebrosus*	Spring grayfish	X	X	G5										
Cambarinae	*Fallicambarus fodiens*	Digger crayfish	X		G5										S2S3
Cambarinae	*Orconectes barrenensis*	Green River crayfish			G4		E								
Cambarinae	*Orconectes bisectus*	Crittenden crayfish			G2									T	
Cambarinae	*Orconectes illinoiensis*	Illinois crayfish	X		G3		SC								
Cambarinae	*Orconectes immunis*	Papershell crayfish	X	X	G5										
Cambarinae	*Orconectes indianensis*	Indiana crayfish	X	X	G2G3		SC		R			E			
Cambarinae	*Orconectes inermis*	Subterranean crayfish		X	G5T3T4			R							
Cambarinae	*Orconectes kentuckiensis*	Kentucky crayfish	X		G2		T		R			E			
Cambarinae	*Orconectes lancifer*	Shrimp crayfish			G5							E		E	S1S2
Cambarinae	*Orconectes luteus*	Golden crayfish			G5										
Cambarinae	*Orconectes margorectus*	Cobble crayfish			?	?	?								
Cambarinae	*Orconectes palmeri*	Gray-speckled crayfish			G5									E	
Cambarinae	*Orconectes pellucidus*	Eyelash crayfish			G3									S	
Cambarinae	*Orconectes placidus*	Placid crayfish	X		G5				R			E			
Cambarinae	*Orconectes putnami*	Disjunct crayfish			G5										
Cambarinae	*Orconectes rafinesquei*	Rafinesque's crayfish			G2		SC								
Cambarinae	*Orconectes ronaldi*	Mud River crayfish			G3										
Cambarinae	*Orconectes rusticus*	Rusty crayfish	X		G5										
Cambarinae	*Orconectes stannardi*	Little Wabash crayfish			G2		T								
Cambarinae	*Orconectes tricuspis*	Headwater crayfish			G4										
Cambarinae	*Orconectes virilis*	Virile crayfish	X		G5										
Cambarinae	*Procambarus acutus*	White River crayfish	X		G5										
Cambarinae	*Procambarus clarkii*	Red swamp crayfish	X	X	G5										
Cambarinae	*Procambarus gracilis*	Prairie crayfish	X		G5										
Cambarinae	*Procambarus viaeviridis*	Vernal crayfish	X		G5									T	S3

E = Endangered in the State
T = Threatened in the State
S = Special concern in the State
SC = Special concern federally
G1 = Critically imperiled globally (typically occurs in 5 or fewer counties)
G2 = Imperiled globally (typically occurs in 6 to 20 counties)
G3 = Very rare and local throughout range or found locally in a restricted range
G4 = Widespread, abundant, and apparently secure globally
G5 = Demonstrably widespread, abundant, and secure globally
T3 = Taxonomic subdivision: very rare and local throughout range or found locally in a restricted range
T4 = Taxonomic subdivision: widespread, abundant, and apparently secure globally
S1 = Missouri-Critically imperiled in the State (typically 5 or fewer occurrences)
S2 = Missouri-Imperiled in the State (typically 6 to 20 occurrences)
S3 = Missouri-Rare and uncommon in the state (21 to 100 occurrences)
R= rare within a national forest
SNF = Shawnee National Forest
HNF = Hoosier National Forest
AFS = American Fisheries Society
MIS = Management Indicator Species

Table 6. Native crayfish species richness, density, index of relative importance, and overall rank order for watersheds of the Hoosier-Shawnee Ecological Assessment Area.

River Basin Hydrologic unit name	Watershed code (HUC)	Total area	Area of HUC in assessment	Species richness (rank order)		Species density (rank order)		Index of relative importance (sum rank orders)	Overall rank order *	Endemic Species
		mi²	*mi²*	*no.*		*no. per mi²*				
Lower Missouri River Basin										
Lower Missouri	10300200	1,590	20.67	1	(12)	0.048	(7)	19	8	0
Upper Mississippi-Salt River Basins										
Peruque-Piasa	07110009	633	14.559	1	(12)	0.069	(3)	15	4	0
Kaskaskia River Basin										
Lower Kaskaskia	07140204	1,600	88	1	(12)	0.011	(15)	27	13	0
Upper Mississippi-Meramec River Basins										
Cohokia-Joachim	07140101	1,650	618.75	4	(9)	0.006	(19)	28	14(12)	0
Upper Mississippi-Cape Girardeau	07140105	1,690	397.15	8	(5)	0.020	(12)	17	6(7)	0
Big Muddy	07140106	2,350	289.05	8	(5)	0.028	(10)	15	4(5)	1
Whitewater	07140107	1,210	33.88	4	(9)	0.118	(2)	11	2	0
Cache	07140108	352	302.72	10	(3)	0.033	(9)	12	3(1)	1
St. Francis River Basin										
New Madrid-St. Johns	08020201	703	7.03	0	(13)	0.000	(24)	37	17	0
Little River Ditches	08020204	2,620	36.68	5	(8)	0.136	(1)	9	1	0
Lower Tennessee River Basin										
Lower Tennessee	06040006	689	79.235	4	(9)	0.050	(6)	15	4	1
Lower Cumberland River Basin										
Lower Cumberland	05130205	2,300	317.4	8	(5)	0.025	(11)	16	5	1
Red	05130206	1,450	55.1	2	(11)	0.036	(8)	19	8	0
Green River Basin										
Upper Green	05110001	3,130	1,311.47	8	(5)	0.006	(19)	24	10(8)	0
Barren	05110002	2,230	138.26	7	(6)	0.051	(5)	11	2	0
Middle Green	05110003	1,010	968.59	6	(7)	0.006	(19)	26	12(10)	0
Rough	05110004	1,070	1,070	9	(4)	0.008	(17)	21	9(7)	0
Lower Green	05110005	911	911	6	(7)	0.007	(18)	25	11(9)	0
Pond	05110006	784	784	5	(8)	0.006	(19)	27	13(11)	0
Wabash River Basin										
Middle Wabash-Little Vermillion	05120108	2,230	6.69	ND	ND	ND	ND	ND	ND	ND
Lower Wabash	05120113	1,300	202.8	0	(9)	0.000	(24)	33	16	0
Patoka-White River Basins										
Upper White	05120201	2,700	278.1	ND	ND	ND	ND	ND	ND	ND
Lower White	05120202	1,650	664.95	0	(13)	0.000	(24)	37	17	0
Eel	05120203	1,200	231.6	0	(13)	0.000	(24)	37	17(15)	0
Driftwood	05120204	1,150	40.25	0	(13)	0.000	(24)	37	17	0
Upper East Fork White	05120206	806	29.016	0	(13)	0.000	(24)	37	17	0
Muskatatuck	05120207	1,130	14.69	0	(13)	0.000	(24)	37	17	0
Lower East Fork White	05120208	2,030	1,822.94	3	(10)	0.002	(23)	33	16(14)	0
Patoka	05120209	854	620.004	4	(9)	0.006	(19)	28	14(12)	1

(table continued on next page)

(table 6 continued)

River Basin Hydrologic unit name	Watershed code (HUC)	Total area	Area of HUC in assessment	Species richness (rank order)	Species density (rank order)	Index of relative importance (sum rank orders)	Overall rank order *	Endemic Species
		mi^2	mi^2	no.	no. per mi^2			
Lower Ohio River Basin (to Miss. R. confl.)								
Lower Ohio-Little Pigeon	05140201	1,370	1,370	6 (7)	0.004 (21)	28	14(12)	1
Highland-Pigeon	05140202	1,000	957	5 (8)	0.005 (20)	28	14(12)	1
Lower Ohio-Bay	05140203	1,090	1,079.10	11 (2)	0.010 (16)	18	7(5)	2
Saline	05140204	1,160	300.44	6 (7)	0.020 (12)	19	8(6)	1
Tradewater	05140205	936	936	5 (8)	0.005 (20)	28	14(12)	1
Lower Ohio	05140206	928	668.16	12 (1)	0.018 (14)	15	4(2)	1
Lower Ohio River Basin (to mile 703)								
Silver-Little Kentucky	05140101	1,240	12.4	0 (13)	0.000 (24)	37	17	0
Salt	05140102	1,450	30.45	2 (11)	0.066 (4)	15	4	0
Rolling Fork	05140103	1,430	105.82	2 (11)	0.019 (13)	24	10	0
Blue Sinking	05140104	1,880	1,757.80	6 (7)	0.003 (22)	29	15(13)	0

* The overall ranks in parentheses have been determined with the small Hydrologic Units (less than 12% proportion of inclusion in the assessment area) removed from the ranking procedure. Small Hydrologic Units have inflated species densities and therefore convey artificailly high indicies of relative importance. See text for further discussion.

(Taylor 2002) occurs in Crittenden and Livingston Counties in Kentucky, and it is found in Deer Creek and its tributaries, Buck Creek, and the mainstem of the Cumberland River just upstream of Smithland, Kentucky. The description of this species (Taylor 2002) is so recent that no government agency has given *O. margorectus* official conservation status. *Orconectes rafinesquei,* found only in Kentucky, is endemic to the entire Rough River basin, Highland Creek in Henderson and Union Counties, the South Fork of Panther Creek in Ohio County, and two tributaries to the Green River, Pond Creek in Muhlenberg County and Deer Creek in Webster County. Kentucky lists this species as currently stable.

As an aside to crayfish endemicity in the assessment area, if the entire lower Cumberland and lower Tennessee watersheds were included in the assessment area, *O. tricuspis* would also be considered endemic. It occurs in upper Pond River tributaries, tributaries to Lake Barkley, the mainstem of the Cumberland River, and one tributary of Kentucky Lake. Although *O. tricuspis* is not a true endemic to the assessment area, aquatic management plans encompassing that portion of western Kentucky could certainly have an effect on individuals from throughout most of the species' range.

Implications and Opportunities

We synthesized information on diversity and the geographic patterns of fish, mussel, and crayfish distribution within the assessment area. The synthesis revealed that the assessment area and its surrounding hydrologic units support a large portion of continental, national, and regional fish, mussel, and crayfish species diversity, including a moderate number of endemic species. For example, the eastern half of North America represents the center of diversity for freshwater mussels worldwide. In fact, the World Wildlife Fund's recent (Abell et al. 2000) conservation assessment of freshwater ecoregions of North America ranks three of the assessment area's subregions as globally outstanding and the remaining two as bioregionally outstanding. These two categories, globally outstanding and bioregionally outstanding, are the highest conservation rankings possible on a worldwide scale. The implications of these rankings are almost mind boggling because temperate freshwater faunas in other parts of the world (e.g., Europe, China) have experienced severe degradation and loss of diversity. The Forest Service carries a staggering responsibility for management and protection of this unique resource within the hydrologic units included on its property.

We were able to examine these rich aquatic faunas only on a relatively large and coarse scale (i.e., presence or absence of fishes, mussels, and crayfishes in hydrologic units). The synthesis relied on available literature and did not account for declines in populations in recent times even though abundant evidence is available that several fish and mussel species have experienced a reduction in range or fragmentation of populations within the assessment area (Burr and Page 1986, Burr and Warren 1986, Cummings 1991, Cummings and Mayer 1997, Smith 1979, Warren et al. 2000). For example, of the 297 native freshwater mussels in North America, 213 species (nearly 72 percent) are considered endangered, threatened, or of special concern (Williams et al. 1993). More than 75 percent of these species are believed to be suffering from range reductions, leaving distantly isolated populations that may be functionally extinct—having numbers too low to support a viable population (Watters 2000).

Many aquatic species in the assessment area are found in waters under Federal management (i.e., in national forests), including several hydrologic units of either primary or secondary rank of overall importance. Given the trend toward continued human population growth, the concomitant increase in consumption, and the accompanying modification of aquatic habitats across the assessment area, waters on federally managed lands are becoming increasingly critical for the continued existence of viable populations and communities of native aquatic species. For example, studies are needed to determine how many of the original mussel communities in the assessment area are still viable, but maintenance of stable mussel communities requires an understanding of the factors involved in recruitment, especially the presence of suitable fish hosts.

The effect of forest management practices on fishes, mussels, and crayfishes is a significant, but little understood, component of land management within the assessment area. The response of Pacific salmon and trout to forest disturbance has been examined extensively in the Pacific Northwest. As yet, no comparable body of literature exists for fishes, mussels, or crayfishes of the assessment area, even though the fishes are the best known and most visible members of the aquatic community. Provisional assessments of forest cutting and removal of riparian zones indicate that stream fish and mussel communities generally suffer losses in both diversity and abundance of species (Cummings and Mayer 1997, Smith 1971, Page 1991), but carefully planned experimental studies of these sorts of practices have not yet been done in either the Shawnee or Hoosier National Forests.

The introduction and spread of exotic freshwater bivalve species such as the zebra mussel (*Dreissena polymorpha*) and Asian clam (*Corbicula fluminea*) have had significant impacts on native mussels. These exotic species have established high-density populations and have been implicated in the decline of native mussels (Williams et al. 1993). Efforts are needed to control the spread of these nuisance species and their subsequent impacts on additional native mussel communities.

We consider the synthesis of data about the distribution and diversity of fishes, mussels, and crayfishes to be a starting point for identifying and prioritizing information needs that can then be used to better conserve aquatic diversity.

ENDANGERED, THREATENED, AND OTHER AQUATIC SPECIES OF SPECIAL CONCERN

North America's freshwater habitats support some of the most extraordinary biotic assemblages in the world (Abell et al. 2000), and yet in a few short decades we have systematically recorded the loss of a significant number of native American fishes and mussels that took the concerted efforts of hundreds of individuals more than 200 years to discover, record, and describe (Warren and Burr 1994). The major proximate causes of declines in fishes, mussels, and crayfishes are (1) physical habitat loss, degradation, or alteration; (2) chemical pollution or alteration; (3) overexploitation; and (4) introduction of competitive nonindigenous organisms (Allan and Flecker 1993, Williams et al. 1993). The process of extinction in the Eastern United States can be related to landscape-scale phenomena that decrease habitat area or quality and ultimately fragment and isolate populations (Angermeier 1995). This process usually takes place gradually with total extinction or extirpation preceded by local losses or regional annihilations (Angermeier 1995). Understanding and eventually preventing local extirpations or total extinctions will surely require greater attention to landscape-level patterns and processes than has been done in the past.

Recent case histories have demonstrated that one of the most powerful defenses against aquatic biodiversity loss, at least in the United States, is the Endangered Species Act (ESA) of 1973, as amended. Additionally, the Clean Water Act (CWA) of 1972, as amended, is another powerful statutory tool for habitat and species conservation that can prevent human-caused endangerment of aquatic communities and environments (Angermeier and Karr 1994). Under the ESA, "species" are interpreted as including species, subspecies, and certain distinctive populations. Those species listed by Federal authority are provided legal protection under specific categories such as endangered, threatened, proposed endangered, and proposed threatened. Species determined as worthy of protection are maintained on official lists by the U.S. Fish and Wildlife Service (1997a, b).

Other private organizations and State agencies are playing increasingly significant roles in the early recognition, listing, and protection of those species potentially at risk of decline or extirpation. Using protocols developed by The Nature Conservancy and State Natural Heritage Programs, listed species have their distributions and conservation statuses monitored. Globally ranked (i.e., G1, G2, or G3) taxa and those considered imperiled at the state level (a variety of categories used here) are also tracked by natural heritage programs and other independent organizations.

More recently, the American Fisheries Society, using panels of professional biologists, has provided additional independent rankings of conservation status for fishes (Warren et al. 2000), mussels (Williams et al. 1993), and crayfishes (Taylor et al. 1996). In this report, we have included rankings from the four State Natural Heritage Programs and the reports by expert panels representing the American Fisheries Society, as well as the Federal listings. The information provided by these varied listings will be an aid to the Fish and Wildlife Service to draw from in considering possible future candidate species for listing and can help with prioritizing and planning of recovery efforts, status surveys, and research on aquatic species.

DATA SOURCES

Within constraints of time and the patterns and trends in the assessment area, we modeled the following section after the excellent chapter on *Endangered, Threatened, and Other Species of Special Concern* (Warren and Tinkle 1999), in *Ozark-Ouachita Highlands Assessment: Aquatic*

Conditions (General Technical Report SRS-33 (1999), regarding the Ozark-Ouachita Ecological Assessment in Missouri, Arkansas, Kansas, and Oklahoma). We synthesized information in tabular format on endangered, threatened, and special concern aquatic organisms including fishes, mussels, and crayfishes. We included species with Federal status (i.e., endangered or threatened under the ESA or candidate species); those ranked globally as G1, G2, or G3 by The Nature Conservancy (Natureserve Web site 2001); and those ranked by State Natural Heritage Programs (Illinois Endangered Species Protection Board 2000, Indiana Department of Fish and Wildlife Web site 2001, Kentucky State Nature Preserves Commission Web site 2001, Missouri Natural Heritage Program 2000). Separate columns were used for the conservation status rankings of the American Fisheries Society (Taylor et al. 1996, Warren et al. 2000, Williams et al. 1993) and the USDA Forest Service (Chad Stinson, Forest Service, personal communication).

We used the latest lists of endangered and threatened animals compiled by the Missouri, Illinois, Indiana, and Kentucky natural heritage or conservation programs and posted on their respective Web sites or their less frequently published lists (e.g., Illinois Endangered Species Protection Board 2000). Some species in the lists may no longer occur where they were once documented, and their listing does not indicate the continued existence of a species in a particular watershed or State. We corrected any inconsistencies between various lists by consulting the most recent species occurrence data available, including that accumulated by several of us actively researching the target aquatic groups. We also included global rankings for all species in the assessment area to provide the status of all taxa at a given point in time (i.e., September 2001).

PATTERNS AND TRENDS

Fishes

Only two federally listed fish species, pallid sturgeon and northern cavefish, occur within the assessment area (table 2). The endangered pallid sturgeon is narrowly restricted to the main channel of the Mississippi and Missouri Rivers in the region and has never been reported in the mainstem Ohio or Wabash Rivers. As a big river inhabitant, it is technically outside the boundaries of the Shawnee National Forest; its status and management are being actively studied by a team of aquatic biologists from several states bordering the Mississippi and Missouri Rivers. The range of the threatened northern cavefish falls within some of the property under jurisdiction of the Hoosier National Forest but presents an unusual case because it occurs only in karst habitat where subterranean streams may be difficult to access. A reasonably comprehensive status survey of this species was completed by Pearson and Boston (1995), whose distributional and population estimates indicated the species was stable but subject to decline through vandalism, overcollecting, groundwater pollution, and other factors.

Three candidate species within the assessment area are the Alabama shad, sturgeon chub, and sicklefin chub. All three of these species are denizens of the mainstem Mississippi River, with a few historical records of the Alabama shad available from the mainstem Ohio River (Burr and Warren 1986). The shad appears to have declined precipitously in the last century, at least in the upper Mississippi River basin. It is unique in our area for being the only species that migrates from the Gulf of Mexico up the Mississippi River into freshwater streams to spawn. In fact, the only known spawning reaches in the entire upper Mississippi basin are in the State of Missouri (Pflieger 1997); none are known in Illinois, Indiana, or Kentucky. The two chub species are being studied by both Illinois and Missouri personnel, and a new technique involving trawl nets in water about 12 feet deep or less has revealed more adults and young-of-the-year than expected. The new populational and distributional data indicate that neither species may meet requirements for listing as federally endangered or threatened. Once again, all three of these species are peripheral to either the Shawnee or Hoosier National Forests.

Other species listed by more than one State and known to presently occur within the assessment area include the lake sturgeon and southern cavefish. Lake sturgeon records from the Ohio and Mississippi Rivers were far more frequent in the past 10 years than the previous 20. Both Missouri and Wisconsin have released hatchery stock into public waters, which may account in part for the number of recent records, especially because this species is known to travel long distances in more northern waters (Becker 1983). A probable breeding population of the lake sturgeon is apparently present in the White River, Indiana, where the species is being intensively studied. This is the only known potential site of reproduction in the entire assessment area. The cavefish is an obligate cave dweller (troglobite) and is extremely rare in the southern Indiana karst region. A status survey of the southern cavefish is needed for Kentucky.

Rare fishes in the Shawnee and Hoosier Forests

Perhaps of greatest relevance to the assessment area is the status of fish species known to presently inhabit streams of the Shawnee and Hoosier National Forests. Of some 140 fish species documented from Shawnee National Forest waters, those with restricted or sporadic ranges or naturally low population numbers include the least brook lamprey, bluehead shiner, bigeye chub, rosefin shiner, slender madtom, starhead topminnow, bantam sunfish, and redspotted sunfish. The least brook lamprey has had one of only five spawning streams in southern Illinois decimated by recent reservoir construction (Burr and Stewart 1999, Weitzell et al. 1998). Other Shawnee populations appear currently stable. The bluehead shiner is probably extinct in Illinois although it once occurred in the LaRue-Pine Hills Research Natural Area (see Burr et al. 1996). The bigeye chub and rosefin shiner were both known historically from Big Creek, Hardin County, within traditional Shawnee National Forest boundaries. Neither species has been found in the southeastern Illinois forest region in decades. The slender madtom is known only from small streams in the upper Clear Creek system in the western region of the Shawnee (e.g., Green and Hutchins Creeks). It is currently stable but highly restricted in range in national forest waters. The starhead topminnow, bantam sunfish, and redspotted sunfish all occur in the LaRue-Pine Hills Research Natural Area where they are currently stable but have very narrow ranges within southern Illinois and the Shawnee boundaries. Additional species worthy of conservation attention in the Shawnee include the southern redbelly dace, lake chubsucker, and spring cavefish. All three occur in sensitive habitats, including springs, spring runs, karst areas, wetlands, and swamps that have been drastically altered in surrounding regions.

Of the 128 native fishes in the Hoosier National Forest, a few are of conservation concern including the muskellunge, northern cavefish, bluebreast darter, and Tippecanoe darter. These four species are all listed by the State of Indiana as either endangered or extirpated. Numerous additional species of conservation concern are known from streams in areas near the Hoosier National Forest boundaries and may occur within the national forest, but the lack of comprehensive sampling data in Indiana waters by competent and well-trained ichthyologists and aquatic biologists has hampered our assessment of aquatic animals at all scales. Nonetheless, status surveys in southern Indiana should target the following rare or restricted (and listed) species: lake sturgeon, popeye shiner, northern studfish, harlequin darter, spotted darter, variegate darter, gilt darter, and eastern sand darter.

According to McComish and Brown (1980), the muskellunge was caught by anglers in different watersheds in the southern portion of Hoosier National Forest up until the 1960s. Apparently no voucher specimens are known and accurate identification is equivocal. The species may be extirpated or at such low population levels that detection by conventional sampling methods has not been forthcoming. Known to anglers as an elusive and challenging sportfish, this species warrants a comprehensive plan for appropriate stocking and management. A thorough and recent field study of the northern cavefish documented reliable records for the species at 44 different sites in southern Indiana (Pearson and Boston 1995). These authors conservatively estimated that there were at least 5,602 individuals of northern cavefish in Indiana and Kentucky combined, the entire known range of this species. Further extrapolations, based on probable phreatic conduits among cave openings and the probable number of cave openings not explored, indicated the population may reach at least 56,000 individuals. For details, the reader is referred to the excellent report by Pearson and Boston (1995). The bluebreast and Tippecanoe darters are both known from the East Fork White River, but published information based on thorough sampling in the drainage is not available. Other fishes that historically occurred in the Hoosier but that are becoming uncommon in the Midwest and need status surveys are the following: all lamprey species, gravel chub, bigeye chub, pallid shiner, trout perch, and channel darter. Searches for the southern cavefish within karst areas of the Hoosier are also desired because Pearson and Boston (1995) found none in the Indiana locations they and others surveyed.

Extirpated and extinct fishes

Of the nearly 200 native fish species recorded in the assessment area, at least 125 are considered currently stable; with thorough field searches in appropriate habitat an additional 20 or so species could probably be removed from further conservation concern. These numbers are reassuring but could be misleading considering that a number of species have already disappeared from national forest watersheds in both Indiana and Illinois. Over the latter half of the 20th century, three species—alligator gar, pallid shiner, and harelip sucker (*Lagochila lacera* or *Moxostoma lacerum*)—have been documented as extinct or nearly extirpated from waters of the upper Mississippi River basin. The alligator gar has not been recorded in the assessment area since the 1960s (Burr et al. 1996, Poly 2001), and the pallid shiner has virtually disappeared from the region since the 1950s (Burr and Warren 1986, Pflieger 1997, Warren and Burr 1988). The harelip sucker, last observed in 1893, once occurred in Indiana waters (Jenkins in Jenkins and Burkhead 1994) but is considered extinct throughout its range. On a smaller scale, 19th century records (Forbes and Richardson 1909) of the blacknose and longnose daces are available for streams in the western Shawnee; no records since that time are known. The rosefin shiner and bigeye chub once occurred in Spring Branch or Big Creek, Hardin County, in the eastern Shawnee, but neither species has been documented in southern Illinois since 1900 (Smith 1979) and 1935 (B. M. Burr, personal observation), respectively. The popeye shiner once occurred in the East Fork White River, Indiana, in the late 19th century, but appears to be extirpated there (and elsewhere in Indiana) now (Gilbert 1969). This location was near the western edge of the Hoosier.

Mussels

Conservation ranks assigned to the 76 native mussel species occurring within the assessment area reveal that 42 are currently stable, 13 are of special concern, 5 are threatened, and 16 are either endangered or possibly extinct, according to the assignment of status categories by the American Fisheries Society Endangered Species Committee (Williams et al. 1993). Ten species are federally listed as endangered—orangefoot pimpleback, clubshell, rough pigtoe, fanshell, catspaw, northern riffleshell, tubercled blossom, pink mucket, ring pink, and fat pocketbook (http://ecos.fws.gov). Nearly 70 percent of the species within the assessment area are considered rare, threatened, or endangered in at least one of the States included in the assessment area. Global ranks (Association for Biodiversity www.natureserve.org) assigned to native freshwater mussels occurring within the assessment area show that 48 species are secure or apparently secure, 8 are vulnerable, 16 are either imperiled or critically imperiled, and 4 are presumed extinct (table 4).

Crayfishes

Four crayfish species (*Orconectes bisectus, O. kentuckiensis, O. rafinesquei*, and *O. stannardi*) in the assessment area are globally imperiled, three (*O. illinoisensis, O. pellucidus,* and *O. ronaldi*) are globally very rare (i.e., locally restricted ranges), and one species (*O. indianensis*) is designated as globally imperiled or at least very rare (table 5). Three of these species (*O. illinoisensis, O. indianensis,* and *O. kentuckiensis*) occur in at least one watershed that drains the Shawnee National Forest, and one species (*O. pellucidus*) occurs in several watersheds of the Hoosier National Forest. All other species are locally abundant throughout their ranges and are considered globally secure. The assessment area harbors no federally listed crayfish species. The American Fisheries Society lists one crayfish species as endangered (*O. barrenensis*), two as threatened (*O. kentuckiensis* and *O. stannardi*), and three species of special concern (*O. illinoisensis, O. indianensis, O. rafinesquei*). The Forest Service lists one species as threatened (*O. indianensis*) and two species (*O. kentuckiensis* and *O. placidus*) of special concern in the Shawnee National Forest, and one species (*O. inermis*) of special concern in the Hoosier National Forest.

Implications and Opportunities

Increased and coordinated efforts to conduct status surveys and inventories of aquatic species are highly desired for the assessment area. We cannot emphasize enough the lack of available data for the Hoosier National Forest or the State of Indiana, especially for aquatic organisms. For example, Indiana listed no crustaceans as endangered, threatened, or of special concern, even though two crayfishes are listed as globally rare. In comparison to Kentucky, Illinois, and Missouri, where biologists have accumulated nearly comprehensive data sets for fishes, mussels, and crayfishes, Indiana agencies and personnel need to strive for establishing baseline data on aquatic species except those identified as of sport or commercial value. For example, springs and spring runs are among the most valuable of groundwater resources. Both the Shawnee and Hoosier National Forests have numerous springs and spring runs and yet there has been no concerted effort to simply document and describe these unique habitats and examine in some detail their aquatic communities.

The current information available for judging the true status (population sizes, distribution, trends, and threats) of many species is so fragmentary that some species now considered imperiled may not deserve consideration whereas other species may be in jeopardy of extinction but go unrecognized (Williams and Neves 1992). It is apparent from recent work documenting the distribution and status of aquatic species (e.g., Pflieger 1996) that comprehensive inventory efforts in some states are given higher priority and greater support than in others. The ability of natural resource managers to recognize species threatened with extinction or experiencing population declines depends on the timeliness, quality, and comprehensiveness of inventory information available to them. The database assembled for this report provides a basis for increased interstate and Federal-State coordination of efforts to provide up-to-date status information on aquatic species in the assessment area.

COMMERCIALLY AND RECREATIONALLY IMPORTANT SPECIES

Angling or recreational fishing continues to be a favorite pastime in the United States; nationwide, 17 percent of the population 16 years of age and older have participated in sport fishing activities. Recent figures for Illinois and other states in the assessment area are similar. Angling is also a significant source of revenue; sport fishers spend nearly $40 billion annually pursuing their sport nationwide. In Illinois alone, angler expenditures totaled more than $1.6 billion in 1999. The assessment area is home to thriving musky guide services; popular fishing resorts; major fishing, boat, and tackle manufacturers, large and productive aquaculture facilities and fish farms; and major professional sport fishing tournaments and champions. These activities are highly visible and generate huge revenues for the economies of the assessment area.

The intense level of interest in angling would not have developed if a significant fishery resource had not existed naturally. Historical accounts of early inhabitants indicate that they found a plentiful supply of stream and river fisheries. In the assessment area, however, flowing waters have been altered by construction of dams, levees, channelization and dredging, gravel mining, locks, impoundments, and ponds and by ever increasing demands on the harvest of fishery resources.

Fishery managers respond to the challenge of altered aquatic environments by trying to manage for sustainable yield (through natural fish reproduction) where possible. When necessary, managers supplement or replenish sport fish stocks with fish from either hatcheries or aquaculture facilities. Subsequent yields vary depending on the amount of sport and commercial fishing pressure tempered by habitat quality, the effectiveness of fishing regulations, and the ability of resource agencies to fund improvements in aquatic habitat, increasing demands for stocking, and better hatchery facilities.

In this section, we briefly discuss harvest information and identify differences in legal definitions of sport and commercial fish. More limited information is available on commercial uses and values of crayfish species in the states of the assessment area. The legal harvest of mussel species among assessment area states has been under investigation for several years, especially in the mainstem Ohio River. The recent (1999) collapse in the export market for shells will be beneficial to mussels. For example, no commercial harvest for mussels has been reported in Illinois since the collapse of the market. We also present information on the stocking of nonindigenous fish species and the supplemental stocking of native fish species within the assessment area.

DATA SOURCES

Within constraints of time and the patterns and trends in the assessment area, we modeled the following section after the excellent chapters on *Commercially and Recreationally Important Species* (Standage 1999a), and *Management Indicator Species* (Standage 1999b) in *Ozark-Ouachita Highlands Assessment: Aquatic Conditions* (General Technical Report SRS-33 (1999), regarding the Ozark-Ouachita Ecological Assessment in Missouri, Arkansas, Kansas, and Oklahoma). We derived lists of species of legal sport and commercial fishes from the Wildlife Codes (hunting and fishing regulations) of each state or from its respective Web page. All of the lists, except Missouri, were vague in terms of taxonomy (e.g., use of the term "sucker" or "redhorse" for several species of *Moxostoma*), and we adjusted the names in table 10 to reflect our best professional judgment (from interviews with commercial fishermen over the last several years and visits to fish markets on the Mississippi and Ohio Rivers) of the species most often caught and sold at market. We found that in many cases fish family groups were listed as sport/game and/or commercial species, when in fact, a particular species in a group does not grow large enough to have angling or commercial value. We identified only those species within a given fish family that might have sport or commercial value. Thus, blue catfish are shown as both a sport and commercial species, whereas the smaller madtom catfish are not.

It is difficult to obtain statistical information on commercial harvest of fishes from natural populations in North America except for the Laurentian Great Lakes. The National Marine Fisheries Service publishes an annual summary entitled *Fisheries of the United States,* but freshwater landings were not listed separately until 1995. Some commercial data from State Natural Resource Agencies can be compared to a survey made in 1975.

We did not make an attempt to tabulate "minnows" that are captured for bait or sold by commercial fishermen because if caught in the wild any number of species might be involved. Sport fish were identified by examining the lists of record size fish caught on hook and line for each of the four states. Some states have listed their stocking records on their respective Web pages. Nearly all included largemouth bass, bluegill, and channel catfish, all of which are ubiquitous in the assessment area and are stocked in nearly all lentic habitats in the region. We have used some information about additional species raised in the State hatchery systems as an indicator of special areas being stocked with specific exotic or nonindigenous species.

General information regarding human consumption of crayfishes was summarized from Huner (1978), Lodge et al. (2000a), and Page (1985). Data on the commercial harvest of mussels were taken from Cummings (1991) for Illinois, Williams and Schuster (1989) for Kentucky, and Oesch (1984) for Missouri.

PATTERNS AND TRENDS

Commercial Fish Harvest

More than 50 species of fish make up the freshwater commercial harvest in North America (Heidinger 2000); this figure does not include the bait minnow industry. In North America, less than 1 percent of the total commercial harvest of finfish comes from fresh water. Average yearly harvest of selected freshwater fishes from 1982 to 1984 compared to the average yearly harvest from 1995 to 1997 indicates a 61 percent reduction in harvest in the United States (Heidinger 2000). In a 1994 survey, just over 66 percent of the total United States harvest was from either the Great Lakes (29.2 million pounds) or the State of Arkansas (29 million pounds). To place this freshwater harvest in perspective, one only needs to realize that the 1998 commercial harvest of salmon from Alaska was 713 million pounds (Heidinger 2000) and the channel catfish aquaculture industry produced 507 million pounds in 1996 (USDA 1997). The price paid for fish in the round varies both by species and by location. Prices paid for selected species in, for example, Illinois and Missouri, range from $0.07 to $0.75 per pound (table 7).

Species legally available for harvest in Missouri, Illinois, Indiana, and Kentucky are presented in table 8 which also includes species that some states categorize as "rough" fish (e.g., gars, bowfin, shads, redhorses, freshwater drum). We have observed all of these species in the catches of commercial fishermen in Illinois and Kentucky or being sold in the few fish markets

Table 7. Approximate price per pound (round) of selected species (in cents) of commercial fishes of the Hoosier-Shawnee Ecological Assessment Area.

Species	Illinois 1993 (Dufford 1994)	Missouri 1992 (Robinson 1994)
American eel	12-32	18
Blue catfish	36-75	54
Bowfin	7-15	7
Buffalofishes	19-35	24
Bullheads	23-50	24
Common carp	7-35	12
Channel catfish	44-75	55
Flathead catfish	35-75	54
Freshwater drum	9-40	15
Gars	15-50	10
Grass carp	7-25	21
Other Asian carp	7-25	---
Paddlefish	20-31	30
Quillback carpsucker	7-50	19
Shovelnose sturgeon	25-60	25
Suckers	7-20	---

still open on the bordering big rivers of the assessment area.

Except for the major rivers (i.e., Mississippi, Ohio, and Wabash) in the assessment area, freshwater commercial fishing often is banned and is usually unpopular with sport anglers. Anglers fear exploitation of sportfishes by commercial fishermen and interference from commercial gear. Sportfishes taken with commercial gear must be returned to the body of water from which they were captured. Sport anglers often destroy commercial fishing gear especially if their lures get entangled by it.

Waters open to commercial fishing in Missouri include the Missouri, Mississippi, and lower St. Francis Rivers (MO DC 1997). From 1993 through 1995, the number of licensed commercial fishers with gear was 340, 319, and 395, respectively. A commercial fish license is also required of mussel harvesters, but their nets and other fishing gear are not regulated. Most commercial fishers (94 percent) have reported harvesting fewer than 5,000 pounds of fish annually since the 1988 license period. This level of harvesting strongly indicates that few fishers make much money from commercial fishing (Robinson 1994). Even at the price of \$0.54/pound (the greatest price in 1992 for any commercial fish species), maximum earnings are below the poverty level.

Removal of all catfish species from the commercial fish list on the Missouri River (effective in 1992) is also considered to have caused a drop in the number of commercial fishers (Robinson 1994). The commercial harvest in Missouri for 1993 through 1995 ranged from 541,000 to 668,000 pounds with nearly half of all catches in weight consisting of buffalofishes and common carp. The grass carp harvest grew from 8,787 pounds in 1993 to 15,330 pounds in 1994, and 21,366 pounds in 1995. The majority of the grass carp harvest was from the Missouri and Mississippi Rivers. Undoubtedly, similar increases have occurred for bighead and silver carp, but the data are preliminary at the time of this writing. Commercial fishing is anticipated to remain fairly constant on the big rivers unless: (1) license fees increase significantly; (2) consumption advisories are imposed; (3) further restrictions on the harvest of catfish are imposed; (4) further restrictions on the harvest of sturgeon for caviar are imposed; or (5) the market for fresh fish changes dramatically.

Excluding the bordering rivers and the Great Lakes, Illinois continues to allow commercial fishing in two of the three large U.S. Army Corps of Engineers' reservoirs, Rend and Carlyle Lakes. Rend Lake was open to commercial fishing from January 31 to March 24, 2000. A total of 365,589 pounds of commercial species, primarily bigmouth buffalo, were harvested. Carlyle Lake was opened to commercial fishing from December 28, 1999 to January 28, 2000. A total of 109,519 pounds of commercial species were harvested. Both of these lakes are located to the north and outside of the assessment area. Commercial fishing on the portion of the big rivers (i.e., Mississippi, Ohio, and Wabash Rivers) that lie within the assessment

Table 8. Sport and commercial fishes of the Hoosier-Shawnee Ecological Assessment Area, by State. List includes exotic and non-indigenous species.

			Illinois		Indiana		Kentucky		Missouri	
Family	**Scientific name**	**Common name**	**Sport**	**Comm.**	**Sport**	**Comm.**	**Sport**	**Comm.**	**Sport**	**Comm.**
Acipenseridae	*Acipenser fulvescens*	Lake sturgeon		x			x			
Acipenseridae	*Scaphirhynchus platorynchus*	Shovelnose sturgeon	x	x	x	x		x		
Amiidae	*Amia calva*	Bowfin	x	x	x	x	x	x	x	x
Anguillidae	*Anguilla rostrata*	American eel		x				x	x	x
Catostomidae	*Carpiodes carpio*	River carpsucker		x		x				x
Catostomidae	*Carpiodes cyprinus*	Quillback		x		x				x
Catostomidae	*Carpiodes velifer*	Highfin carpsucker		x		x				x
Catostomidae	*Catostomus commersoni*	White sucker		x				x	x	x
Catostomidae	*Cycleptus elongatus*	Blue sucker		x				x	x	x
Catostomidae	*Hypentelium nigricans*	Northern hog sucker		x					x	
Catostomidae	*Ictiobus bubalus*	Smallmouth buffalo	x	x	x	x		x	x	x
Catostomidae	*Ictiobus cyprinellus*	Bigmouth buffalo	x	x	x	x			x	x
Catostomidae	*Ictiobus niger*	Black buffalo	x	x		x			x	x
Catostomidae	*Minytrema melanops*	Spotted sucker		x						x
Catostomidae	*Moxostoma anisurum*	Silver redhorse		x					x	x
Catostomidae	*Moxostoma carinatum*	River redhorse						x	x	x
Catostomidae	*Moxostoma duquesnei*	Black redhorse		x						x
Catostomidae	*Moxostoma erythrurum*	Golden redhorse		x				x	x	x
Catostomidae	*Moxostoma macrolepidotum*	Shorthead redhorse		x					x	x
Centrarchidae	*Ambloplites rupestris*	Rock bass	x		x		x		x	
Centrarchidae	*Centrarchus macropterus*	Flier			x				x	
Centrarchidae	*Lepomis auritus*	Redbreast sunfish					x			
Centrarchidae	*Lepomis cyanellus*	Green sunfish	x		x		x		x	
Centrarchidae	*Lepomis gulosus*	Warmouth	x		x		x		x	
Centrarchidae	*Lepomis humilis*	Orangespotted sunfish								
Centrarchidae	*Lepomis macrochirus*	Bluegill	x		x		x		x	
Centrarchidae	*Lepomis megalotis*	Longear sunfish					x			
Centrarchidae	*Lepomis microlophus*	Redear sunfish	x		x		x		x	
Centrarchidae	*Lepomis symmetricus*	Bantam sunfish								
Centrarchidae	*Micropterus dolomieu*	Smallmouth bass	x		x		x		x	
Centrarchidae	*Micropterus punctulatus*	Spotted bass	x		x		x		x	
Centrarchidae	*Micropterus salmoides*	Largemouth bass	x		x		x		x	
Centrarchidae	*Pomoxis annularis*	White crappie	x		x		x		x	
Centrarchidae	*Pomoxis nigromaculatus*	Black crappie	x		x		x		x	
Clupeidae	*Alosa chrysochloris*	Skipjack herring					x			
Clupeidae	*Dorosoma cepedianum*	Gizzard shad		x						
Cyprinidae	*Carassius auratus*	Goldfish		x						
Cyprinidae	*Cyprinus carpio*	Common carp	x	x	x	x	x	x	x	x
Cyprinidae	*Ctenopharyngodon idella*	Grass carp	x	x	x	x	x	x	x	x
Cyprinidae	*Hypophthalmichthys molitrix*	Silver carp		x		x		x		x
Cyprinidae	*Hypophthalmichthys nobilis*	Bighead carp	x	x	x	x	x	x	x	x
Esocidae	*Esox americanus*	Grass pickerel					x		x	
Esocidae	*Esox lucius*	Northern pike	x		x		x		x	
Esocidae	*Esox masquinongy*	Muskellunge	x		x		x		x	
Esocidae	*Esox masquinongy* x *E. lucius*	Tiger musky	x		x		x		x	

(table continued on next page)

(table 8 continued)

Family	Scientific name	Common name	Illinois		Indiana		Kentucky		Missouri	
			Sport	Comm.	Sport	Comm.	Sport	Comm.	Sport	Comm.
Esocidae	*Esox niger*	Chain pickerel			x		x		x	
Gadidae	*Lota lota*	Burbot			x					
Hiodontidae	*Hiodon alosoides*	Goldeye	x	x					x	
Hiodontidae	*Hiodon tergisus*	Mooneye								
Hiodontidae	*Hiodon tergisus*	Mooneye		x						
Ictaluridae	*Ameiurus catus*	White catfish			x				x	
Ictaluridae	*Ameiurus melas*	Black bullhead	x	x	x	x	x	x	x	x
Ictaluridae	*Ameiurus natalis*	Yellow bullhead	x	x	x	x	x	x	x	x
Ictaluridae	*Ameiurus nebulosus*	Brown bullhead	x	x	x	x	x	x	x	x
Ictaluridae	*Ictalurus furcatus*	Blue catfish	x	x	x	x	x	x	x	
Ictaluridae	*Ictalurus punctatus*	Channel catfish	x	x	x	x	x	x	x	
Ictaluridae	*Pylodictis olivaris*	Flathead catfish	x	x	x	x	x	x	x	
Lepisosteidae	*Atractosteus spatula*	Alligator gar								x
Lepisosteidae	*Lepisosteus oculatus*	Spotted gar	x	x		x	x	x	x	
Lepisosteidae	*Lepisosteus osseus*	Longnose gar		x		x		x	x	x
Lepisosteidae	*Lepisosteus platostomus*	Shortnose gar	x	x		x		x		x
Moronidae	*Morone chrysops*	White bass	x		x		x		x	
Moronidae	*Morone mississippiensis*	Yellow bass	x		x		x		x	
Moronidae	*Morone saxatilis*	Striped bass	x		x		x		x	
Moronidae	*Morone saxatilisx M. chrysops*	Sunshine or Calico bass	x		x		x		x	
Percidae	*Perca flavescens*	Yellow perch	x		x		x		x	
Percidae	*Stizostedion canadense*	Sauger	x		x		x		x	
Percidae	*Stizostedion vitreum*	Walleye	x		x		x		x	
Percidae	*Stizostedion canadense* x *S. viterum*	Saugeye	x		x		x			
Polyodontidae	*Polyodon spathula*	Paddlefish		x	x	x	x	x	x	x
Salmonidae	*Oncorhynchus mykiss*	Rainbow trout	x		x		x		x	
Salmonidae	*Salmo trutta*	Brown trout	x		x		x		x	
Sciaenidae	*Aplodinotus grunniens*	Freshwater drum	x	x	x	x	x	x	x	x

area generally target buffalofishes, paddlefish, the large catfishes (channel, blue, and flathead), and all of the Asian carps. A contentious and contemporary issue involves native sturgeon populations and the caviar industry. The black eggs removed from sturgeon and paddlefish are sold to the caviar markets. Because the federally endangered pallid sturgeon may be taken incidentally along with shovelnose and lake sturgeon, various agencies have lobbied for a complete shutdown of any fishing for sturgeon species. At the time of this writing, the issue had not been resolved. Excluding Lake Michigan, Illinois commercial anglers harvested 5.4 million pounds of fish in calendar year 1999 valued at nearly $1.4 million. There was no reported mussel harvest in calendar year 1999 due to a collapse of the export market for shells.

Commercial fishing is allowed or has been allowed on the Ohio and Mississippi Rivers in Kentucky and the largest reservoirs including those near the assessment area—Kentucky Lake and Lake Barkley and Rough River and Nolin River reservoirs (Hoyt and Flynn 1974, Timmons et al. 1989). The commercial fishery of Kentucky Lake is especially important to the economy of western Kentucky. Renaker and Carter (1968) estimated the annual harvest and value of the trotline fishery in the Kentucky section of Kentucky Lake as 136,101 pounds and

$32,740 in 1965 and 575,301 pounds and $166,806 in 1966, whereas Timmons et al. (1985) reported a harvest of 913,560 pounds worth $448,620 in 1984. Bull (1985) estimated a trotline harvest of 379,191 pounds worth $172,000 in 1984 in the same section of Kentucky Lake. Species accounting for the bulk of the harvest included paddlefish, gars, American eels, common carp, buffalofishes, the large catfishes, and freshwater drum. The fate of harvested fish falls into three general categories: 1) fish sold alive, 2) fish sold dressed, and 3) fish for personal use. Few individual fishers or families earn a living above the poverty line if commercial fishing is their only source of income.

Recreational fisheries

Designated species of sport fish, by State, are listed in table 8. These listed species reflect named species of sport fish or members of families of sport fish sought by anglers and for which fishing records are maintained on an annual basis in each State. We distinguish between the terms “game” and “sport” fish and maintain that most recreational or “sport” fishing in the assessment area involves the return of individual fish to the body of water soon after capture. “Game” implies exploitation for food and is a term now often restricted to birds and mammals exploited for recreational hunting and consumption. The listings are similar for each State, ranging from 41 to 52 sport fishes depending on definition, angler preferences, geography, angler gear, and other factors. All of the States are maintaining angler records for four different hybrid forms: tiger musky, sunshine bass, calico bass, and saugeye. Some of the hybrids cannot be accurately distinguished from their parental species and require genetic tests for identification and establishment of a record fish. The full suite of sport fish listed for the four States reflects what recreational fishers seek. In addition, many—if not most—of the commercial species are also caught and harvested. While the four States may have different lists of sport fish, in practice, similar species are being managed through statewide creel limits (the number of fish than can be harvested) or more localized size limits.

In addition to the stocking of the standard largemouth bass, bluegill, and channel catfish, each of the States has programs for stocking or releasing exotic or nonindigenous species into reservoirs in or near the assessment area. For example, Illinois operates four hatcheries to annually produce more than 50 million fish of 19 species for stocking into Illinois waters. Indiana operates 6 State hatcheries and Missouri 11 with literally hundreds of thousands of fish produced and released into waters near or in the assessment area. Some fish are also provided by private industry and the Federal government (e.g., Fish and Wildlife Service). Examples of stockings in the assessment area include striped bass, muskellunge, northern pike, brown trout, and rainbow trout, only one (muskellunge) of which is native to the region. The stockings are conducted to 1) develop self-sustaining fisheries; 2) provide unique sport-fishing opportunities; and 3) encourage non-reproducing species to take advantage of unique habitats (e.g., reservoirs and their tailwater fisheries) and/or underutilized forage fish. Trout are stocked into many of the large reservoirs or their cold tailwaters. Striped bass, sunshine bass, and calico bass are stocked in many of the large reservoirs to prey upon shad. Muskellunge are stocked in Lake Kinkaid, Illinois, where a substantial fishery and musky guide livelihood have developed. Some States (e.g., Illinois) in the assessment area allow stocking of triploid grass carp (purportedly sterile) in farm ponds to control aquatic plant growth.

Recent research in the assessment States has concentrated on determining genetic stock of the region’s sport fishes. Information gained provides for more effective management of, for example, largemouth bass that are native to the region rather than introduction of southern or Florida largemouth bass that have their own physiological adaptations for warmer environments. Hatcheries are raising native river-run stocks of walleye to protect their genetic integrity. There is a large and ongoing interstate study of paddlefish in the bordering big rivers emphasizing distribution and abundance. The growing aquaculture industry is having its activities closely monitored in all four States, and a comprehensive aquatic nuisance species management plan has been developed and submitted to the Federal task force dealing with these matters.

Commercial Mussel Importance

In the early part of the 20th century, large quantities of freshwater mussels were harvested commercially for the pearl button industry from the largest rivers in the Mississippi basin. Once mussels were collected, the soft tissues were cooked and removed, and the shells shipped to factories where they were cut into blanks, sorted, polished, and finished into buttons (Cummings 1991). Species that were most valuable to the button industry were those having white, unblemished nacres that were relatively large and of uniform thickness. The yellow sandshell was used primarily in the early years of the industry, followed by the plain pocketbook and black sandshell. As the industry progressed, additional species were used. For example, Williams and Schuster (1989) inspected several "dumps" on the lower Ohio River where drilled out shells had been discarded and found the following species to be common: ebonyshell, Wabash pigtoe, Ohio pigtoe, mapleleaf, monkeyface, pimpleback, wartyback, and mucket (table 9). Additional species considered valuable to the industry included the pistolgrip and the butterfly (Oesch 1984).

The pearl button industry flourished for nearly 75 years, then collapsed in the early 1950s following the development and widespread use of plastics (Parmalee and Bogan 1998). Although shells are no longer manufactured into buttons, a mussel industry and commercial harvest exists in the assessment area, especially on the mainstem Ohio River. Today, freshwater mussel shells are used in the Japanese cultured pearl industry. Shells harvested from rivers in the United States from Wisconsin to Alabama are exported to Japan where they are cut into small pellets that serve as nuclei for cultured pearls. The following species are most desired for pearl nuclei because of their size, thickness, and hardness: threeridge, washboard, ebonyshell, Wabash pigtoe, Ohio pigtoe, mapleleaf, monkeyface, wartyback, and pimpleback (table 9, Williams and Schuster 1989). Mussel shells are also used to a much lesser extent as specialty items (Oesch 1984). For example, there is still some small demand for the so-called "pinks"—spike, purple wartyback, and elephant ear (table 9), which have pink to purple nacre. These and other species are used primarily in the manufacture of jewelry and other novelty items such as inlaid furniture and knife handles (Williams and Schuster 1989).

Commercial Crayfish Importance

Except for those species in the genus *Cambarellus,* almost all crayfish species in the assessment area have the potential to reach sizes suitable for human consumption (table 10). However, midwesterners do not consume large quantities of crayfish as is customary among some of the Southern States—mainly Texas and Louisiana (Taylor et al. 1996). No publication summarizes the current crayfish harvest for human consumption in the Midwest, and we therefore judged it to be minimal. Internationally, crayfish are an important product of commerce (Moody 2000). The total annual commercial harvest of crayfish is more than 110,000 metric tons; the United States produces 55 percent of that volume, and the People's Republic of China produces 36 percent. *Procambarus clarkii* is the single most

Table 9. Primary habitat and commercial importance of native freshwater mussel species in the Hoosier-Shawnee Ecological Assessment Area.

Family Subfamily	Species	Common name	Occurrence		Preferred Habitat														Commercial importance		
			SNF	HNF	*Creek	*Headwater	*Small river	*Medium river	*Large river	*Impoundments	*Mud/ silt	*Sand	*Gravel	*Mixed sand & gravel	**Slow current	**Moderate current	**Swift current	Cultured Pearl	Button	***Polished chip
Margaretiferidae	*Cumberlandia monodonta*	Spectaclecase	X						X			X	X		X					
Unionidae																				
Ambleminae	*Amblema plicata*	Threeridge	X	X			X	X	X	X	X	X	X		X	X	X	X	X	X
Ambleminae	*Cyclonaias tuberculata*	Purple wartyback	X	X				X	X				X	X	X	X				
Ambleminae	*Elliptio crassidens*	Elephant ear	X	X					X		X	X	X				X			X
Ambleminae	*Elliptio dilatata*	Spike	X	X			X	X	X	X	X		X			X	X			X
Ambleminae	*Fusconaia ebena*	Ebonyshell	X	X					X					X		X	X	X	X	X
Ambleminae	*Fusconaia flava*	Wabash pigtoe	X	X	X	X	X	X	X		X	X	X		X	X	X		X	
Ambleminae	*Fusconaia subrotunda*	Long-solid		X					X				X				X	?	?	?
Ambleminae	*Hemistena lata*	Cracking pearlymussel						X	X		X	X	X			X				
Ambleminae	*Megalonaias nervosa*	Washboard	X	X				X	X		X	X	X			X		X	X	
Ambleminae	*Plethobasus cicatricosus*	White wartyback							X				X				X	?	?	?
Ambleminae	*Plethobasus cooperianus*	Orange-foot pimpleback	X	X					X				X	X			X			
Ambleminae	*Plethobasus cyphyus*	Sheepnose	X	X				X	X				X	X			X			
Ambleminae	*Pleurobema clava*	Clubshell		X				X	X				X	X			X	?	?	?
Ambleminae	*Pleurobema sintoxia*	Round pigtoe		X				X	X		X	X	X			X			X	X
Ambleminae	*Pleurobema cordatum*	Ohio pigtoe	X	X				X	X			X	X			X		X	X	
Ambleminae	*Pleurobema plenum*	Rough pigtoe		X				X	X			X	X			?		?	?	?
Ambleminae	*Pleurobema rubrum*	Pyramid pigtoe		X				X	X			X	X				X	?	?	?
Ambleminae	*Quadrula nobilis*	Southern mapleleaf (2)							X	X		X	X		X	X	X	?	?	?
Ambleminae	*Quadrula cylindrica*	Rabbitsfoot	X	X				X	X					X			X			
Ambleminae	*Qudrula metanevra*	Monkeyface	X	X				X	X				X	X		X	X	X	X	X
Ambleminae	*Quadrula nodulata*	Wartyback	X					X	X			X	X			?		X	X	X
Ambleminae	*Quadrula pustulosa*	Pimpleback	X	X				X	X		X	X	X		X	X	X	X	X	X
Ambleminae	*Quadrula quadrula*	Mapleleaf	X	X				X	X		X	X	X		X	X	X	X	X	X
Ambleminae	*Tritogonia verrucosa*	Pistolgrip	X	X				X	X		X	X	X			X		X	X	X
Ambleminae	*Uniomerus tetralasmus*	Pondhorn	X	X	X	X				X	X	X			X					
Anodontinae	*Alasmidonta marginata*	Elktoe					X	X					X	X		X	X			
Anodontinae	*Alasmidonta viridis*	Slippershell			X	X					X	X	X				X			
Anodontinae	*Anodonta suborbiculata*	Flat floater	X	X	X	X				X	X				X					
Anodontinae	*Anodontoides ferussacianus*	Cylindrical papershell		X	X	X					X	X			X					
Anodontinae	*Arcidens confragosus*	Rock-pocketbook	X	X				X	X		X	X			X					
Anodontinae	*Strophitus undulatus*	Squawfoot		X			X	X	X		X	X	X			?	?			
Anodontinae	*Utterbackia imbecillis*	Paper pondshell		X	X	X				X	X				X					
Lampsilinae	*Actinonaias ligamentina*	Mucket	X	X				X	X				X	X	X	X	X	X		X
Lampsilinae	*Cyprogenia stegaria*	Fanshell		X				X	X				X				X			
Lampsilinae	*Ellipsaria lineolata*	Butterfly	X	X					X			X	X				X	X	X	X
Lampsilinae	*Epioblasma archaeformis*	Sugarspoon						X	X				X	X			X			
Lampsilinae	*Epioblasma flexuosa*	Leafshell (3)							X				X	X			X			
Lampsilinae	*Epioblasma obliquata*	Catspaw						X	X				X				X			

(table continued on next page)

(table 9 continued)

Family Subfamily	Species	Common name	Occurrence: SNF	Occurrence: HNF	Preferred Habitat: *Creek	*Headwater	*Small river	*Medium river	*Large river	*Impoundments	*Mud/ silt	*Sand	*Gravel	*Mixed sand & gravel	**Slow current	**Moderate current	**Swift current	Commercial importance: Cultured Pearl	Button	***Polished chip
Unionidae																				
Lampsilinae	*Epioblasma propinqua*	Tennessee riffleshell(2)		X					X				X	X			X			
Lampsilinae	*Epioblasma rangiana*	Northern riffleshell		X				X	X				X				X			
Lampsilinae	*Epioblasma sampsonii*	Wabash riffleshell						?	?				?	?			?			
Lampsilinae	*Epioblasma torulosa*	Tubercled blossom		X				X	X				X				X			
Lampsilinae	*Epioblasma triquetra*	Snuffbox		X				X	X				X				X			
Lampsilinae	*Lampsilis abrupta*	Pink mucket	X						X			X	X				X			
Lampsilinae	*Lampsilis cardium*	Plain pocketbook	X	X	X		X	X	X		X	X	X		X	X	X	X	X	X
Lampsilinae	*Lampsilis fasciola*	Wavy-rayed lampmussel		X				X					X			X			?	?
Lampsilinae	*Lampsilis ovata*	Pocketbook	X						X			X	X		X	X	X			
Lampsilinae	*Lampsilis siliquoidea*	Fatmucket	X	X		X	X	X		X	X	X	X		X				X	X
Lampsilinae	*Lampsilis teres*	Yellow sandshell	X	X				X	X			X	X		X	X			X	X
Lampsilinae	*Leptodea fragilis*	Fragile papershell	X	X	X		X	X	X		X	X	X		X	X	X			
Lampsilinae	*Leptodea leptodon*	Scaleshell							X		X						X			
Lampsilinae	*Ligumia recta*	Black sandshell	X	X				X	X			X	X				X		X	X
Lampsilinae	*Ligumia subrostrata*	Pondmussel	X		X					X	X	X			X					
Lampsilinae	*Obliquaria reflexa*	Threehorn wartyback	X	X					X	X		X	X		X	X				X
Lampsilinae	*Obovaria olivaria*	Hickorynut	X	X					X			X		X		X	X			
Lampsilinae	*Obovaria retusa*	Ring pink	X						X			X	X			?	?			
Lampsilinae	*Obovaria subrotunda*	Round hickorynut	X	X				X				X	X			X				
Lampsilinae	*Potamilus alatus*	Pink heelsplitter	X	X				X	X		X	X	X	X	X	X	X			X
Lampsilinae	*Potamilus capax*	Fat pocketbook	X	X					X		X	X			X					
Lampsilinae	*Ptychobranchus fasciolaris*	Kidneyshell	X	X				X	X				X			X	X			
Lampsilinae	*Toxolasma lividus*	Purple lilliput					X	X		X			X		?					
Lampsilinae	*Toxolasma parvus*	Lilliput			X		X	X	X	X	X	X	X		?					
Lampsilinae	*Toxolasma texasensis*	Texas lilliput	X			X	X	X			X	X			X					
Lampsilinae	*Truncilla donaciformis*	Fawnsfoot	X	X				X	X			X	X		X	X	X			
Lampsilinae	*Truncilla truncata*	Deertoe	X	X				X	X		X	X	X		X	X	X			
Lampsilinae	*Villosa fabalis*	Rayed bean					X	X		X		X	X			?	?			
Lampsilinae	*Villosa iris*	Rainbow					X	X				X	X			X	X			
Lampsilinae	*Villosa lienosa*	Little spectaclecase		X			X	X				X	X		X					
Lampsilinae	*Villosa ortmanni*	Kentucky creekshell					?	?				?	?	?	?	?	?			
Unioninae	*Plectomerus dombeyanus*	Bankclimber					X	X			X		X		X	X				X

*Cummings and Mayer (1992)
**Parmalee and Bogan (1998)
***Polished chip (Oesch 1984); jewelry and specialty items (Williams and Schuster 1989)

Table 10. Primary habitat and commercial importance of native freshwater crayfish species in the Hoosier-Shawnee Ecological Assessment Area.

Family Subfamily	Scientific Name	Common Name	Occurence SNF	HNF	Preferred habitat ∆	Commercial importance
Cambaridae						
Cambarellinae	*Cambarellus puer*	Cajun dwarf crayfish	X		3º burrower	
Cambarellinae	*Cambarellus shufeldtii*	Shufeldt's dwarf crayfish	X		3º burrower	
Cambarinae	*Barbicambarus cornutus*	Bottlebrush crayfish			3º burrower	Potentially consumable
Cambarinae	*Cambarus bartonii*	Appalachian brook crayfish			3º burrower & troglophilic	
Cambarinae	*Cambarus diogenes*	Devil crayfish	X	X	1º burrower	Potentially consumable
Cambarinae	*Cambarus graysoni*	Nashville crayfish			3º burrower or Open water	
Cambarinae	*Cambarus ortmanni*	Lentic crayfish			2º burrower	
Cambarinae	*Cambarus rusticiformis*	Riffle crayfish	X		Open water	Potentially consumable
Cambarinae	*Cambarus tenebrosus*	Spring grayfish	X	X	Open water, springs & troglophilic	Potentially consumable
Cambarinae	*Fallicambarus fodiens*	Digger crayfish	X		1º burrower	Potentially consumable
Cambarinae	*Orconectes barrenensis*	Green River crayfish			Open water & 3º burrower	
Cambarinae	*Orconectes bisectus*	Crittenden crayfish*			Open water & 3º burrower	
Cambarinae	*Orconectes illinoiensis*	Illinois crayfish*	X		Open water & 3º burrower	Potentially consumable
Cambarinae	*Orconectes immunis*	Papershell crayfish	X	X	3º burrower	Potentially consumable
Cambarinae	*Orconectes indianensis*	Indiana crayfish*	X	X	Open water & 3º burrower	
Cambarinae	*Orconectes inermis*	Subterranean crayfish		X	Troglobitic	
Cambarinae	*Orconectes kentuckiensis*	Kentucky crayfish*	X		Open water & 3º burrower	
Cambarinae	*Orconectes lancifer*	Shrimp crayfish			Open water & 3º burrower	
Cambarinae	*Orconectes luteus*	Golden crayfish			Open water & 3º burrower	
Cambarinae	*Orconectes margorectus*	Cobble crayfish*			Open water & 3º burrower	
Cambarinae	*Orconectes palmeri*	Gray-speckled crayfish			3º burrower & Open water	
Cambarinae	*Orconectes pellucidus*	Eyeless crayfish			Troglobitic	
Cambarinae	*Orconectes placidus*	Placid crayfish	X		Open water & 3º burrower	Potentially consumable
Cambarinae	*Orconectes putnami*	Disjunct crayfish			Open water & 3º burrower	
Cambarinae	*Orconectes rafinesquei*	Rafinesque's crayfish*			Open water & 3º burrower	
Cambarinae	*Orconectes ronaldi*	Mud River crayfish			Open water & 3º burrower	
Cambarinae	*Orconectes rusticus*	Rusty crayfish	X		Open water & 3º burrower	Potentially consumable**
Cambarinae	*Orconectes stannardi*	Little Wabash crayfish			Open water & 3º burrower	
Cambarinae	*Orconectes tricuspis*	Headwater crayfish			Open water & 3º burrower	
Cambarinae	*Orconectes virilis*	Virile crayfish	X		Open water & 3º burrower	Potentially consumable***
Cambarinae	*Procambarus acutus*	White River crayfish	X		3º burrower	Potentially consumable
Cambarinae	*Procambarus clarkii*	Red swamp crayfish	X	X	3º burrower	Potentailly consumable****
Cambarinae	*Procambarus gracilis*	Prairie crayfish	X		1º burrower	
Cambarinae	*Procambarus viaeviridis*	Vernal crayfish	X		2º burrower	

See text for full description of the different habitats
1º = primary, 2º = secondary, 3º = tertiary, Troglophilic = lives in caves and surface waters, and Troglobitic = obligate cave dweller
∆ Most crayfish preferring flowing, open-water, burrow either in times of low water, to brood eggs, or to escape below the frost line in winter.
* endemic to the Hoosier-Shawnee Ecological Assessment Area.
** Has historically been sold as bait throughout the midwest and New England which lead to significant range expansion (Page 1985).
*** Has historically been harvested and eaten in Illinois (Page 1985).
**** Continues to be harvested commercially for human consumption and bait in more southern portions of its range (Pflieger 1996).

commercially important species in North America, making up more than 70 percent of all harvested species (Moody 2000). Significant crayfish harvest for human consumption, as well as bait, historically occurred in Wisconsin and Ohio (Huner 1978) with other Midwestern States either not reporting catches or not having significant harvests. Page (1985) mentioned that in Illinois, *Orconectes virilis*, an abundant and ubiquitous species, often was harvested for food historically, but does not appear to be harvested currently. Pflieger (1996) noted that *Procambarus clarkii*, found in the assessment area primarily in southern Illinois, was the most commonly harvested and cultured (for human consumption) species in the United States but largely in the extreme southern portions of its range—Texas and Louisiana. For the most part, however, crayfishes of the assessment area are not commercially harvested for human consumption.

Crayfishes are of potential importance in the commercial bait industry and as a food source for wild sportfish stocks. There is also a small but persistent interest in keeping crayfishes as aquarium pets. Although no literature was found that discussed crayfish harvest for the bait industry in or near the assessment area, harvest certainly occurs. Huner (1978) suggested that most North American crayfish species have been collected for bait historically. On a local level, numerous species are captured for bait throughout the assessment area, in part because the practice of harvesting and selling crayfishes as bait is legal in all four States in the assessment area. Certainly it is common practice for bass and catfish anglers to personally harvest crayfish to be used as bait on fishing outings. As noted earlier, crayfish abundance and species composition can have significant effects on sportfish populations (Lodge et al. 2000a). Crayfishes are indirectly important recreationally in this regard because they make up a significant portion of the biomass in a given aquatic system. This biomass becomes a food source for many life stages of numerous sportfish species, particularly basses and sunfishes (Lodge et al. 2000a).

Implications and Opportunities

The era of major reservoir construction in the assessment area is about over and it is unlikely that major changes will be made in management of existing reservoirs and their water releases. Species introductions and manipulation will still occur. The success of the introduced muskellunge fishery in southern Illinois may cause other States in the assessment area to consider a similar program. There was some natural reproduction in earlier years of management, but this seems to have disappeared in the most recent years. A major management problem now is escape of introduced sportfishes over the dams of reservoirs into streams that connect to the big rivers. This sort of behavior could pose ecological problems for native stream fishes and other sport fishes unaccustomed to having a large nonindigenous predator (e.g., muskellunge) in their midst. It is also costly to State resource agencies because considerable personnel time and effort are spent retrieving, for example, adult muskellunge, and returning them to the lake in which they were originally stocked.

We anticipate that fisheries managers will increasingly focus on maintaining or restoring significant warm-water and cool-water stream fisheries and improve sport-fish populations and angling in progressively smaller water bodies as time goes on. Most of the large cities now have active urban fishing programs. Emphasis on managing striped bass and other reservoir sport fish is not likely to diminish in the reasonable future. Considerable technical assistance is now available for the landowner with private pond waters. In the assessment area, largemouth, smallmouth, and spotted basses, bluegill, crappie, white and striped basses, walleye, and large catfishes are still the species of choice of most anglers.

Commercial mussel harvesting has been driven by the overseas demand for shell blanks for the cultured pearl industry. Mussel harvesting needs to be carefully monitored to ensure sustainability of the harvested species as well as other species that may be indirectly affected by harvest activities. Uniformity of harvest regulations (including harvest method [i.e., brailing versus diving], minimum shell sizes, season dates, and time of day open for harvest) and uniformity of reporting would support management of harvest within the assessment area and beyond.

Commercial fishing within the assessment area is primarily restricted to the big rivers at this time. Lack of analysis of required commercial fishers reports and lack of close monitoring of fishing are viewed here as a handicap for efficient fisheries management. A shutdown of the caviar industry would halt all fishing for the three sturgeon species and possibly the paddlefish. Commercial fishing is a lifestyle for some families in the region, but none are making a substantial living with fishing alone. Despite fears of sport fishers, commercial fishing is harvesting a renewable resource and can be compatible with general fishery management objectives in the region.

Management of recreational fishing is an ever-changing science. Significant progress has been made in improving habitats and fishery populations, particularly in reservoirs. Continued efforts with private landowners to help assess and manage the hundreds of small water bodies in the assessment area should yield quality fishing. Conserving native genetic stocks of sportfish is an important long-term goal to maintain the integrity of popular species including the largemouth bass, walleye, and bluegill. Development of high quality stream and river fisheries requires more research, attention, and funding in the near future. Some nearly unexploited river catfish fisheries could be developed into new tournaments, especially considering that most fishing records of any size will almost certainly be set with increased catfish angling. Restoration of many streams and rivers in the region would be required to address the degradation of many waters from mining and logging activities, outdated agricultural practices, and chemical pollution. Support of grassroots teams devoted to stream restoration and conservation by government agencies and private corporations (e.g., The Nature Conservancy) could help to restore and protect the fishing quality of assessment area waters.

As mentioned above, because crayfishes can make up a significant portion of the biomass in an aquatic ecosystem, and because they are often "dominant consumers of benthic invertebrates, detritus, macrophytes, and algae in lakes and streams," removals and additions of crayfish species "often lead to large ecosystem effects, in addition to changes in fish populations, and losses in biodiversity" (Lodge et al. 2000a). Although crayfishes naturally expand their ranges by moving both overland and underwater from drainage to drainage, anthropogenic mechanisms for range expansion are much more effective (Lodge et al. 2000a). Lodge et al. (2000a) recognized eight ways humans can expand the ranges of crayfishes: "(1) dispersal into new drainages via canals; …(2) legal and (3) illegal stocking in natural waters; …(4) escapes from aquaculture ponds, (5) live food vendors; …(6) the aquarium and pond trade; …(7) escapes or releases from students after studying live crayfishes obtained from biological supply houses; and (8) escapes from the live bait trade." In the assessment area, crayfishes escaping from the live bait trade are probably the most likely cause of human-induced range expansion. A secondarily important range expansion mechanism is probably escape from aquaculture ponds.

Probably the best North American example of the effects of a nonindigenous crayfish on newly encountered ecosystems is the progressive movement of *Orconectes rusticus* (rusty crayfish) across the upper Midwest, Canada, northern Appalachia, New England, and parts of the Southwestern United States (Lodge et al. 2000a, Page 1985). Rusty crayfish physically and ecologically outcompete smaller, slower growing, less aggressive native crayfish species, destroy macrophyte communities, and decimate benthic invertebrate communities (Lodge et al. 2000a, Page 1985). These detrimental ecosystem-wide changes affect numerous native aquatic species, in addition to crayfishes, and including sport and non-game fishes. Rusty crayfish also hybridize with native crayfish species, in effect genetically eliminating them from the ecosystem in addition to physically and ecologically outcompeting them (Perry et al. 2001). The rusty crayfish is native to the eastern and southern portions of the assessment area (Indiana and Kentucky) and could potentially invade surrounding areas.

An effective way to reduce the threat of nonindigenous crayfishes would be to place a ban on the practice of using live crayfishes as bait for sportfishing within the national forest boundaries. Furthermore, residents and businesses near the national forests could be encouraged to culture and sell bait minnows rather than nonindigenous crayfishes.

AQUATIC HABITATS

The diversity and abundance of aquatic organisms (e.g., fishes, mussels, crayfishes) and characteristics of their physical habitat (e.g., stream size, substrate type) are primary tools to assess the quality of habitats (Dolloff et al. 1993, Karr et al. 1986). In recent years it has become commonplace to assess aquatic systems by taking a series of measurements and samples at a particular site or series of sites on a stream. Such specific information is unavailable for large portions of the assessment area. The U.S. Environmental Protection Agency (USEPA) and the USEPA programs at the State level have initiated protocols to be used by their field personnel to assess physical and chemical qualities of aquatic habitats. Much of the field work in Illinois and Kentucky has been accomplished in a cooperative and consistent manner with the State Natural Resource Agency or State Nature Preserves Commission. Large-scale analyses in Illinois have linked water quality and other physical variables to fish diversity and abundance and stream ratings for the entire state are available (e.g., Illinois Biological Stream Characterization Work Group 1995). In previous sections, we were able to evaluate diversity of major aquatic groups across the assessment area. No comparable information base exists that can be used to directly examine the status of aquatic habitats in that same area.

The assessment area encompasses a number of major physiographic regions and a diversity of geologic features that, along with an abundance of water bodies, has produced a plethora of aquatic habitats suitable for fishes, mussels, and crayfishes. Habitat occupation varies considerably among the groups of aquatic organisms targeted in this study. For example, several crayfish species are burrowers that may spend much of their lives more than a yard deep in the mud along a stream or wetland. No comparable examples of this kind of habitat occupation are available among fishes or mussels in the area.

DATA SOURCES AND METHODS OF ANALYSIS

Fishes

We classified habitat diversity for fishes around a framework and definitions from Cowardin et al. (1979) and Jenkins et al. (1971). The primary purposes of this habitat classification are to allow the user a quick and accurate characterization of fish habitats known to occur in the assessment area and to allow analysis of affinities of groups of fishes to particular habitat types. The following definitions are provided as a guide to our concepts and use of terms in the characterization of major fish habitat systems and subsystems. The *Lacustrine System* includes permanently flooded lakes and reservoirs generally greater than 20 acres in surface area (except sinkhole ponds) with all of the following features: 1) situated in a dammed river channel or topographic depression; 2) lacking trees, shrubs, and emergent vegetation with greater than 30 percent areal coverage; and 3) the deepest part of the basin exceeds 2 m at low water (Cowardin et al. 1979). The subsystems are *Reservoir* (e.g., Lake of Egypt, Illinois), *Floodplain Lake and Oxbow* (e.g., Taylor Lake, Butler County, Kentucky), and Sinkhole Pond (e.g., Dripping Sinks, Lawrence County, Indiana).

The *Palustrine System* includes wetlands dominated by trees, shrubs, and/or emergent vegetation or those lacking such vegetation with both of the following features: 1) surface area less than 20 acres and 2) water depth in the deepest part of the basin less than 2 m at low water. This system includes vegetated wetlands variously known as swamps, oxbows, sloughs, ditches, marshes, or backwaters. It also encompasses a variety of small, shallow impoundments often called ponds (Cowardin et al. 1979). The subsystems are *Floodplain Lake and Oxbow* (e.g., Mud Lake, Hardin County, Illinois), *Pond* (i.e., farm ponds), and *Wetland* (e.g., Cypress Creek Wetland, Muhlenberg County, Kentucky).

The *Riverine System* includes a large majority of the aquatic habitats in the assessment area and is defined as all waters contained within a channel (sensu Cowardin et al. 1979) except for habitats dominated by trees, shrubs, and emergent plants. Water is usually flowing in this system. The modifiers *upland* and *lowland* characterize gradient and velocity in riverine subsystems. Upland is used to describe riverine subsystems in which the gradient is high and the velocity of water is rapid; water generally flows year round; substrates consist of bedrock, boulder, cobble, pebble, and gravel with occasional patches of sand; dissolved oxygen concentrations are near saturation; and the floodplain is little developed (Cowardin et al. 1979). The concept is also partly based on the presence of shoals or riffles within these subsystems constituting 5 to 10 percent or more of the length of the stream (Jenkins and others 1971). In contrast, lowland applies to those subsystems in which gradient and water velocity are low; flow may be negligible in late summer or early fall; substrates consist of sand, mud, or organic debris; oxygen deficits occur; and the floodplain is well developed. The occurrence of riffles and shoals is low, constituting less than 5 to 10 percent of the stream length.

Subsystems in the *Riverine System* are *Cave Stream, Spring, Headwater Creek, Stream and River,* and *Big River*. The distinction between *Cave Stream* and *Spring* subsystems is based on the larger size of a *Cave Stream* and its association with an obvious surface opening; nevertheless, the distinction in some cases may be arbitrary. We regard sinking streams, a common feature of karst topography, as a part of the *Cave Stream* subsystem. The *Headwater Creek* subsystem includes streams ranging up to about 30 feet in width (Jenkins et al. 1971). In forested areas, flow may be present all year; however, many headwater creeks typically consist of isolated pools or lack surface water during seasons of drought. The *Stream and River* subsystem applies to those waters ranging in size from about 30 to 200 feet in width (Jenkins et al. 1971), having water in the channels, and generally flowing year round (e.g., Green River, Kentucky). The *Big River* subsystem includes waters greater than 200 feet wide and follows the concept of Jenkins et al. (1971). This subsystem is used for the largest rivers of the area (e.g., Ohio River, Missouri River, Mississippi River), most of which are impounded by a series of locks and dams or single large dams, but have an admixture of slow-quiet pools and occasional fast-water shoals or tailwater reaches. Substrates are variable and the floodplain is generally well developed. This subsystem also includes the embayed mouths of streams and rivers that empty into big rivers.

Mussels

We used Cummings and Mayer (1992) and Parmalee and Bogan (1998) for descriptions of aquatic habitats occupied by mussel species in the assessment area. We followed the definitions as used above for fishes when assigning mussel species to specific habitat categories.

Crayfishes

We relied on Hobbs (1981), Page (1985), and Pflieger (1996) for descriptions, illustrations, and definitions of aquatic habitats of crayfishes, which can occupy smaller bodies of water (e.g., ditches) or more temporary bodies of water (e.g., vernal ponds, flooded backyards) more readily than either fishes or mussels. Definitions of the five major types of crayfish habitats as well as a few individual species accounts of habitat occurrence were thoroughly documented by Hobbs (1981). Habitat occurrence for most species was presented in either Page (1985) or Pflieger (1996).

Information on the ecological role and importance of crayfishes in aquatic and terrestrial habitats came mainly from Lodge et al. (2000a, 2000b) and Taylor et al. (1996). General information on cave ecology and conservation was supplied in the reviews by Culver et al. (1999) and Elliott (2000). Forest Service riparian regulations on logging and recreational activities within national forests were provided by Chad Stinson, Shawnee National Forest.

PATTERNS AND TRENDS

Fish Habitat

Flowing waters are the dominant habitat of fishes in the assessment area with nearly 150 species recorded from upland streams and rivers or big rivers. Additionally, most fishes are found over substrates of sand and gravel and in glides or raceways of the riverine system (table 11). Only six species are found in the cave stream subsystem, and a few others would be expected to occasionally enter the twilight zones of caves for limited times. Twelve species have been recorded from springs, but more field efforts are needed to consider this an accurate assessment of this uncommon habitat. Riffle and shoal habitats account for only about 5 to 10 percent of stream length and yet 52 species are recorded from that specific habitat, nearly always over a gravel or pebble substrate. Following definitions of the lacustrine system, it is clear that all "lakes" are artificial in the region and technically are human-made reservoirs that have effectively halted the flow and velocity of riverine systems. As a consequence, the fish communities of reservoirs are depauperate when compared to riverine systems, largely because habitat heterogeneity has been reduced or completely altered. Fish diversity in reservoirs is less than half that of rivers (table 11) and is artificially maintained, in part, by expensive stocking programs to meet the perceived demand of recreational fishers. Most palustrine habitats in the area consist of farm ponds and the few oxbows and wetlands that have not been converted to agricultural land. Nearly all accessible ponds are heavily managed for recreational fishing and have little fish diversity beyond the tailor-made fish populations of channel catfish, bluegill, and largemouth bass. Just over 50 species are associated with aquatic plants, a habitat feature that is rather rare in the assessment area.

Table 11. Primary habitat of native freshwater fishes in the Hoosier-Shawnee Ecological Assessment Area.

		Occurrence		Preferred habitat																									
Species	Common name	SNF	HNF	Reservoir	Floodplain lake & oxbow	Sinkhole ponds	Ponds	Wetlands	Cave stream	Springs	Upland headwater creek	Upland stream & river	Lowland headwater creek	Lowland stream & river	Big river	Organic debris/mud	Sand/gravel (0.08-3 in.)	Pebble/cobble (3-24 in.)	Boulder/bedrock (>24 in.)	Emergent vegetation/cover	Aquatic bed	Scrub-shrub	Forested	Instream shelter	Riffles	Glides	Pools	Backwaters	Embayments
Acipenser fulvescens	Lake sturgeon	X	X									X			X		X	X											
Scaphirhynchus albus	Pallid sturgeon	X													X		X	X											
Scaphirhynchus platorynchus	Shovelnose sturgeon	X	X												X		X	X											X
Amblyopsis spelaea	Northern cavefish		X						X							X	X										X		
Forbesichthys agassizi	Spring cavefish	X				X			X	X	X					X	X										X		
Typhlichthys subterraneus	Southern cavefish		X						X							X	X										X		
Amia calva	Bowfin	X	X		X		X					X		X	X	X	X			X	X		X	X					X
Anguilla rostrata	American eel	X	X									X		X	X	X	X							X					X
Aphredoderus sayanus	Pirate perch	X	X							X		X	X	X			X	X			X	X	X	X					
Labidesthes sicculus	Brook silverside	X	X	X	X							X		X	X		X	X											X
Menidia beryllina	Inland silverside	X		X	X									X	X	X	X												X
Carpiodes carpio	River carpsucker	X	X	X								X		X	X	X	X											X	X
Carpiodes cyprinus	Quillback	X		X								X		X	X	X	X											X	X
Carpiodes velifer	Highfin carpsucker	X	X	X								X		X	X	X	X											X	X
Catostomus commersoni	White sucker	X	X							X	X	X	X	X			X	X	X	X	X			X	X		X		
Cycleptus elongatus	Blue sucker	X	X									X			X		X	X											
Erimyzon oblongus	Creek chubsucker	X	X		X			X			X	X	X	X		X	X			X	X			X			X		
Erimyzon sucetta	Lake chubsucker	X	X		X			X								X	X			X	X	X	X						
Hypentelium nigricans	Northern hog sucker	X	X							X	X	X					X	X	X										
Ictiobus bubalus	Smallmouth buffalo	X	X	X	X			X				X			X	X	X											X	X
Ictiobus cyprinellus	Bigmouth buffalo	X	X	X	X			X				X		X	X	X	X											X	X
Ictiobus niger	Black buffalo	X		X	X							X		X	X	X	X											X	X
Minytrema melanops	Spotted sucker	X	X	X	X							X		X		X	X									X	X		
Moxostoma anisurum	Silver redhorse		X									X		X	X		X	X								X			
Moxostoma carinatum	River redhorse		X									X			X		X	X											
Moxostoma duquesnei	Black redhorse	X	X									X					X	X								X	X		
Moxostoma erythrurum	Golden redhorse	X	X								X	X		X	X		X	X	X							X	X		
Moxostoma macrolepidotum	Shorthead redhorse	X	X	X								X		X	X		X	X								X	X		
Ambloplites rupestris	Rock bass	X	X	X								X					X	X	X	X				X			X		
Centrarchus macropterus	Flier	X	X		X			X						X		X	X				X						X		
Lepomis auritus	Redbreast sunfish			X			X					X		X		X	X				X			X			X	X	
Lepomis cyanellus	Green sunfish	X	X	X	X		X	X			X	X	X	X	X	X	X	X						X			X	X	X
Lepomis gulosus	Warmouth	X	X	X	X		X	X				X		X	X	X	X			X	X			X			X		X
Lepomis humilis	Orangespotted sunfish	X	X	X	X			X				X		X	X	X	X										X		X
Lepomis macrochirus	Bluegill	X	X	X	X		X	X			X	X	X	X	X	X	X	X			X			X			X		X
Lepomis megalotis	Longear sunfish	X	X	X	X		X	X			X	X	X	X	X	X	X	X						X			X		X
Lepomis microlophus	Redear sunfishes	X	X	X	X		X					X		X	X	X	X			X	X			X			X		X
Lepomis miniatus	Redspotted sunfish	X			X			X						X		X	X			X	X		X	X					
Lepomis symmetricus	Bantam sunfish	X			X			X						X		X					X			X					
Micropterus dolomieu	Smallmouth bass	X	X	X								X			X		X	X	X					X		X	X		X

(table continued on next page)

(table 11 continued)

Species	Common name	Occurrence		Preferred habitat																									
		SNF	HNF	Reservoir	Floodplain lake & oxbow	Sinkhole ponds	Ponds	Wetlands	Cave stream	Springs	Upland headwater creek	Upland stream & river	Lowland headwater creek	Lowland stream & river	Big river	Organic debris/mud	Sand/gravel (0.08-3 in.)	Pebble/cobble (3-24 in.)	Boulder/bedrock (>24 in.)	Emergent vegetation/cover	Aquatic bed	Scrub-shrub	Forested	Instream shelter	Riffles	Glides	Pools	Backwaters	Embayments
Micropterus punctulatus	Spotted bass	X	X	X	X			X				X		X	X		X	X						X		X	X		X
Micropterus salmoides	Largemouth bass	X	X	X	X		X	X				X		X	X	X	X	X		X	X	X	X	X			X	X	X
Pomoxis annularis	White crappie	X	X	X	X		X	X				X		X	X	X	X			X	X	X	X	X			X	X	X
Pomoxis nigromaculatus	Black crappie	X	X	X	X		X	X				X		X	X	X	X			X	X	X	X	X			X	X	X
Alosa alabamae	Alabama shad														X		X									X			
Alosa chrysochloris	Skipjack herring	X	X	X								X		X	X		X												X
Dorosoma cepedianum	Gizzard shad	X	X	X	X							X		X	X	X	X												X
Dorosoma petenense	Threadfin shad	X	X	X								X			X	X	X												X
Cottus bairdi	Mottled sculpin		X								X	X					X	X							X	X			
Cottus carolinae	Banded sculpin	X	X						X	X	X	X					X	X							X	X			
Campostoma anomalum	Central stoneroller		X								X	X	X	X			X	X	X						X	X	X		
Campostoma pullum	Mississippi stoneroller	X									X	X	X	X			X	X	X						X	X	X		
Campostoma oligolepis	Largescale stoneroller	X									X	X					X	X	X						X	X			
Cyprinella lutrensis	Red shiner	X			X								X	X	X	X	X									X	X		
Cyprinella spiloptera	Spotfin shiner	X	X									X		X	X		X	X						X	X	X	X		
Cyprinella venusta	Blacktail shiner	X												X	X		X							X		X	X		
Cyprinella whipplei	Steelcolor shiner	X	X									X		X			X	X						X	X	X	X		
Ericymba buccata	Silverjaw minnow	X	X								X	X	X	X			X									X	X		
Erimystax dissimilis	Streamline chub											X					X								X	X			
Erimystax x-punctatus	Gravel chub		X									X					X								X	X			
Hybognathus argyritis	Western silvery minnow	X													X		X									X			
Hybognathus hayi	Cypress minnow	X	X		X			X						X		X					X	X	X	X			X	X	
Hybognathus nuchalis	Mississippi silvery minnow	X	X		X							X		X	X	X	X									X	X		
Hybognathus placitus	Plains minnow	X													X		X									X			
Hybopsis amblops	Bigeye chub	X	X									X					X									X	X		
Hybopsis amnis	Pallid shiner	X	X									X		X		X	X							X			X		
Luxilus chrysocephalus	Striped shiner	X	X								X	X		X	X		X	X							X	X	X		
Luxilus cornutus	Common shiner		X								X	X					X	X							X	X	X		
Luxilus zonatus	Bleeding shiner											X					X	X							X	X	X		
Lythrurus fasciolaris	Scarletfin shiner	X	X									X					X	X								X	X		
Lythrurus fumeus	Ribbon shiner	X	X											X		X	X										X	X	
Lythrurus umbratilis	Redfin shiner	X	X								X	X	X	X		X	X							X		X	X		
Macrhybopsis gelida	Sturgeon chub	X													X		X									X			
Macrhybopsis hyostoma	Speckled chub	X	X									X			X		X									X			
Macrhybopsis meeki	Sicklefin chub	X													X		X									X			
Macrhybopsis storeriana	Silver chub	X	X	X								X		X	X		X	X								X	X		
Nocomis biguttatus	Hornyhead chub	X	X									X					X	X								X	X		
Nocomis effusus	Redtail chub											X					X	X							X	X	X		
Notemigonus crysoleucas	Golden shiner	X	X	X	X		X	X				X		X	X	X	X				X	X	X	X					
Notropis ariommus	Popeye shiner		X									X					X	X		X						X	X		

(table continued on next page)

(table 11 continued)

Species	Common name	Occurrence		Preferred habitat																									
		SNF	HNF	Reservoir	Floodplain lake & oxbow	Sinkhole ponds	Ponds	Wetlands	Cave stream	Springs	Upland headwater creek	Upland stream & river	Lowland headwater creek	Lowland stream & river	Big river	Organic debris/mud	Sand/gravel (0.08-3 in.)	Pebble/cobble (3-24 in.)	Boulder/bedrock (>24 in.)	Emergent vegetation/cover	Aquatic bed	Scrub-shrub	Forested	Instream shelter	Riffles	Glides	Pools	Backwaters	Embayments
Notropis atherinoides	Emerald shiner	X	X	X	X						X			X	X	X	X	X								X	X		
Notropis blennius	River shiner	X	X	X	X										X	X	X									X	X	X	X
Notropis boops	Bigeye shiner	X	X									X					X	X		X						X	X		
Notropis buchanani	Ghost shiner	X	X									X		X	X	X	X										X	X	X
Notropis chalybaeus	Ironcolor shiner		X		X									X	X	X	X			X	X						X	X	X
Notropis dorsalis	Bigmouth shiner	X									X	X					X									X	X		
Notropis hudsonius	Spottail shiner	X													X		X									X	X		
Notropis ludibundus	Sand shiner	X	X									X		X			X									X	X		
Notropis maculatus	Taillight shiner	X	X		X									X		X	X				X		X	X			X	X	
Notropis nubilus	Ozark minnow	X										X			X		X	X								X	X		
Notropis photogenis	Silver shiner		X									X					X	X								X	X		
Notropis rubellus	Rosyface shiner		X									X					X	X								X	X		
Notropis shumardi	Silverband shiner	X	X											X	X		X									X			
Notropis texanus	Weed shiner				X									X	X	X	X			X	X						X	X	X
Notropis volucellus	Mimic shiner	X	X									X		X			X			X	X					X	X		
Notropis wickliffi	Channel shiner	X	X												X	X	X			X						X	X	X	X
Opsopoeodus emiliae	Pugnose minnow	X	X		X			X				X		X		X	X				X	X	X	X			X	X	
Phenacobius mirabilis	Suckermouth minnow	X	X								X	X	X	X	X		X	X							X	X			
Phenacobius uranops	Stargazing minnow											X					X	X							X	X			
Phoxinus erythrogaster	Southern redbelly dace	X	X						X	X	X	X				X	X				X			X		X	X		
Pimephales notatus	Bluntnose minnow	X	X								X	X	X	X	X	X	X	X			X			X		X	X		X
Pimephales promelas	Fathead minnow	X	X		X		X				X	X	X	X	X	X	X							X			X	X	
Pimephales vigilax	Bullhead minnow	X	X	X								X		X	X		X	X	X					X		X	X		
Platygobio gracilis	Flathead chub	X													X		X									X		X	
Pteronotropis hubbsi	Bluehead shiner	X			X											X					X	X	X	X					
Rhinichthys atratulus	Blacknose dace	X	X							X	X	X					X	X						X	X	X			
Rhinichthys cataractae	Longnose dace	X										X						X							X				
Semotilus atromaculatus	Creek chub	X	X			X			X	X	X	X	X	X		X	X	X	X		X			X		X	X		
Elassoma zonatum	Banded pygmy sunfish	X			X			X								X	X				X	X	X	X			X		
Esox americanus	Grass pickerel	X	X	X	X		X	X				X		X		X	X	X		X	X	X	X	X			X		
Esox lucius	Northern pike	X	X	X			X									X	X			X	X			X			X		
Esox masquinongy	Muskellunge		X	X								X					X	X	X	X	X			X			X		
Esox niger	Chain pickerel			X	X			X						X		X	X				X		X	X			X		
Fundulus catenatus	Northern studfish	X									X	X					X	X		X							X		
Fundulus dispar	Starhead topminnow	X			X			X								X	X				X								
Fundulus notatus	Blackstripe topminnow	X	X		X			X			X	X	X	X	X	X	X				X						X	X	X
Fundulus olivaceus	Blackspotted topminnow	X			X			X			X	X	X	X			X				X						X		
Lota lota	Burbot											X		X	X	X	X	X						X			X		X
Hiodon alosoides	Goldeye	X		X										X	X		X									X	X		X
Hiodon tergisus	Mooneye	X	X	X								X		X	X		X									X	X		X

(table continued on next page)

(table 11 continued)

Species	Common name	Occurrence: SNF	HNF	Preferred habitat: Reservoir	Floodplain lake & oxbow	Sinkhole ponds	Ponds	Wetlands	Cave stream	Springs	Upland headwater creek	Upland stream & river	Lowland headwater creek	Lowland stream & river	Big river	Organic debris/mud	Sand/gravel (0.08-3 in.)	Pebble/cobble (3-24 in.)	Boulder/bedrock (>24 in.)	Emergent vegetation/cover	Aquatic bed	Scrub-shrub	Forested	Instream shelter	Riffles	Glides	Pools	Backwaters	Embayments
Ameiurus melas	Black bullhead	X	X	X	X		X	X				X	X	X	X	X	X				X			X			X	X	X
Ameiurus natalis	Yellow bullhead	X	X	X	X		X	X			X	X	X	X	X	X	X				X			X			X	X	X
Ameiurus nebulosus	Brown bullhead	X	X	X	X		X	X				X		X	X	X	X				X			X			X	X	X
Ictalurus furcatus	Blue catfish	X		X								X		X	X	X	X							X		X	X	X	X
Ictalurus punctatus	Channel catfish	X	X	X	X		X					X		X	X	X	X	X						X		X	X	X	X
Noturus elegans	Elegant madtom											X					X	X							X	X			
Noturus eleutherus	Mountain madtom		X									X			X		X	X							X	X			
Noturus exilis	Slender madtom	X										X					X	X							X	X			
Noturus flavus	Stonecat	X	X									X			X		X	X	X						X	X			
Noturus gyrinus	Tadpole madtom	X	X	X	X							X		X		X	X			X	X			X			X		
Noturus miurus	Brindled madtom	X	X									X		X		X	X							X	X		X		
Noturus nocturnus	Freckled madtom	X	X									X		X	X	X	X							X	X		X		
Noturus stigmosus	Northern madtom		X									X			X	X	X	X			X			X	X	X			
Pylodictis olivaris	Flathead catfish	X	X	X								X		X	X	X	X	X						X					
Atractosteus spatula	Alligator gar	X			X									X	X	X	X												
Lepisosteus oculatus	Spotted gar	X		X	X			X						X	X	X	X				X	X	X	X			X		
Lepisosteus osseus	Longnose gar	X	X	X	X							X		X	X	X	X			X	X			X			X		
Lepisosteus platostomus	Shortnose gar	X	X	X	X									X	X	X	X			X	X			X			X		
Morone chrysops	White bass	X		X								X		X	X		X	X									X		
Morone mississippiensis	Yellow bass	X	X	X	X							X		X	X		X	X											
Ammocrypta clara	Western sand darter	X										X			X		X									X			
Ammocrypta pellucida	Eastern sand darter		X									X		X			X									X			
Crystallaria asprella	Crystal darter											X			X		X									X			
Etheostoma asprigene	Mud darter	X			X			X						X	X	X	X							X	X	X			
Etheostoma barbouri	Teardrop darter										X	X					X	X								X	X		
Etheostoma bellum	Orangefin darter											X					X	X							X	X			
Etheostoma blennioides	Greenside darter		X									X					X	X		X	X				X	X			
Etheostoma caeruleum	Rainbow darter	X	X								X	X					X	X							X	X			
Etheostoma camurum	Bluebreast darter		X									X					X	X							X				
Etheostoma chlorosoma	Bluntnose darter	X	X		X			X					X	X		X	X				X			X			X		
Etheostoma crossopterum	Fringed darter										X	X					X	X								X	X		
Etheostoma flabellare	Fantail darter	X	X								X	X					X	X							X	X			
Etheostoma flavum	Saffron darter											X						X								X	X		
Etheostoma gracile	Slough darter	X	X		X			X					X	X		X	X			X	X			X		X	X		
Etheostoma histrio	Harlequin darter											X		X		X	X							X	X	X			
Etheostoma kennicotti	Stripetail darter	X									X	X					X	X								X	X		
Etheostoma maculatum	Spotted darter											X					X	X	X						X				
Etheostoma microperca	Least darter									X	X					X	X				X			X			X		
Etheostoma nigrum	Johnny darter	X	X								X	X					X	X						X		X	X		
Etheostoma oophylax	Guardian darter										X	X					X	X							X	X			

(table continued on next page)

(table 11 continued)

Species	Common name	Occurrence: SNF	HNF	Preferred habitat: Reservoir	Floodplain lake & oxbow	Sinkhole ponds	Ponds	Wetlands	Cave stream	Springs	Upland headwater creek	Upland stream & river	Lowland headwater creek	Lowland stream & river	Big river	Organic debris/mud	Sand/gravel (0.08-3 in.)	Pebble/cobble (3-24 in.)	Boulder/bedrock (>24 in.)	Emergent vegetation/cover	Aquatic bed	Scrub-shrub	Forested	Instream shelter	Riffles	Glides	Pools	Backwaters	Embayments
Etheostoma proeliare	Cypress darter							X		X			X			X	X				X			X					
Etheostoma rafinesquei	Kentucky darter										X	X					X	X		X					X		X		
Etheostoma proeliare	Cypress darter	X																											
Etheostoma smithi	Slabrock darter			X							X						X	X							X		X		
Etheostoma spectabile	Orangethroat darter	X	X								X	X	X	X			X								X	X	X		
Etheostoma squamiceps	Spottail darter	X									X	X						X							X		X		
Etheostoma stigmaeum	Speckled darter											X					X	X								X	X		
Etheostoma tecumsehi	Shawnee darter										X						X	X			X				X	X	X		
Etheostoma tippecanoe	Tippecanoe darter		X									X					X	X							X				
Etheostoma variatum	Variegate darter		X									X					X	X							X	X			
Etheostoma virgatum	Striped darter										X	X					X	X								X	X		
Etheostoma zonale	Banded darter		X									X					X	X			X				X	X			
Perca flavescens	Yellow perch		X	X											X	X	X				X						X	X	X
Percina caprodes	Logperch	X	X	X	X							X		X	X	X	X	X								X	X		
Percina copelandi	Channel darter		X									X			X		X									X			
Percina evides	Gilt darter											X			X		X	X							X	X			
Percina maculata	Blackside darter	X	X								X	X	X	X		X	X	X								X	X		
Percina phoxocephala	Slenderhead darter	X	X									X			X		X	X							X	X			
Percina sciera	Dusky darter	X	X									X		X		X	X							X		X	X		
Percina shumardi	River darter	X	X									X		X			X	X	X		X				X	X			
Percina stictogaster	Frecklebelly darter											X					X	X		X				X		X			
Percina vigil	Saddleback darter											X		X			X								X	X			
Stizostedion canadense	Sauger	X	X	X								X		X	X		X	X						X		X			
Stizostedion vitreum	Walleye	X		X								X		X	X		X	X						X		X	X		
Percopsis omiscomaycus	Trout-perch	X	X									X					X									X	X		
Ichthyomyzon bdellium	Ohio lamprey		X	X								X		X		X	X	X						X	X	X	X		
Ichthyomyzon castaneus	Chestnut lamprey	X	X	X								X		X		X	X	X						X	X	X	X		
Ichthyomyzon fossor	Northern brook lamprey		X									X				X	X	X						X	X	X	X		
Ichthyomyzon unicuspis	Silver lamprey	X	X	X								X		X		X	X	X						X	X	X	X		
Lampetra aepyptera	Least brook lamprey	X	X					X		X	X	X	X	X		X	X	X						X	X	X			
Lampetra appendix	American brook lamprey											X				X	X	X						X	X	X			
Polyodon spathula	Paddlefish	X		X	X							X		X	X	X	X	X									X	X	X
Aplodinotus grunniens	Freshwater drum	X	X	X	X							X		X	X	X	X										X	X	X
Umbra limi	Central mudminnow	X	X		X			X		X						X	X				X			X					

Unique and rare aquatic habitats for fishes in the area include cave streams, springs, wetlands, and floodplain lakes and oxbows. An outstanding example of all these habitats in one location is the LaRue-Pine Hills Research Natural Area, Union County, Illinois. Other especially scenic sites and those with excellent water quality and high aquatic diversity and found within the two national forests include the middle Blue River system and portions of the East Fork White River in the Hoosier, and the upper Clear Creek system and Big and Lusk Creeks in the Shawnee.

Mussel Habitat

Most freshwater mussels inhabit permanent flowing bodies of water (i.e., riverine system) but some vary considerably with respect to their microhabitat occurrences (Parmalee 1967, Cummings and Mayer 1992). The aquatic assessment area encompasses a variety of local habitats and environments that support a diverse native freshwater mussel fauna. Those hydrologic units (e.g., lower Ohio, lower Ohio Bay, and lower Ohio-Little Pigeon) that border major ecotones of physiographic regions provide a mixture of hilly upland areas and broad alluvial valleys. Within these areas, habitats ranging from small upland streams to large and small rivers, sloughs, and impoundments (artificial ponds and reservoirs) support a variety of mussel species adapted to different habitat types.

Habitat occurrences of native mussel species recorded within the assessment area are presented in table 9. Species diversity was greatest in those hydrologic units containing portions of medium and large rivers (e.g., lower Tennessee, lower Cumberland, upper Green, and lower Ohio). In fact, 64 percent of the mussel species reported from the assessment area inhabit primarily medium and large rivers. Examples of this riverine mussel fauna include snuffbox, fanshell, plain pocketbook, threehorn wartyback, hickorynut, ring pink, sheepnose, mapleleaf, elephant ear, and ebonyshell. These and other riverine species are generally most successful in sand, gravel, or mixed sand-gravel substrates (table 9). Riverine species (most species in Ambleminae and Lampsilinae, table 9) that live in swift current develop thick shells, heavy hinge teeth, and well-developed muscle insertion scars (Parmalee 1967). In larger rivers, mussel distributions vary with depth, current velocity, substrate composition, and other physical factors affecting their development. For example, according to Parmalee (1967), in fast flowing sections of the Mississippi River, mussels can be found at depths of greater than 15 feet. Williams and Schuster (1989) reported that most mussels in large rivers prefer habitat that has a substrate of sand and fine to coarse gravel in depths of 8 to 20 feet in enough current to prevent excessive siltation.

Native freshwater mussels reported from the assessment area that are particular to creek, headwater, slough, or pond habitats with little or no flow include pondhorn, flat floater, cylindrical papershell, paper pondshell, white heelsplitter, giant floater, and pondmussel (table 9). These species (most species in Anodontinae, table 9) differ morphologically from the riverine species in having thin shells, shallow muscle scars, and reduced or absent hinge teeth (Parmalee 1967). Mussels occurring in lentic habitats in mud or silt substrates also are often limited to shallow water (above the epilimnion) because of their relatively poor tolerance of hypoxia (McMahon 1991). Other mussels are ubiquitous throughout the assessment area and occur in a variety of different habitat types: Wabash pigtoe, threeridge, plain pocketbook, fatmucket, and fragile papershell (table 7). These species have been reported to be adaptable to varying water depths and can tolerate impoundments (Cummings and Mayer 1992, Parmalee 1967).

Crayfish Habitat

Crayfishes in the assessment area occupy all five major habitat types defined and outlined in Hobbs (1981). The assessment area has species that occupy open water habitats, species exhibiting all three types of burrowing behaviors, and those that dwell in cave streams—both troglobites and troglophiles (table 10).

According to Hobbs (1981), open-water dwellers can be found in permanent or nearly permanent lentic and lotic environments. Most construct simple burrows out of benthic debris or seek cover under rocks or coarse woody debris. Although these crayfishes are generally found in the main body of water, all will burrow in the substrate down to the water table to seek cover in the event of loss of standing water due to drought. They also may burrow to avoid freezing in winter. This burrowing behavior is similar to tertiary burrowers (see below). In the assessment area, 18 species of crayfish occupy open-water habitats: 16 of the genus *Orconectes* and 2 of the genus *Cambarus* (table 10). Eight open-water crayfish species are found in the watersheds that drain the Shawnee National Forest. The watersheds draining the Hoosier National Forest are home to only two crayfish species that have been recorded from open-water habitats.

Primary burrowers are crayfish species that excavate a complex system of tunnels that generally contact the water table in at least one place. These species rarely leave their burrows that seldom come into contact with permanent bodies of surface water. Burrows can be located well inland from such bodies of water, a location that may preclude them from protection by forested filter strips designed to minimize the impacts of logging and recreation on national forest watersheds (see below for description of filter strips). Three primary burrowers occur in the assessment area—*Cambarus diogenes*, *Fallicambarus fodiens*, and *Procambarus gracilis* (table 10). All three of these species are found in the watersheds that drain the Shawnee National Forest. Only *C. diogenes* has been reported in watersheds that drain the Hoosier National Forest.

Secondary burrowers dig simple, straight-shafted tunnels in areas that are prone to flood during certain times of the year such as roadside ditches, borrow pits, swamp pools, and other depressions. These burrowers seldom live in saturated areas where the water table is at or near the soil surface for most of the year. The tunnels of secondary burrowers often do not contact the water table but generally are excavated in moist soils ensuring that the relative humidity of the air in the burrow remains near 100 percent. These species may remain torpid in their burrows during times of drought. They also leave their burrows and spend much of the year in open-water habitats, particularly when the low-lying areas in which they live flood. There are two secondary burrowing species in the assessment area—*Cambarus ortmanni* and *Procambarus viaeviridis* (table 8). The latter species is found in the watersheds that drain the Shawnee National Forest. There are no secondary burrowers in the watersheds of the Hoosier National Forest.

Tertiary burrowing crayfishes are those that spend most of their lives in open water but retreat to burrows during periods of inactivity, to hide from predators, to avoid freezing in the winter, to lay and brood eggs, or to avoid desiccation during low water periods. In contrast to the limited burrowing activities of open-water species, tertiary burrowers may construct elaborate burrows that may or may not come into direct contact with open water. Tertiary burrowers maintain their burrows for most of the year whereas open-water species burrow only when absolutely necessary. The demarcation between open-water species and tertiary burrowers can at times be very narrow, hence most species in table eight are listed as both. Nine tertiary burrowing species are found in the assessment area—two in the genus *Cambarellus*, one in the genus *Barbicambarus*, two in the genus *Cambarus*, two in the genus *Orconectes*, and two in the genus *Procambarus* (table 10). Five of those species are found in watersheds that drain the Shawnee National Forest and two are found in the watersheds of the Hoosier National Forest.

Four species of crayfish in the assessment area either must live in caves (troglobitic) or frequent caves (troglophilic) during their lifetimes (table 10). *Orconectes pellucidus* and *O. inermis* are eyeless, non-pigmented, troglobitic species found in caves of karst formations in western Kentucky and south-central Indiana. *Cambarus tenebrosus* is a troglophilic species that frequents rocky headwater streams and springs, hence its common occurrence in caves. *Cambarus bartonii* is found in a diversity of habitats including caves, springs, riffles, stream pools, and rarely impoundments. *Cambarus tenebrosus* is the only cave-dwelling species found in the Shawnee National Forest. *Cambarus tenebrosus* and *O. inermis* are found in watersheds of the Hoosier National Forest. Eberly (1955) listed *O. pellucidus* as occurring in several counties that overlap the Hoosier National Forest, but Hobbs et al. (1977) reported no valid records of this species in Indiana.

Implications and Opportunities

Habitat degradation has been a major factor involved in the decline of freshwater mussel and fish populations. For example, construction of dams, channelization, and improper maintenance of riparian zones have resulted in changes to stream environments that are unfavorable to most mussel and some fish species, including increased sedimentation, changed stream hydrology, and reduced habitat heterogeneity. The use of best management practices for timber harvest and road building would minimize impacts to adjacent streams. To be effective, habitat protection and good conservation practices must also extend beyond the boundaries of Federal lands to include entire watersheds. This requires the cooperation of all agencies that share responsibilities for public watersheds and their faunas, as well as riparian landowners. Empirical studies directed at crayfishes are needed to determine the effects of habitat degradation on them.

The activities and home ranges of both primary and secondary burrowing crayfishes can occur great distances from surface bodies of permanent flowing or standing water. Maintenance of vegetative filter strips of varying widths adjacent to lakes, wetlands, perennial streams, and intermittent streams in which logging, road construction, and recreational activities occur will help minimize the potential negative effects those practices might have on aquatic environments and their inhabitants. Primary and secondary burrowing crayfishes, although aquatic species, should perhaps be considered terrestrial species because of their potential to live well beyond the relative protection of designated filter strips. If these species are not considered terrestrial, specific concessions could be made to ensure monitoring and conservation. Restrictions on road building, logging activities, and recreational activities in areas where crayfish burrows are present might benefit these species. Frequent burrow destruction and soil compaction could hinder crayfish burrowing activity, forcing populations to move or trapping them below ground for potentially lethal lengths of time.

As noted earlier, there are no federally listed crayfishes in the assessment area, but three crayfishes in the Shawnee National Forest are listed as endangered in the State of Illinois—*O. indianensis, O. kentuckiensis*, and *O. placidus*. The Forest Service has specific policies for creating stream and river fords (in association with road building and logging activities) within the national forests to minimize the negative effects of the fords on aquatic ecosystems. Crayfishes are relatively immobile compared to other aquatic organisms (e.g., fishes) and are less able to evade fording vehicles.

Much of the assessment area is underlain by karst formations with numerous caves in limestone and other soluble rock (Culver et al. 1999). Cave ecosystems are fragile and complex and can be severely damaged by: (1) water projects such as damming, diverting, and well drilling; (2) land development such as paving, excavating, and filling; (3) nutrient loss from exclusion or loss of important species; (4) nutrient enrichment from sewage, agricultural runoff, slash from forest cutting, and excessive runoff from logged areas; (5) introduction of exotic and pest species; (6) chemical pollution; (7) overcollection; (8) overvisitation; and (9) isolation caused by fragmentation of cave networks from all factors mentioned previously (Elliot 2000). Although many other terrestrial and aquatic organisms depend on cave habitats for survival, the troglophilic and troglobitic fishes and crayfishes in the assessment area could serve as relatively conspicuous and easily monitored indicator species representing the relative health of the caves of the assessment area. Currently, neither of the two cave-associated crayfish species (i.e., *Orconectes inermis* and *O. pellucidus*), only one of which is documented to occur in the Hoosier National Forest, is listed as a Management Indicator Species (MIS) (table 5). These species could be monitored as an indicator of the effects of logging and recreational activities on caves of the assessment area.

LITERATURE CITED

Abell, R.A.; Olson, D.M.; Dinerstein, E.; Hurley, P.T.; et al. 2000.
Freshwater ecoregions of North America: a conservation assessment. World Wildlife Fund (U.S.). Washington, DC: Island Press. 319 p.

Allan, J.D.; Flecker, A.S. 1993.
Biodiversity conservation in running waters. Bioscience. 43(1): 32-43.

Angermeier, P.L. 1995.
Ecological attributes of extinction-prone species: loss of freshwater fishes of Virginia. Conservation Biology. 9(1): 143-158.

Angermeier, P.L.; Karr, J.R. 1994.
Biological integrity versus biological diversity as policy directives. Bioscience. 44(10): 690-697.

Baker, F.C. 1906.
A catalogue of the Mollusca of Illinois. Bulletin of the Illinois State Laboratory of Natural History. 7(6): 53-136 + 1 map.

Becker, G.C. 1983.
Fishes of Wisconsin. Madison, WI: The University of Wisconsin Press. 1,052 p.

Bull, L.A. 1985.
A creel survey of the commercial and sport trotline fishermen of the Kentucky sections of Kentucky Lake and Lake Barkley. Murray, KY: Murray State University. 64 p. Unpubl. M.S. thesis.

Burr, B.M.; Mayden, R.L. 1992.
Phylogenetics and North American freshwater fishes. In: Mayden, R.L., ed. Systematics, historical ecology, and North American freshwater fishes. Stanford, CA: Stanford University Press: 18-75.

Burr, B.M.; Page, L.M. 1986.
Zoogeography of fishes of the lower Ohio-upper Mississippi River basin. In: Hocutt, C.H.; Wiley, E.O., eds. The zoogeography of North American freshwater fishes. New York, NY: John Wiley & Sons, Inc.: 287-324.

Burr, B.M.; Page, L.M. 1993.
A new species of Percina (Odontopholis) from Kentucky and Tennessee with comparisons to Percina cymatotaenia (Teleostei: Percidae). Bulletin of the Alabama Museum of Natural History. 16: 15-28.

Burr, B.M.; Stewart, J.G. 1999.
Status review, distribution, and aspects of life history of the threatened least brook lamprey, Lamptera aepyptera (Pisces: Petromyzontidae), in Illinois. Final Rep. Springfield, IL: Illinois Department of Natural Resources, Division of Natural Heritage. 25 p.

Burr, B.M.; Warren, M.L., Jr. 1986.
A distributional atlas of Kentucky fishes. Sci. .Tech. Ser. 4. Frankfort, KY: Kentucky Nature Preserve Commission. 398 p.

Burr, B.M.; Cook, K.M.; Eisenhour, D.J.; Piller, K. R.; et al. 1996.
Selected Illinois fishes in jeopardy: new records and status evaluations. Transaction of the Illinois State Academy of Science. 89(3-4): 169-186.

Call, R.E. 1900.
A descriptive illustrated catalog of the Mollusca of Indiana. Indiana Department of Geology and Natural Resources, 24th annual report 1899: 335-535, 1013-1017 [index], pls. 1-78.

Ceas, P.A. 1997.
Systematic studies of the orangethroat darter, Etheostoma spectabile, complex (Percidae; Subgenus Oligocephalus). Urbana-Champaign, IL: University of Illinois, Urbana-Champaign. 161 p. Unpubl. Ph.D. dissertation.

Ceas, P.A.; Page, L.M. 1997.
Systematic studies of the Etheostoma spectabile complex (Percidae; Subgenus Oligocephalus), with descriptions of four new species. Copeia. 1997(3): 496-522.

Cicerello, R.R.; Warren, M.L., Jr.; Schuster, G.A. 1991.
A distributional checklist of the freshwater unionids of KY. American Malacological Bulletin. 8(2): 113-129.

Cicerello, R.R. 2001.
Unpublished spot-distributions maps for the freshwater mussels of Kentucky. Frankfort, KY: Kentucky State Nature Preserves Commission.

Clarke, A.H.; Hovingh, P.; Clarke, J.J. 1999.
A freshwater mussel inventory of four tributary watersheds of the east Fork of White River, Hoosier National Forest, Indiana, with notes on other freshwater mollusks and on amphibians and leeches. Final Rep. Bedord, IN: U.S. Department of Agriculture, Forest Service, Hoosier National Forest, Brownstown Ranger District. 33 p. + maps and field notes.

Cowardin, L.M.; Carter, V.; Golet, F.C.; LaRoe, E.T. 1979.
Classification of wetlands and deepwater habitats of the United States. FWS/OBS-79/31. Washington, DC: U.S. Department of the Interior, Office of Biological Services, Fish and Wildlife Service. 131 p.

Culver, D.C.; Master, L.L.; Christman, M.C.; Hobbs, H.H., III. 1999.
Obligate cave fauna of the 48 contiguous United States. Conservation Biology. 14(2): 386-401.

Cummings, K.S. 1991.
The aquatic Mollusca of Illinois. In: Page, L.M.; Jeffords, M.R., eds. Our living heritage: the biological resources of Illinois. Illinois Natural History Survey Bulletin. 34(4): 428-438.

Cummings, K.S. 2001.
Unpublished spot-distribution maps for the freshwater mussels of Illinois and Indiana. Champaign, IL: Illinois Natural History Survey. [maps]

Cummings, K.S.; Mayer, C.A. 1992.
Field guide to freshwater mussels of the Midwest. Illinois Natural History Survey Bulletin Manual 5. 194 p.

Cummings, K.S.; Mayer, C.A. 1997.
Distributional checklist and status of Illinois freshwater mussels (Mollusca: Unionacea). In: Cummings, K.S.; et al., eds. Conservation and management of freshwater mussels II: initiatives for the future: Proceedings of a UMRCC symposium; 1995 October 16-18; St. Louis, MO. Rock Island, MS: Upper Mississippi River Conservation Committee: 129-145.

Cummings, K.S.; Mayer, C.A.; Page, L.M. 1992.
Survey of the freshwater mussels (Mollusca: Unionidae) of the Wabash River drainage. Tech. Rep. 6. Final Report prepared for Indiana Department of Natural Resources. Indianapolis, IN: Illinois Natural History Survey, Center for Biodiversity: iii + 201 p.

Daniels, L.E. 1903.
A check list of Indiana Mollusca, with localities. Indiana Geological Survey Annual Report. 26: 629-652.

Dimmick, W.W.; Fiorino, K.L.; Burr, B.M. 1996.
Reevaluation of the Lythrurus ardens (Cypriniformes: Cyprinidae) complex with recognition of three evolutionary species. Copeia. 1996(4): 813-823.

Dolloff, C.A.; Hankin, D.G.; Reeves, G.H. 1993.
Basin-wide estimation of habitat and fish populations in streams. Gen. Tech. Rep. SE-83. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 25 p.

Dufford, D.W. 1994.
Illinois 1993 commercial catch report exclusive of Lake Michigan. Springfield, IL: Illinois Department of Conservation. 15 p.

Eberly, W.R. 1955.
Summary of the distribution of Indiana crayfishes, including new state and county records. Proceedings of the Indiana Academy of Science. 64: 281-283.

Eisenhour, D.J. 1997.
Distribution and systematics of Notropis wickliffi (Cypriniformes: Cyprinidae) in Illinois. Transactions of the Illinois State Academy of Science. 90(1-2): 65-78.

Elliot, W.R. 2000.
Conservation of the North American cave and karst biota (Chapter 34). In: Wilkens, H.; et al., eds. Ecosystems of the world, volume 30: subterranean ecosystems. London, UK: Elsevier: 665-689.

Forbes, S.A.; Richardson, R.E. 1909.
The fishes of Illinois. Illinois State Laboratory of Natural History. cxxxi + 357 p. plus separate atlas of 103 maps.

Gerking, S.D. 1945.
Distribution of the fishes of Indiana. Investigations of Indiana Lakes and Streams. 3: 1-137.

Gilbert, C.R. 1969.
Systematics and distribution of the American cyprinid fishes Notropis ariommus and Notropis telescopus. Copeia. (3): 474-492.

Goodrich, C.; van der Schalie, H. 1944.
A revision of the Mollusca of Indiana. American Midland Naturalist. 32(2): 257-326.

Harmon, J.L. 1998.
Finalization of freshwater mussel (Bivalvia: Unionidae) survey of Indiana's East Fork White River Drainage. Final Rep. Indianapolis, IN: Indiana Department of Natural Resources, Division of Fish and Wildlife. 166 p.

Harris, J.L. 1999.
Status of aquatic resources—diversity of mussels. In: Ozark-Ouachita highlands assessment: aquatic conditions. Gen. Tech. Rep. SRS-33. Asheville, NC: U.S. Department of Argriculture, Forest Service, Southern Research Station: 115-132.

Hay, W.P. 1896.
The crustacea of Indiana. Proceedings of the Indiana Academy of Science. 1: 147-151.

Heidinger, R.C. 2000.
Commercial harvest and biology of major freshwater finfish species. In: Martin, R.E.; et al., eds. Marine and freshwater products handbook. Lancaster, PA: Technomic Publishing Co., Inc.: 209-252.

Herkert, J.R., eds. 1992.
Endangered and threatened species of Illinois: status and distribution, volume 2: animals. Springfield, IL: Illinois Endangered Species Protection Board. 142 p.

Hobbs, H.H., Jr. 1981. T
he crayfishes of Georgia. Smithsonian Contributions to Zoology 318. 549 p.

Hobbs, H.H., Jr.; Hobbs, H.H., III; Daniel, M.A. 1977.
A review of the troglobitic decapod crustaceans of the Americas. Smithsonian Contributions to Zoology 244. 183 p.

Hoyt, R.E.; Flynn, R.B. 1974.
Commercial fishery investigations of Rough River and Nolin River reservoirs, Kentucky. Final Rep. Frankfort, KY: Kentucky Department of Fish and Wildlife Resources, Division of Fisheries. 31 p.

Huner, J.V. 1978.
Exploitation of freshwater crayfishes in North America. Fisheries. 3(6): 2-5.

Illinois Biological Stream Characterization Work Group. 1995.
[Map of] Biological stream characterization of Illinois streams. Champaign, IL: Illinois Natural History Survey. 1 map.

Illinois Endangered Species Protection Board. 2000.
Checklist of endangered and threatened animals and plants of Illinois. Springfield, IL: Endangered Species Protection Board. 20 p.

Illinois Natural History Survey Database of Crayfishes. 2001.
Champaign, IL: Illinois Natural History Survey.

Indiana Department of Fish and Wildlife Resources Web site. Viewed March, 2001.
http://www.in.gov/dnr. Web site a service of the Indiana Department of Natural Resources.

Jenkins, R.E.; Burkhead, N.M. 1994.
Freshwater fishes of Virginia. Bethesda, MD: American Fisheries Society. 1,079 p.

Jenkins, R.E.; Lachner, E.A.; Schwartz, F.J. 1971.
Fishes of the central Appalachian drainages: their distribution and dispersal. In: Holt, P.C., ed. The distributional history of the biota of the southern Appalachians, Part III: Vertebrates. Res. Div. Monogr. 4. Blacksburg, VA: Virginia Polytechnic Institute and State University: 43-117.

Johnson, R.I. 1980.
Zoogeography of the North American Unionacea (Mollusca: Bivalvia) north of the maximum Pleistocene glaciation. Museum of Comparative Zoology Bulletin. 149(2): 77-189.

Karr, J.R.; Fausch, K.D.; Angermeier, P.L.; et al. 1986.
Assessing biological integrity in running waters: a method and its rationale. Spec. Publ. 5. Champaign, IL: Illinois Natural History Survey. 28 p.

Kentucky State Nature Preserve Commission Web site. Viewed October, 2001.
http://www.kynaturepreserves.org/reports.html. Endangered, threatened, special concern, and historic plants and animals of Kentucky. [A pdf file].

Layman, S.R. 1994.
Phylogenetic systematics and biogeography of darters of the subgenus Doration (Percidae: Etheostoma). Tuscaloosa, AL: University of Alabama. Ph.D. dissertation.

Lee, D.S.; Gilbert, C.R.; Hocutt, C.H.; Jenkins, R.E.; et al. 1980 et seq.
Atlas of North American freshwater fishes. North Carolina State Museum of Natural History. 867 p.

Lodge, D.M.; Taylor, C.A.; Holdich, D.M.; Skurdal, J. 2000a.
Nonindigenous crayfishes threaten North American freshwater biodiversity: lessons from Europe. Fisheries. 25(8): 7-20.

Lodge, D.M.; Taylor, C.A.; Holdich, D.M.; Skurdal, J. 2000b.
Reducing impacts of exotic crayfish introductions: new policies needed. Fisheries. 25(8): 21-23.

Maxwell, J.R.; Edwards, C.J.; Jensen M.E.; et al. 1995.
A hierarchical framework of aquatic ecological units in North America (Nearctic zone). Gen. Tech. Rep. NC-176. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 72 p.

Mayden, R.L. 1987.
Pleistocene glaciation and historical biogeography of North American central highland fishes. In: Johnson, W.C., ed. Quaternary environments of Kansas. Kansas Geological Survey Guidebook Series 5: 141-151.

Mayden, R.L. 1988.
Vicariance biogeography, parsimony, and evolution in North American freshwater fishes. Systematic Zoology. 37(4): 329-355.

Mayden, R.L.; Burr, B.M.; Page, L.M.; Miller, R.R. 1992.
The native freshwater fishes of North America. In: Mayden, R.L., ed. Systematics, historical ecology, and North American freshwater fishes. Stanford, CA: Stanford University Press: 825-863.

McComish, T.S.; Brown, F.C. 1980.
Distribution and life history notes for fishes of the Hoosier National Forest, Indiana. [Report to agency not indicated]. 225 p.

McMahon, R.F. 1991.
Mollusca: Bivalvia. In: Thorpe, J.H.; Covich, A.P., eds. Ecology and classification of north american freshwater invertebrates. San Diego, CA: Academic Press: 315-399.

Meyer, E.R. 1974.
Unionid mussels of the Wabash, White, and East Fork White rivers, Indiana. Virginia Journal of Science. 25: 20-25.

Missouri Department of Conservation (MO DC). 1997.
Wildlife code of Missouri. Jefferson City, MO: Missouri Department of Conservation. 145 p.

Missouri Natural Heritage Program. 2000.
Missouri species of conservation concern checklist. Jefferson City, MO: Missouri Department of Conservation. vi + 28 p.

Moody, M.W. 2000.
Handling and processing crawfish. In: Martin, R.E.; et al., eds. Marine and freshwater products handbook. Lancaster, PA: Technomic Publishing Co., Inc: 309-322.

Natureserve Web site. Viewed October 2001.
http://www.natureserve.org/. Web site a service of the Association for Biodiversity Information.

Oesch, R.D. 1984.
Missouri Naiads. A guide to the mussels of Missouri. Jefferson City, MO: Missouri Department of Conservation. 270 p.

Page, L.M. 1985.
The crayfishes and shrimps (Decapoda) of Illinois. Illinois Natural History Survey Bulletin. 33(4): 35-448.

Page, L.M. 1991.
Streams of Illinois. In: Page, L.M.; Jeffords, M.R., eds. Our living heritage: the biological resources of Illinois. Illinois Natural History Survey Bulletin. 34(4): 439-446.

Page, L.M.; Burr, B.M. 1991.
A field guide to freshwater fishes. Boston, MA: Houghton Mifflin Co. 432 p.

Page, L.M.; Mottesi, G.B. 1995.
The distribution and status of the Indiana crayfish, Oconectes indianensis, with comments on the crayfishes of Indiana. Proceedings of the Indiana Academy of Science. 104: 103-111.

Page, L.M.; Ceas, P.A.; Swofford, D.L.; Buth, D.G. 1992.
Evolutionary relationships within the Etheostoma squamiceps complex (Percidae; subgenus Catonotus) with descriptions of five new species. Copeia. (3): 615-646.

Parmalee, P.W. 1967.
The fresh-water mussels of Illinois. Illinois State Museum, Popular Science Series 8. 108 p.

Parmalee, P.W.; Bogan, A.E. 1998.
The freshwater mussels of Tennessee. Knoxville, TN: The University of Tennessee Press. 328 p.

Pearson, W.D.; Boston, C.H. 1995.
Distribution and status of the northern cavefish, Amblyopsis spelaea. Final Report to Indiana Department of Natural Resources, Division of Fish and Wildlife, Nongame and Endangered Wildlife Program. 101 p.

Perry, W.L.; Feder, J.L.; Dwyer, G.; Lodge, D.M. 2001.
Hybrid zone dynamics and species replacement between Orconectes crayfishes in a northern Wisconsin lake. Evolution. 55(6): 1153-1166.

Pflieger, W.L. 1971.
A distributional study of Missouri fishes. University of Kansas Publications, Museum of Natural History. 20(3): 225-570.

Pflieger, W.L. 1996.
The crayfishes of Missouri. Jefferson City, MO: Missouri Department of Conservation. 152 p.

Pflieger, W.L. 1997.
The fishes of Missouri. Jefferson City, MO: Missouri Department of Conservation. 372 p.

Poly, W.J. 2001.
Distribution of the alligator gar, Atractosteus spatula (Lacépède,1803), in Illinois. Transactions of the Illinois State Academy of Science. 94(3): 185-190.

Poly, W.J.; Wilson, A.K. 1998.
The fringed darter, Etheostoma crossopterum, in the Cache River basin of southern Illinois (Percidae: Subgenus Catonotus). Ohio Journal of Science. 98(2): 6-9.

Renaker, R.; Carter, B.T. 1968.
The commercial fish harvest in Kentucky during 1965 and 1966. Rep. 25. Frankfort, KY: Kentucky Department of Fish and Wildlife Resources. 25 p.

Robinson, J.W. 1994.
Missouri's commercial fishery harvest, 1992. Jefferson City, MO: Missouri Department of Conservation. 14 p.

Smith, P.W. 1971.
Illinois streams: a classification based on their fishes and an analysis of factors responsible for disappearance of native species. Biol. Notes 76. Champaign, IL: Illinois Natural History Survey. 14 p.

Smith, P.W. 1979.
The fishes of Illinois. Urbana, IL: University of Illinois Press. 314 p.

Standage, R.W. 1999a.
Status of aquatic resources—commercially and recreationally important species (Chapter 2). In: Ozark-Ouachita highlands assessment: aquatic conditions. Gen. Tech. Rep. SRS-33. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 162-171.

Standage, R.W. 1999b.
Status of aquatic resources—management indicator species. In: Ozark-Ouachita Highlands assessment: aquatic conditions. Gen. Tech. Rep. SRS-33. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 171-176.

Strange, R.M.; Burr, B.M. 1997.
Intraspecific phylogeography of North American highland fishes: a test of the Pleistocene vicariance hypothesis. Evolution. 51(3): 885-897.

Taylor, C.A. 2000.
Systematic studies of the Orconectes juvenilis complex (Decapoda: Cambaridae), with descriptions of two new species. Journal of Crustacean Biology. 20(1): 132-152.

Taylor, C.A. 2002.
A new crayfish of the genus Orconectes Cope, 1872 from the lower Ohio River drainage of western Kentucky (Crustacea: Decapoda: Cambaridae). Proceedings of the Biological Society of Washington. 115(1): 129-137.

Taylor, C.A.; Anton, T.G. 1999.
Distribution and ecological notes on some of Illinois' burrowing crayfishes. Transactions of the Illinois State Academy of Science. 92(1-2): 137-145.

Taylor, C.A.; Schuster, G.A. 2001.
Unpublished spot-distribution maps for the crayfishes of Kentucky. Champaign, IL: Illinois Natural History Survey and Richmond, KY: Eastern Kentucky University.

Taylor, C.A.; Warren, M.L., Jr.; Fitzpatrick, J.F., Jr.; et al. 1996.
Conservation status of the crayfishes of the U.S. and Canada. Fisheries. 22(4): 25-38.

Taylor, R.W. 1982.
The freshwater mussels (naiads) of Big Indian Creek, a small southern Indiana tributary of the Ohio River (Bivalvia: Unionidae). Nautilus. 96(2): 66-68.

Timmons, T.J.; Bull, L.A.; Johnson, R.L. 1985.
Trotline fishery survey of the Kentucky sections of Kentucky Lake and Lake Barkley. Project 2-409-R-1, Final Rep. Frankfort, KY: Kentucky Department of Fish and Wildlife Resources, Federal Aid in Fish Restoration. 22 p.

Timmons, T.J.; Hoffnagle, T.; Hale, R.C.; Soldo, J.B. 1989.
Incidence of sport fishes in the commercial fish catch from Kentucky Lake, Kentucky and Tennessee. North American Journal of Fisheries Management. 9: 209-212.

U.S. Department of Agriculture, Forest Service (USDA FS). 1997.
Rare invertebrates, North America. Rep. 15, Washington, DC: U.S. Department of Agriculture, Forest Service, Threatened, Endangered, and Special Concern Program, 212 p. [Based on the report of The Nature Conservancy and the Natural Heritage Central databases].

U.S. Department of the Interior, Fish and Wildlife Service (USDI FWS). 1997a.
Endangered and threatened species: review of plant and animal taxa. Federal Register. 62(182): 49,397-49,411.

U.S. Department of the Interior, Fish and Wildlife Service (USDI FWS). 1997b.
List of endangered and threatened wildlife and plants, May 13, 1997. Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service, Division of Endangered Species. 42 p.

van der Schalie, H.; van der Schalie, A. 1950.
The mussels of the Mississippi River. American Midland Naturalist. 44: 448-466.

Warren, M.L., Jr.; Burr, B.M. 1988.
Reassessment of the Illinois ranges of the bigeye chub, Hybopsis amblops, and the pallid shiner, Notropis amnis. Ohio Journal of Science. 88(5): 181-183.

Warren, M.L., Jr.; Burr, B.M. 1994.
Status of freshwater fishes of the United States: overview of an imperiled fauna. Fisheries. 19(1): 6-18.

Warren, M.L., Jr.; Hlass, L. 1999.
Status of aquatic resources—diversity of fishes (Chapter 2). In: Ozark-Ouachita Highlands assessment: aquatic conditions. Gen. Tech. Rep. SRS-33. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 100-115.

Warren, M.L., Jr.; Tinkle, K. 1999.
Status of aquatic resources—endangered, threatened, and other aquatic species of special concern (Chapter 2). In: Ozark-Ouachita Highlands assessment: aquatic conditions. Gen. Tech. Rep. SRS-33. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 153-162.

Warren, M.L., Jr.; Robison, H.W.; Tinkle, K. 1999.
Status of aquatic resources—diversity of crayfishes (Chapter 2). In: Ozark-Ouachita Highlands assessment: aquatic conditions. Gen Tech Rep. SRS-33. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 132-140.

Warren, M.L., Jr.; Burr, B.M.; Etnier, D.A.; Starnes, W.C. 1991.
Fishes of Kentucky and Tennessee: a hierarchical classification of drainages. Journal of the Tennessee Academy of Science. 66(4): 135-140.

Warren, M.L., Jr.; Burr, B.M.; Walsh, S.J.; et al. 2000.
Diversity, distribution, and conservation status of the native freshwater fishes of the southern U.S. Fisheries. 25(10): 7-29.

Watters, G.T. 2000.
Freshwater mussels: a complicated resource to conserve. In: Abell, R.A.; Olson, D.M.; Dinerstein, E.; et al. 2000. Freshwater ecoregions of North America: a conservation assessment. World Wildlife Fund (U.S.). Washington, DC: Island Press: 37-38.

Weilbaker, C.; Baker, C.D.; Forsyth, B.J.; Christenson, C.M.; Taylor, R.W. 1985.
The freshwater naiads, Bivalvia: Unionidae, of the Blue River, a Southern Indiana tributary of the Ohio River. Proceedings of the Indiana Academy of Science. 94: 687-691.

Weitzell, R.E.; Stewart, J.G.; Burr, B.M. 1998.
Status survey of the least brook lamprey, Lamptera aepyptera (Pisces: Petromyzontidae), a threatened species in Illinois. Final Rep. Springfield, IL: Illinois Department of Natural Resources, Division of Natural Heritage. 26 p.

Wiley, E.O.; Mayden, R.L. 1985.
Species and speciation in phylogenetic systematics, with examples from the North American fish fauna. Annals of the Missouri Botanical Gardens. 72: 596-635.

Williams, F.E.; Neves, R.J. 1992.
Introducing the elements of biological diversity in the aquatic environment. In: Williams, J.E.; Neves, R.J., eds. Reprint of special session 6, biological diversity in aquatic management. Transactions of the 57th North American wildlife and natural resources conference, Wildlife Management Institute. Washington, DC: Wildlife Management Institute: 345-354.

Williams, J.C.; Schuster, G.A. 1989.
Freshwater mussel investigations of the Ohio River: mile 317.0 to mile 981.0. Frankfort, KY: Kentucky Department of Fish and Wildlife Resources. 57 p.

Williams, J.D.; Warren, M.L., Jr.; Cummings, K.S.; et al. 1993.
Conservation status of freshwater mussels of the U.S. and Canada. Fisheries. 18(9): 6-22.

http://endangered.fws.gov/wildlife. 2001.
U.S. listed invertebrate animal species report by taxonomic group. U.S. Fish and Wildlife Service.

http://www.in.gov/dnr/fishwild/endangered/mollusks.htm. 2001.
Indiana endangered Mollusks. Indiana Department of Natural Resources, Division of Fish and Wildlife.

http://www.conservation.state.mo.us. 2001.
Endangered species checklist. Missouri Department of Conservation.