Exotic Aquatic and Terrestrial Animals in the Hoosier-Shawnee Ecological Asessment Area

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ABSTRACT

We reviewed the impact of exotic aquatic and terrestrial wildlife on ecosystems within the Hoosier-Shawnee Ecological Assessment Area. Recent collections within the assessment area have demonstrated that faunal diversity is expanding rapidly from the intentional and unintentional release of nonindigenous species. We report on the origin, status, trends, habitat associations, and distribution of 58 exotic species including 44 fish or invertebrate species, 5 hybrid fish species, and 9 terrestrial vertebrates. The aquatic species include 19 species from the Midwest used in stocking programs, 6 from Asia or Eurasia, 5 from the Gulf coast, 3 from the Atlantic coast, 4 from South America, 2 from the Pacific coast, and 1 from the Southeastern United States. Five of these species are hybrids that originated in aquaculture facilities or hatcheries. Six non-native species were released or stocked in the assessment area in the 1950s, another three in the 1960s, and another fifteen in the 1970s when the releases peaked in the area. Releases and some natural dispersal from origins along the Gulf coast have continued throughout the 1980s, 1990s, and into the 21st century. The majority of exotic terrestrial vertebrates found in the assessment area originated in Europe, Asia, or Africa. Only one species, the house finch, is native to North America. Three species were intentionally introduced to the Eastern United States, four species were intentionally introduced with subsequent escapes resulting in established feral populations, and two species dispersed naturally into the area. All of the terrestrial exotics reviewed in this chapter are well adapted to, and flourish in association with, human habitation.

Table 1. The worldwide number of vertebrate extinctions from major known causes (modified from Cox 1993).

Group	Human exploitation	Invading species	Habitat disruption	Other	Unknown
Mammals	24	20	19	1	36
Birds	11	22	20	2	37
Reptiles	32	42	5		21
Fishes	3	25	29	3	40
Total	70	109	73	6	134
Total percentage of known causes	27.1	42.3	28.3	2.3	

HISTORY OF EXOTIC SPECIES

An important natural resource issue in the Hoosier-Shawnee Ecological Assessment Area is the invasion of exotic species and their ability to alter population, community, and ecosystem structure and function. Exotic/nonindigenous species were defined by the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 as, "The condition of a species being moved beyond its natural range or natural zone of potential dispersal, including all domesticated and feral species and hybrids." Within the United States, exotics have often been purposefully introduced with little consideration of the long-term negative consequences that these species may eventually have on native biotic communities. Although some introductions have had nominal impacts on native populations and habitats, several have caused devastating damage to natural ecosystems. The Congressional Office of Technology Assessment has recorded at least 4,500 species of foreign origin that have established free-living populations within the United States. Approximately 4 to 19 percent of these species cause severe economic or environmental harm, and 6 to 53 percent are estimated to have neutral or unknown effects. Stein and Flack (1996) estimate that 20 species of exotic mammals, 97 species of exotic birds, and 53 species of exotic reptiles and amphibians now inhabit the United States. Nationwide, about $27.5 billion is spent annually controlling these exotic species (Pimentel et al. 1999).

The outright loss of native species is one of the major effects that invasive exotic species have on biodiversity (Nott et al. 1995); globally, invasive exotic species have caused the extinction of at least 109 vertebrate species (Cox 1993). This is a significant percentage of the overall identified causes of vertebrate extinctions (table 1). Exotic species contribute to a significant proportion of listings of threatened and endangered species within the United States. Exotic species have contributed to the decline of approximately 35 percent of listed taxa (U.S. Congress 1993) (fig. 1). Yet, exotic species also have other serious effects on ecosystems including general decline in abundance of native species, change in ecosystem structure and function, and rearrangement of tropic relations.

Although there are exceptions, successful invasive exotic species seem to exhibit one or more

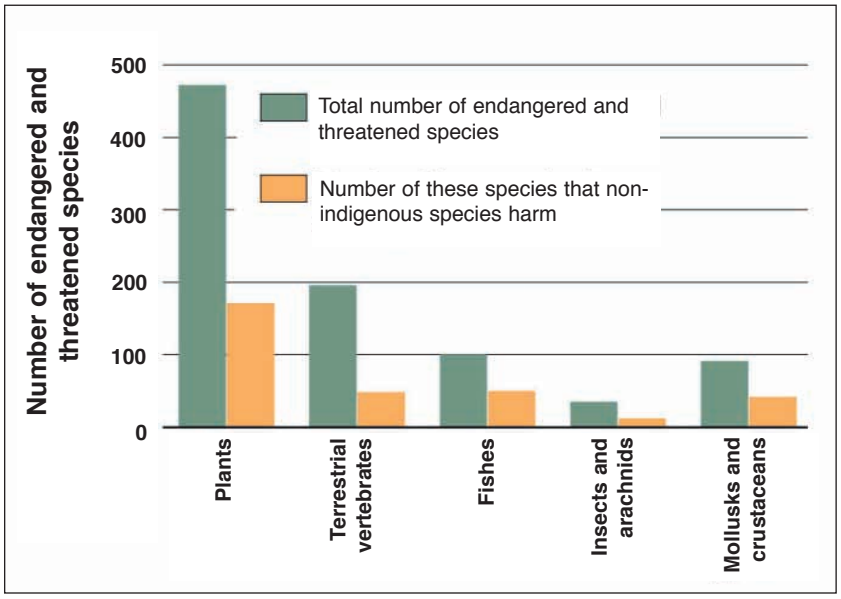


Figure 1. Number of United States species listed under provisions of the U.S. Endangered Species Act of 1973 (U.S. Fish and Wildlife Service 1994) whose status is attributed to threats from nonindigenous species (Office of Technology Assessment 1993).

characteristics that further their establishment and expansion:

Characteristics of Invasive Species:

- High rate of reproduction; pioneer species; short generation time
- Long-lived
- Single-parent reproduction (e.g., a gravid or pregnant female can colonize)
- Vegetative or clonal reproduction
- High genetic variability
- Phenotypic plasticity
- Broad native range
- Tolerant of wide range of conditions
- Habitat generalist
- Broad diet (polyphagous)
- Gregarious
- Human commensal

(Characteristics modified from Ehrlich 1989, Lodge 1993, and Meffe and Carroll 1994.) The presence or absence of these characteristics neither precludes the invasion of a species nor guarantees that a particular nonindigenous invader will succeed. Because the success of invasive exotic species is highly variable, these characteristics can serve only as general guidelines for predicting the success of exotic species.

Ecological communities have characteristics that promote invasion by exotic species:

Characteristics of Communities:

- Climactically similar to original habitat of invader
- Early successional (recently disturbed)
- Low diversity of native species
- Absence of predators on invading species
- Absence of native species morphologically or ecologically similar to invader
- Absence of predators or grazers in evolutionary history
- Absence of fire in evolutionary history
- Low-connectance food web
- Disturbed by humans

(Characteristics modified from Lodge 1993.) The level of human-induced disturbance is one of the most important features that make a community susceptible to invasion by exotic species (Hobbs 1989). Generally, human disruptions of natural communities, through soil alterations, removal of vegetative cover, or suppression of natural disturbance regimes, seem to promote the invasion of a community by nonindigenous species, whereas intact communities may be more difficult to invade. For example, disturbances stemming from dams, water diversions, destruction of riparian habitat, and other factors have greatly enhanced the ability of many nonindigenous fish species to invade riverine ecosystems within the assessment area. And many nonindigenous bird species, including European starlings (*Sturnus vulgaris*) and house sparrows (*Passer domesticus*), flourish in disturbed areas such as cities, suburbs, and farms.

In the United States, the problem of biological invasion began with European colonization over 500 years ago. Colonists introduced species for aesthetic, economic, and recreational reasons. Livestock and nonindigenous food crops essential to survival were the earliest introductions. Many species such as cats and dogs were introduced as domestic animals, but they escaped and established feral populations that cause significant ecological problems. Although much attention has been focused on the effects of invasive plants and insects, the impacts of introduced aquatic and terrestrial vertebrates have often been as great or even greater.

METHODS AND DEFINITIONS

We reviewed primary literature (e.g., Burr et al. 1996, Cabe 1993, Laird and Page 1996), secondary literature (e.g., Burr and Warren 1986, Gerking 1945, Hamilton and Wise 1991), as well as aquatic collections deposited at the Illinois Natural History Survey, and Southern Illinois University at Carbondale and Indiana, Illinois, and Kentucky Audubon Society bird records. Most species reported within this chapter were documented within the past two decades and demonstrate the rapid invasion that often occurs once a nonindigenous species gains access to a new environment. When possible, the date (or decade) and location of the

first observation (i.e., collection) of each nonindigenous species within the assessment area have been included. The mechanism or vector of introduction is defined as the most probable means by which a species was introduced into the assessment area. Some species have invaded by more than one mechanism and are so noted. Although the precise origins of many of the nonindigenous species in the assessment area are not known, a broad geographic origin has been determined. The native range of a species may not necessarily be the source of the assessment area populations of the species. For example, the Asian clam (*Corbicula fluminea*), a native of Asia, was firmly established in western North America before it was discovered in the Midwest. Therefore, we can reasonably presume that the assessment area populations did not originate in Asia, but from some other part of North America.

Transportation mechanisms of exotic aquatic and terrestrial species can be divided into the following four broad categories: natural dispersal, intentional introduction, intentional introductions with subsequent escape, and unintentional introduction. The first category is a natural biological invasion, which is generally considered a range expansion. The other three categories are dependent on human activities.

Intentional Introduction

Intentional introductions are those which nonindigenous species have been transported beyond their native range and released into the wild for establishment. Many of the aquatic and terrestrial species introduced within the assessment area were deliberately imported for aesthetic, sport hunting/fishing, or livestock purposes. The early history of intentionally introduced aquatic and terrestrial wildlife species into the assessment area is mostly lost in obscurity. Federal records, however, indicate that deliberate stocking of fish species such as Atlantic salmon (*Salmo salar*) and common carp (*Cyprinus carpio*) by government fish hatcheries had begun by the early 1870s (Heidinger 1999). Accidental release of other species of fishes, in addition to intended species, is a means through which stocking programs can indirectly and unintentionally introduce non-native aquatic organisms. Stocking to enhance sport fishing now includes the release of about 2.5 billion individual sport fishes annually within the United States and Canada (Heidinger 1999). European starlings, house sparrows, ring-necked pheasants, and feral hogs are all examples of intentionally introduced terrestrial species.

Introduction with Subsequent Escape

Introductions with subsequent escape are those nonindigenous species that are transported beyond their native range under captive conditions from which they later escaped. Subsequently, they may establish reproducing populations; these include the release of aquarium fish, amphibians, and reptiles. The escape of domestic cats and dogs has resulted in free-ranging populations that are widespread throughout the assessment area.

Aquarium

The intentional release of aquarium pets into the aquatic environment is a practice thought to be more humane than other means of disposal. This practice has increased dramatically in the past decade. Pet owners presumably have not intended to establish self-sustaining populations of their pets, yet they knowingly release them into suitable habitat.

Cultivation

The accidental escape of fishes and other aquatic organisms cultured in ponds for sport and commercial purposes, especially on the floodplain of large rivers (e.g., Mississippi River), has resulted in the introduction of thousands of exotic fishes. The major flood of 1993 provided a corridor of dispersal for cultured species in the Mississippi River basin.

Bait

Release of unused bait by anglers and transport of fishes from one drainage to another via fishing vessels are activities through which fish species are introduced into new environments.

Unintentional Introductions

Unintentional introductions are those nonindigenous species that are transported, often without being detected, beyond their native range in the course of some unrelated activity such as zebra mussels (*Dreissena polymorphia*) released in ship ballast water. Other exotic pests, such as rats and mice, have colonized new areas after being transported in cargo holds, shipping containers, produce, and imported forest products.

Ships (ballast water)

By the 1880s, the release of ballast water was a common practice, and as a result, exotic species could have been released into North American ports well before 1900 (Mills et al. 1993). In addition, the opening of the enlarged seaway system on the St. Lawrence River in 1959 dramatically increased opportunities for release of ballast water. This event allowed larger ships and a greater frequency of ships sailing directly from Europe. Since the early 1800s, more than 140 exotic aquatic organisms have become established in the Great Lakes. Roughly one-third of these species have been introduced within the past 40 years, a surge coinciding with the opening of the St. Lawrence Seaway (Great Lakes Information Network 2003).

Canals

In the 1700s, canals began to be built in northeastern North America to help connect adjacent watersheds, dissolving many natural barriers to dispersal of freshwater organisms. Even today the Chicago Sanitary and Ship Canal connects Lake Michigan with the Mississippi River via the Illinois River.

EXOTIC AQUATIC MACROBIOTA

The fishes (table 2, fig. 2) are the best studied group of introduced freshwater organisms in North America (Fuller et al. 1999). Nonindigenous fishes have been released primarily into reservoirs and ponds in 29 cases, hatcheries or aquaculture facilities in 3 cases (mixed stockings), and mainstem rivers in 14 cases, the latter including some natural dispersal. The mechanism of release includes 1) deliberate stocking for sport fishing, 2) unintentional releases by pet owners, anglers, and aquaculture facilities, 3) natural dispersal into the area by way of new waterway canals or by corridors in mainstream rivers that lack structures (e.g., weirs, major dams) that might impede progress, and 4) release of ship ballast water containing nonindigenous aquatic animals (e.g., zebra mussel). The mechanism of release has been deliberate in 29 cases, mostly stocking for sport fishing, and unintentional in 11 cases by pet owners and fishers. Five putative aquarium releases have been recorded as well as five bait-bucket releases and apparently five releases associated with culture ponds or hatchery facilities.

Eighteen species or hybrids have dispersed into the area naturally by way of new waterway canals or by corridors in mainstem rivers that lack structures (e.g., weirs, major dams) that might impede progress. Fifteen fish species have not established self-sustaining populations in the assessment area, but may be abundant seasonally (e.g., rainbow smelt [*Osmerus mordax*]) or have the potential to become established in the foreseeable future. This is especially true if the number of pet releases and the number of power-cooling reservoirs that have unseasonably warm water throughout the year continue to increase. Only four species are reported from the region as casual or waif occurrences, including valid records for the bull shark (*Carcharhinus leucas*). Three aquatic invertebrate species, rusty crayfish (*Orconectes rusticus*), Asian clam, and zebra mussel, are

Table 2. Origin, date, and location of first record, and entry mechanisms and status for nonindigenous aquatic macrobiota of the Hoosier-Shawnee Ecological Assessment Area.

Family	Species	Common name	Origin	Date	Location	Mechanism[1]	Status
Atherinidae	*Menidia beryllina*	Inland silverside	Gulf Coast	1960s	Mississippi River	Introduction (I); Waterway Canals, Dispersal	Established
Belonidae	*Strongylura marina*	Atlantic needlefish	Gulf Coast	1990	Lake Barkley tailwaters, KY	Waterway Canals, Dispersal	Casual/Waif Occurrence
Carcharhinidae	*Carcharhinus leucas*	Bull shark	Gulf Coast	1937	Mississippi River	Dispersal	Casual/Waif Occurrence
Centrarchidae	*Lepomis gibbosus*	Pumpkinseed	N. Midwest States	1970s	Reservoirs, Ponds	Introduction (I)	Reported
Centrarchidae	*Lepomis macrochirus*	Bluegill	Midwest States	1950s	Reservoirs, Ponds	Introduction (I)	Established
Centrarchidae	*Lepomis microlophus*	Redear sunfish	Midwest States	1950s	Reservoirs, Ponds	Introduction (I)	Established
Centrarchidae	*Lepomis macrochirus x L. cyanellus*	Bluegill x Green sunfish	Midwest States	1960s	Reservoirs, Ponds	Introduction (I)	Established
Centrarchidae	*Micropterus dolomieu*	Smallmouth bass	N. Midwestern States	1974	Goreville Reservoir, IL	Introduction (I)	Reported
Centrarchidae	*Micropterus punctulatus*	Spotted bass	SE U.S., Missouri Ozarks	1974	Cedar Lake, IL	Introduction (I)	Reported
Centrarchidae	*Micropterus salmoides*	Largemouth bass	Midwest States	1950s	Reservoirs, Ponds	Introduction (I)	Established
Centrarchidae	*Pomoxis annularis*	White crappie	Midwest States	1978	Reservoirs, Ponds	Introduction (I)	Established
Centrarchidae	*Pomoxis nigromaculatus*	Black crappie	Midwest States	1975	Reservoirs, Ponds	Introduction (I)	Established
Cichlidae	*Cichla ocellatus*	Oscar	South America	1998	Campus Lake, SIUC, IL	Introduction (AQ)	Reported
Clupeidae	*Dorosoma petenense*	Threadfin shad	Gulf Coast	1957	Ohio River	Introduction (I), Dispersal	Established
Cyprinidae	*Carassius auratus*	Goldfish	Eurasia	1953	Horseshoe Lake, IL	Introduction (I, AQ, B), Dispersal	Reported, possibly established
Cyprinidae	*Ctenopharyngodon idella*	Grass carp	Asia	1971	Mississippi River	Introduction (I, C), Dispersal	Established
Cyprinidae	*Cyprinus carpio*	Common carp	Eurasia	1885	Big Muddy River	Introduction (I), Dispersal	Established
Cyprinidae	*Hypophthalmichthys molitrix*	Silver carp	Asia	1983	Mississippi and Ohio Rivers	Introduction (IE, C), Dispersal	Established
Cyprinidae	*Hypophthalmichthys nobilis*	Bighead carp	Asia	1982	Mississippi and Ohio Rivers	Introduction (IE, C), Dispersal	Established
Cyprinidae	*Hypophthalmichthys molitrix x H. nobilis*	Silver x Bighead carp	Culture ponds, Hatcheries	1985	Kentucky Lake, KY	Introduction (IE, C), Dispersal	Reported
Cyprinidae	*Luxilus zonatus*	Bleeding shiner	Ozark Uplands or bait shop	1999	Kinkaid Creek, IL	Introduction (IE, B), Dispersal	Reported
Cyprinidae	*Mylopharyngodon piceus*	Black carp	Asia	1999	Missouri culture pond(s)	Introduction (C)	Reported
Cyprinidae	*Notemigonus crysoleucas*	Golden shiner	Midwest States	1970s	Reservoirs, Ponds	Introduction (IE, B)	Established
Cyprinidae	*Pimephales promelas*	Fathead minnow	N. Midwest States	1981	Reservoirs, Ponds	Introduction (IE, B)	Established
Esocidae	*Esox lucius*	Northern pike	N. Midwest States	1974	Cedar Lake, IL	Introduction (I)	Reported
Esocidae	*Esox masquinongy*	Muskellunge	N. Midwest States	1980	Little Cedar Lake, IL	Introduction (I), Limited Dispersal	Reported, possibly established
Esocidae	*Esox lucius x E. masquinongy*	Tiger muskellunge	Culture ponds, hatcheries	1976	Randolph County Lake, IL	Introduction (I)	Reported (sterile)
Gasterosteidae	*Culaea inconstans*	Brook stickleback	N. Midwest States	2001	Hatcheries	Introduction (IE, B)	Reported
Ictaluridae	*Ameiurus melas*	Black bullhead	Midwest States	1967	Ponds	Introduction (I)	Established
Ictaluridae	*Ictalurus furcatus*	Blue catfish	Midwest States	1990s	Reservoirs	Introduction (I)	Established

(table continued on next page)

(table 2 continued)

Family	Species	Common name	Origin	Date	Location	Mechanism	Status
Ictaluridae	*Ictalurus punctatus*	Channel catfish	Midwest States	1950s	Reservoirs, Ponds	Introduction (I)	Established
Loricariidae	*Pterygoplichthys disjunctivis*	Amazon sailfin catfish	South America	1996	Ohio River	Introduction (IE, AQ)	Reported
Moronidae	*Morone americana*	White perch	Atlantic Coast	1993	Mississippi River	Waterway Canals, Dispersal	Reported, possibly established
Moronidae	*Morone saxatilis*	Striped bass	Atlantic Coast	1974	Ohio River, Reservoirs	Introduction (I), Dispersal	Reported, possibly established
Moronidae	*Morone saxatilis x M. chrysops*	Sunshine/ Palmetto bass	Culture ponds, hatcheries	1970s	Ohio River, Reservoirs	Introduction (I), Dispersal	Reported
Mugilidae	*Mugil cephalus*	Striped mullet	Gulf Coast	1989	Mississippi River	Dispersal	Casual/Waif Occurrence
Osmeridae	*Osmerus mordax*	Rainbow smelt	Atlantic Coast	1978	Mississippi River	Introduction (I), Dispersal	Casual/Waif Occurrence
Percidae	*Etheostoma exile*	Iowa darter	N. Midwest States	2001	Culture Ponds, Hatcheries	Introduction (IE, B)	Reported
Percidae	*Perca flavescens*	Yellow perch	N. Midwest States	1977	Devil's Kitchen Lake, IL	Introduction (I)	Reported, possibly established
Percidae	*Stizostedion canadense x S. vitreum*	Saugeye	Culture ponds, hatcheries	1990s	Ohio River, IN	Introduction (I)	Reported, possibly established
Percidae	*Stizostedion vitreum*	Walleye	PA, N. Midwest States	1974	Cedar Lake, IL	Introduction (I)	Established
Poeciliidae	*Gambusia affinis*	Western mosquitofish	Mississippi River Basin	1981	Ponds	Introduction (I), Dispersal	Established
Salmonidae	*Oncorhynchus mykiss*	Rainbow trout	Western North America	1980	Reservoirs	Introduction (I)	Reported, possibly established
Salmonidae	*Oncorhynchus tshawytscha*	Chinook salmon	Pacific Coast	1978	Kincaid Lake, IL	Introduction (I)	Reported (smolts)
Serrasalmidae	*Piaractus brachypomus*	Redbellied pacu	South America	1992	Little Grassy Lake, IL	Introduction (IE, AQ)	Reported
Serrasalmidae	*Pygocentrus nattereri*	Red piranha	South America	2000	Campus Lake, SIUC	Introduction (IE, AQ)	Reported
Cambaridae	*Orconectes rusticus*	Rusty crayfish	Indiana, Ohio	1960s	Not reported	Introduction (IE, B)	Established
Dreissenidae	*Dreissena polymorpha*	Zebra mussel	Eurasia	1990s	Mississippi and Ohio Rivers	Ships (Ballast Water), Dispersal	Established
Corbiculidae	*Corbicula fluminea*	Asian clam	Asia	1970s	Mississippi and Ohio Rivers	Introduction (IE, AQ), Dispersal	Established

[1] Introduction (I) = Introduction (Intentional); Introduction (IE) = Introduction with escapes; Introduction (AQ) = Introduction (Aquarium); Introduction (C) = Introduction (Cultivation); Introduction (B) = Introduction (Bait).

established in the assessment area (table 2). Only the crayfish is native to the Eastern United States and has been released via bait buckets by fishers. The two clam species originated from Asia or Eurasia and have used the Mississippi and Ohio Rivers as major corridors of dispersal. The zebra mussel is the only species in the assessment area to have been unintentionally released into North American (i.e., Great Lakes) waters from ship ballast water.

The potential ecological effects of nonindigenous species on native aquatic communities include habitat alterations (e.g., removal of vegetation); degradation of water quality; introduction of parasites and diseases; trophic alterations (e.g., increased predation, competition for food resources); hybridization; and spatial interactions (e.g., overcrowding, competition for spawning sites) (Taylor et. al 1984). Greater oversight of exotic and other nonindigenous introductions will be needed in the future with the increasing demands from a growing human population, an expanding aquaculture industry, and changes in cultural values.

At the beginning of the 20th century, the only known established exotic fish in the assessment area was the common carp, (Burr and Warren 1986, Forbes and Richardson 1909, Gerking 1945, Pflieger 1997). There are now over 536 unique fish taxa (i.e., species, reproducing hybrids) introduced outside their native ranges within U.S. waters (Fuller et al. 1999). Likewise, the number of nonindigenous macrobiota introduced into the assessment area and surrounding aquatic systems has increased dramatically in the past decade. Because fish and other aquatic introductions clearly have accelerated, documentation of their current status is warranted.

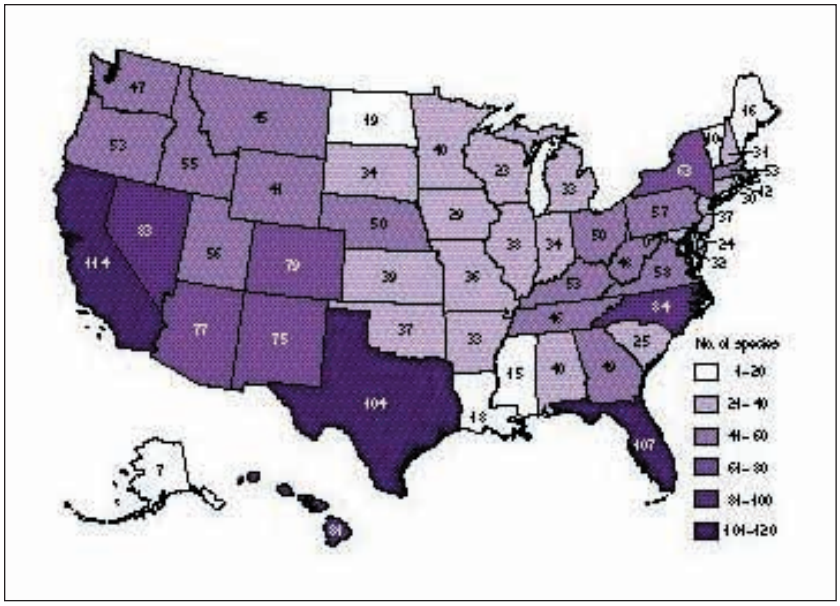


Figure 2. Number of non-indigenous fish species introduced into inland waters of the United States, 1850-1995 (data are from the U.S. Geological Survey, Florida Caribbean Science Center, Gainesville, Florida, March 1995).

Established Non-native and Exoctic Species

White perch, *Morone americana* [Moronidae]

White Perch, an anadromous euryhaline species originally restricted to the North American Atlantic coast, has now become established in many freshwater lakes and rivers. Scott and Christie (1963) reviewed the spread of White Perch into the lower Great Lakes by movement of the species through the Mohawk River Valley and the Erie Barge Canal into Lake Ontario. Johnson and Evans (1990) hypothesized that above-average temperatures during the middle of the 20th century provided a window for white perch to enter the Great Lakes. By 1990-91, white perch had dispersed into the upper Illinois River and the Lake Calumet system. And by 1992, this species was captured near the mouth of the Illinois River. As of 1993-94, white perch had reached extreme southern Illinois via the mainstem Mississippi River, with recent records from the Horseshoe Lake drainage, Alexander County, Illinois.

Other than the Great Lakes, a possible source of white perch in the Mississippi River is via the Missouri River, a result of introductions made into Nebraska lakes beginning in 1964 (Zuerlein 1981). Cross et al. (1986) reported records from the Platte-Niobrara Rivers, and Hesse et al. (1982) reported the species from the middle Missouri River. However, the authors are unaware of any recent records of white perch farther downstream in the Missouri River (see Pflieger 1997).

White perch have reproduced in assessment area waters and may now be an established member of the local fish fauna. The species is reported to spawn in shallow freshwater over a variety of bottom types and often increases rapidly in numbers despite the presence of other established species (Scott and Crossman 1973). The presence of four species of *Morone* (two native and two nonnative) together with stockings of *Morone* hybrids in midwestern rivers (e.g., the Ohio River), is likely to complicate identification of juvenile and subadult representatives of the genus.

In 5 years, white perch dispersed nearly the entire length of Illinois: an outstanding example of how quickly a newly invading species can spread and become established. Only rainbow smelt has been shown to have moved more rapidly downriver in the Mississippi River basin (Mayden et al. 1987) from points of introduction in the upper Missouri River and possibly the Great Lakes.

Striped bass, *Morone saxatilis* [Moronidae]

This anadromous species is native to Atlantic Slope drainages and estuaries of eastern North America and has been widely introduced in the U.S. (Fuller et al. 1999). The striped bass was intentionally stocked by State and Federal agencies in Illinois, Indiana, Kentucky, and Missouri as early as the late 1960s. Beginning in the mid-1970s, adult striped bass were being caught in the Ohio River, some of which escaped over the dams of impoundments. This species is now found in the Wabash and Mississippi Rivers and in a few large reservoirs in or near the assessment area. Although the impact of these stockings has not been established, adults are piscivorous and are capable of getting over the dams of large reservoirs and impacting native fishes in tailwater reaches. There is some evidence that reproduction has occurred in past years, but well-established populations in the assessment area are not known.

Striped mullet, *Mugil cephalus* [Mugilidae]

Burr et al. (1996) reported records of striped mullet for the upper Mississippi River and lower Ohio River basins, noting that this species was known previously only as far north in the Mississippi River as southern Arkansas (Robison and Buchanan 1988). A record from the Mississippi River near the mouth of the Missouri River is the northernmost record known for this otherwise familiar resident of estuaries, salt marshes, and shoreline areas of the Atlantic and Gulf coasts (Etnier and Starnes 1993). The authors speculate that low water levels in the Mississippi River in 1988 and 1989 created water-quality conditions favorable for striped mullet to reach the upper Mississippi River basin. A 1993 record from Kentucky Lake, Tennessee (Etnier and Starnes 1993), suggests that the Tennessee-Tombigbee waterway might be another route of dispersal for this species to reach the mainstems of the Ohio and Mississippi Rivers. Because this species spawns offshore in marine waters, it will never be a persistent component of the fish fauna of the assessment area. Striped mullet is probably best considered a transient or periodic southern invader of midwestern waters.

Rainbow smelt, *Osmerus mordax* [Osmeridae]

Mayden et al. (1987) reviewed the records and literature on the distributional history of rainbow smelt in the Mississippi River basin. They concluded that this species, otherwise unknown from the Mississippi River basin before 1978, reached the lower Missouri River mainstem and lower Mississippi River mainstem from escaped forage stockings in Lake Sakakawea, North Dakota, and some may have originated from Lake Michigan stock. Approximately 7 years elapsed from the initial stock of rainbow smelt in Lake Sakakawea until they were first captured in the free-flowing lower Mississippi River (Mayden et al. 1987). During winter from the late-1970s to the mid-1980s, rainbow smelt was the most common species along the shoreline of the Mississippi River at Grand Tower (Klutho 1983). The status of rainbow smelt in the Mississippi River basin remains uncertain, but its sporadic occurrence over the past two decades in the mainstem suggests that it might best be considered an occasional winter transient.

Rainbow trout, *Oncorhynchus mykiss* [Salmonidae]

The assessment area lacks traditional trout waters, and attempts to develop trout fisheries in the region have typically failed. The most successful rainbow trout fishery is in Devil's Kitchen Lake, Illinois, a Federal property with some deep, cool water. There is no evidence that rainbow trout would survive in the region if they escaped from reservoirs where they are stocked. Limited reproduction and

recruitment may occur, but impacts of introduced populations require additional study and evaluation.

Chinook salmon, *Oncorhynchus tshawytscha* [Salmonidae]

There is apparently only one record of this species having been introduced into a reservoir in the assessment area (table 2). Approximately 4,500 smolts were released in 1978 and there has been no formal record of their status in succeeding years. Because of several life history limitations, the sport fishing potential of this species in relatively warm waters has never been realized.

Rusty crayfish, *Orconectes rusticus* [Cambaridae]

Within the past 25 years, this species has rapidly expanded its range, and the determination of its historical distribution is difficult. It may have occurred natively in the Ohio River basin of Michigan, Ohio, Kentucky, and Indiana (Taylor and Redmer 1995). Introduced populations in the assessment area have not yet been reported, but are expected because of the rapid expansion in many areas of North America (Lodge et al. 2000). This species has spread primarily through bait-bucket releases and is known to alter native crayfish communities through hybridization and habitat alteration (Perry et al. 2002).

Bleeding shiner, *Luxilus zonatus* [Cyprinidae]

Hiland and Poly (2000) first reported the occurrence of the bleeding shiner near the assessment area in Kinkaid Creek, downstream of the Kinkaid Lake dam in southeastern Illinois. The bleeding shiner is native to streams in the nearby Missouri Ozarks, but had never been found east of the Mississippi River. They suggested that the species "could have reached Illinois waters naturally because of the proximity of Illinois to the native range of the species, or the minnow could have been a bait-bucket introduction."

Brook stickleback, *Culaea inconstans* [Gasterosteidae]

Brook stickleback have often been reported in waters far outside their native northern range (Fuller et al. 1999). They are apparently captured incidentally along with fathead minnows in Wisconsin and Minnesota waters and then they are sold in Indiana, Illinois, and Kentucky as part of the bait catch. When anglers are through fishing for the day, they empty their bait buckets, and this species is released unintentionally into the waters being fished. Currently, there are no records of this species spawning in the assessment area, and all records are reports of single individuals.

Iowa darter, *Etheostoma exile* [Percidae]

There are only two records in the assessement area of the Iowa darter, an otherwise common species in northern Midwestern States. One sample was mixed in with other species to be used by a local fish farm, and the other record is from below the dam of Little Grassy Lake, Illinois. When fathead minnows are collected for bait in the wild in Minnesota and Wisconsin and exported to surrounding States, the samples are invariably mixed with other syntopic species (i.e., brook stickleback, central mudminnow [*Umbra limi*]). The fish are sold to local anglers who release the species in their bait buckets directly into the areas they have been fishing. There are no known established populations of this species in the assessment area, even though there are seemingly few biotic factors that would limit reproduction. At present there is no known ecological impact on the local aquatic fauna as a result of release of this species.

Yellow perch, *Perca flavescens* [Percidae]

Stockings of sport fish in reservoirs often contain mixed samples. The yellow perch, a species native to more northern regions in the Midwest, has apparently been accidentally introduced into Devil's Kitchen and Crab Orchard Lakes, Illinois, as well as into Monroe Reservoir, southern

Indiana. The release of rainbow trout and walleye was the original aim of the stockings. Yellow perch have survived, particularly in Devil's Kitchen Lake and Monroe Reservoir where reproduction and recruitment have apparently occurred. Yet, there are no known established populations of this species in lotic systems within the assessment area. The impact of this species in the assessment area has not been studied.

Inland silverside, *Menidia beryllina* [Atherinidae]

In a footnote, Smith (1979) stated that the inland silverside had been found recently in the Mississippi River of southern Illinois from Grand Tower in 1978, indicating that he was unaware of any previous records of this fish in Illinois waters. Pflieger (1975) reported the species to be common in the Mississippi River from the mouth of the Ohio River southward. Since Smith's (1979) report, no additional specimens of the inland silverside were taken in assessment area waters until the 1990s, when the species was found to be common in the lower Ohio River by several independent investigators. The Ohio River records are the first reported for the mainstem. Burr and Adams also recently documented the presence of this species in the lower Big Muddy River. The latter record appears to represent the northernmost extent of this species in the Mississippi River basin. Size ranges of individuals indicate that reproduction has occurred (Stoeckel and Heidinger 1989), and continued capture of this species in free-flowing waters indicates the fish is established permanently in the assessment area.

Inland silverside is abundant in Gulf coastal waters and frequently inhabits pure freshwater rivers and lakes. We assume the Ohio River population of this species has only recently entered the lower mainstem, although it is abundant along both shores of the river. Because of records (1991) from both Kentucky and Barkley reservoirs, it is possible that Inland silverside entered the Ohio River via the Tennessee-Tombigbee waterway that now connects Gulf Coast drainages to the Ohio River (Etnier and Starnes 1993). It is equally possible that the lower Mississippi River population expanded its range after the low water levels of the late 1980s created water-quality conditions (e.g., high dissolved solids) favorable for this species to disperse. Stockings in power-plant cooling reservoirs (i.e., Lake Baldwin and Lake of Egypt, Illinois) to provide forage for sportfishes have occurred in the past few years, but both of these reservoirs are a long distance (in terms of river miles) from capture sites reported here. Shute and Etnier (1994) suggested inland silverside is invading the region from the lower Ohio-Mississippi Rivers and not through the Tennessee-Tombigbee waterway.

Goldfish, *Carassius auratus* [Cyprinidae]

Sporadic occurrences of goldfish, a native of Eurasia, are reported from western Kentucky (Burr and Warren 1986), southern Missouri (Pflieger 1997), and southern Indiana (Gerking 1945). Smith (1979) recorded goldfish as common, especially in the Illinois River drainage but had no records of the species from southern Illinois. Yet, Gunning (1954) captured a specimen from Horseshoe Lake in Alexander County, Illinois, in 1953. Numerous specimens appeared in Southern Illinois University at Carbondale collections from various points in southwestern Illinois following the receding floodwaters of 1993, demonstrating that a number of source pools are now available in the area. All specimens were wild type in color and morphology and almost certainly do not represent the recent release of aquarium stock. It is likely the species invaded southern Illinois with the 1993 flood and took advantage of shallow flooded fields for reproduction and recruitment. Goldfish were originally introduced into North America for ornamental purposes (i.e., public aquaria, fountains).

Grass carp, *Ctenopharyngodon idella* [Cyprinidae]

Grass carp, a native of Asia, was introduced as a means of vegetation control in 1963 into experimental ponds in Arkansas and soon thereafter into impoundments in that State. It escaped almost immediately and dispersed throughout the Missouri-Mississippi mainstem (Pflieger 1978). By 1987 it was established in the Missouri River drainage, Missouri (Brown and Coon 1991). Greenfield (1973) and Stanley et al. (1978) reviewed the literature on the biology of grass carp and noted that it randomly spawns in strong currents of large rivers, apparently in response to rising water levels. Eggs must remain suspended in current for at least 2 days (approximate hatching time), so long reaches of flowing water are required for successful reproduction. These conditions were apparently enhanced during the 1993-94 floodings of the Mississippi River.

For years, triploid grass carp has been stocked into Illinois, Indiana, and Kentucky farm ponds and some lakes to control aquatic vegetation. Commercial fishermen have been catching adults and juveniles from the Mississippi River for over 20 years. The species is clearly established in Midwestern States and is now impossible to eradicate over such a large area. As judged from sampling localities, the lower reaches of four river systems (Illinois, Big Muddy, and Cache Rivers, Clear Creek) in southern Illinois are all serving as apparent spawning or nursery sites. Because triploid grass carp is presumably incapable of producing viable offspring, we conclude that big river diploid stocks are now using nearby waters for some reproduction. Since the floods of 1993 and 1994, adult grass carp is common in both Horseshoe Lake and its outlet, Lake Ceek, Alexander County, Illinois. In the approximately 23 years since grass carp was first reported from Illinois (Smith 1979), evidence for reproduction has occurred only in the last few years, indicating a somewhat lengthy period before establishment.

Aquatic macrophytes dominate the diet of subadult and adult grass carp, although a few studies show consumption of animal matter (Laird and Page 1996). Although the impact of this species in assessment area waters remains to be seen, carp's potential for reducing cover used by a variety of fish species is certainly a potential adverse effect. In addition, excessive removal of aquatic macrophytes from large backwaters could impact waterfowl populations and restructure forage fish communities (Bettoli 1987).

Common carp, *Cyprinus carpio* [Cyprinidae]

The common carp, native to Asia, was transplanted to Europe centuries ago and was eventually introduced to this country as early as 1831 (Fuller et al. 1999). The first stocks were delivered to Midwestern States by government hatcheries in the late-1870s to mid-1880s (Forbes and Richardson 1909). The common carp is now the most successful exotic fish species in North America, occurring in all major river systems, their backwaters, and many ponds, lakes, and reservoirs. This fish is often the dominant species in terms of biomass in many reservoirs and river systems when standard fisheries evaluations are performed. Because this species has been present in the assessment area for well over a century, it has established a reputation for nuisance qualities—bottom feeding in an aggressive manner that fouls water; destroying aquatic vegetation; increasing turbidity; and perhaps eating eggs of other species.

Silver carp, *Hypophthalmichthys molitrix* [Cyprinidae]

This carp, a native of Asia and first introduced into Arkansas in 1973, was then raised and stocked into municipal sewage lagoons. By the early 1980s, the species was reported from the

natural waters of that State (Robison and Buchanan 1988). Sporadic records of this fish were known in Illinois beginning in about 1983, and only occasional specimens began to appear in Southern Illinois University at Carbondale collections and the catches of commercial fishers. In the past 5 years, the silver carp has increased dramatically in abundance and distribution in the Mississippi, Ohio, and Wabash Rivers, as well as in several of their major tributaries. Silver carp and the three other Asian carps now account for the greatest biomass in the mainstem Mississippi River (Chick and Pegg 2001). With its spongelike gill rakers, silver carp is capable of straining organisms as small as 4 microns in diameter and is apparently efficient at digesting green and blue-green algae (Robison and Buchanan 1988). The spawning requirements of this species are similar to that of bighead and grass carps (i.e., spawning occurs when water rises after heavy rains), and capture of several age classes and young-of-the-year in several locations over the past 7 years in southern Illinois, western Kentucky, and southeastern Missouri, is clear evidence of successful spawning in the assessment area. Impacts on natural fish communities and the aquatic environment in general are unknown, but competition for food resources and space with other valued species (i.e., paddlefish, *Polyodon spathula*) is a likely consequence of its recent establishment.

Bighead carp, *Hypophthalmichthys nobilis* [Cyprinidae]

According to Jennings (1988), this native of Asian waters was first introduced into Arkansas in 1972 for use in combination with other phytophagous fishes to improve water quality and increase fish production in culture facilities. It first began to appear in open waters in the early 1980s in both the Ohio and Mississippi Rivers (Jennings 1988). Spawning in Illinois was first documented by Burr and Warren (1993) in the lower Big Muddy River as judged from capture of a postlarval specimen. Recent capture of additional specimens representing young-of-the-year, subadults, and adults strongly suggests that reproduction and recruitment are occurring in the assessment area in the large bordering rivers and their tributaries.

Bighead carp spawn in swift channels of large rivers (Jennings 1988). Flooding of lowland areas is a necessary requirement because these become the nursery areas for larvae and juveniles (Jennings 1988). These fundamental conditions and others summarized in Jennings (1988) were clearly met by major floods in the Midwest and almost certainly account for the recent appearance of postlarvae and juveniles. The large numbers of adults appearing in commercial fishing harvests are also presumably related to flooding, which probably redistributed adults in such a manner as to make them more accessible to fishers. This species is now established in assessment area waters and is capable of using the lower reaches of major Mississippi River tributaries as spawning reaches and nursery areas for larvae and juveniles. The potential impact of this species is not adequately known. The biological interaction of bighead carp with other filter-feeding native fishes such as the paddlefish warrants future investigation.

Asian clam, *Corbicula fluminea* [Corbiculidae]

The Asian clam was first observed in North America in British Columbia in 1924 when dead specimens (shells) were found (Counts 1981). The first live specimens were taken in 1938 on the banks of the Columbia River in Washington State. By the 1970s, huge densities of Asian clams were found at many locations in the Southern United States. (Counts 1986). Mechanisms of dispersal were summarized by Counts (1986) and included transport by birds, accidental transport with sand or gravel, and release as bait or as aquarium specimens. The Asian clam could have been introduced into assessment area waters by any of these means. Most records within the assessment area are

from the mainstem Ohio and Wabash Rivers and their major tributaries.

Zebra mussel, *Dreissena polymorpha* [Dreissenidae]

The zebra mussel is native to European waters and was first discovered in North America in Lake St. Clair in June 1988; it was spreading rapidly throughout the Great Lakes basin and the upper Mississippi River by 1991 (Mills et al. 1993). By the mid-1990s, the zebra mussel had spread throughout much of the Mississippi and Ohio River mainstems and the lower reaches of their major tributaries. This species arrived in the ballast water of transoceanic ships from Europe. Major impacts include bio-fouling and bio-filtering, the former resulting in millions of dollars of damage to boat motors and water-intake systems.

Accidental or Waif Occurrence

Atlantic needlefish, *Strongylura marina* [Belonidae]

The Atlantic needlefish, primarily a marine-estuarine species, is known to penetrate substantial distances into freshwater (Boschung 1989). On 26 November 1990, a 241-mm-long needlefish was captured in the tailwaters of Barkley Dam, Kentucky. The species was collected again in Kentucky Lake, Tennessee, in 1992 (Etnier and Starnes 1993). It has traversed the Tennessee-Tombigbee Waterway to the Tennessee River in Alabama (Mettee et al. 1996) and probably Tennessee. These records represent casual or waif occurrences but demonstrate the dispersal capability of this species and its tolerance for freshwater systems. Subadults prey on fishes and crustaceans (Ross 2001), and the discovery of early juvenile fish hundreds of miles from saltwater indicates almost certain reproduction in freshwater. An established population in the assessment area would likely compete for food resources with other piscivorous species such as the large-mouth bass and muskellunge.

Bull shark, *Carcharhinus leucas* [Carcharhinidae]

This is the only shark species known to ascend freshwaters in North America (Burgess and Ross 1980). An 84-pound specimen, approximately 5 feet long, was commercially captured on September 6, 1937, in the Mississippi River near Alton, Illinois. Other freshwater records occur much farther south in Louisiana and Florida. All evidence available supports the validity of the Alton record (Thomerson et al. 1977). Indeed, another bull shark was taken in the 1990s off the screen of a power plant intake canal. This report does not appear to be the product of a hoax, but there is little information other than a newspaper report. The Alton record is about 2,800 km from the Gulf of Mexico, the probable source of origin. At that time (1937), the Alton Lock and Dam was the first major obstruction to free transit farther up the Mississippi River. Apparently, water temperatures below 24°C limit the movement of sharks up the river (Thomerson et al. 1977). These records are clearly accidental or waif occurrences.

Oscar, *Astronotus ocellatus* [Cichlidae]

Oscars, one of the most popular of aquarium fishes, are native to tropical South America where they are used for both subsistence and commercial fishing. The species has been imported into the U.S. for well over 50 years and has been kept by aquarists interested in spawning and feeding behavior of cichlids. In the winter of 1998, Brooks and Adams found two large adults dead in Campus Lake at Southern Illinois University at Carbondale. These oscars were apparently too large to continue to keep in a home aquarium and were released into the lake as a humane way of discarding a pet. No established population is known, although this species is a voracious predator and could survive in a year-round power-cooling lake such as Lake of Egypt, Illinois.

Threadfin shad, *Dorosoma petenense* [Clupeidae]

The threadfin shad, another primarily marine-estuarine species, first appeared in Tennessee River impoundments in the late 1940s and had been captured at several stations along the Ohio River mainstem from Louisville to Cairo by the late 1950s (Minckley and Krumholz 1960). It is now established in the lower Ohio and Wabash Rivers and occurs above St. Louis, Missouri, in the Mississippi River (Pflieger 1997). It has been and continues to be extensively stocked in reservoirs of the assessment area, primarily as a forage species for piscivorous sport fishes. Young-of-the-year may spawn, but the species winterkills at temperatures below 8°C (Heidinger 1999). The species is planktivorous and competes for food resources with the young of many native species that rely on plankton as their primary food source (Laird and Page 1996). Threadfin shad is an excellent example of a euryhaline species, which by natural dispersal, acclimatization, and stocking, has greatly expanded its historical range and abundance.

Black carp, *Mylopharyngodon piceus* [Cyprinidae]

Black Carp, another native of Asia, has not been found in the waters of the assessment area. Fuller et al. (1999) reported the escape of at least 30 adults into the Osage River, Missouri, following the flooding of a hatchery pond near Lake of the Ozarks. Yet, none of these black carp were ever recaptured. Southern Illinois University at Carbondale received 13 frozen black carp that had been seized from a pond owner in Missouri, but no other natural occurrences in the Midwest are known. The black carp is superficially similar to grass carp, especially the young, and all grass carp specimens warrant careful examination to be certain that black carp is not present. Black carp has significant potential to negatively impact native aquatic communities by consuming unionid mussels and snails, many of which are endangered (Fuller et al. 1999).

Amazon sailfin catfish, *Pterygoplichthys disjunctivus* [Loricariidae]

In 1995, fisheries biologists with the State of Kentucky captured and photographed this species from a boat ramp on the Ohio River at New Albany, Indiana (River Mile 608.6). Sailfin catfishes originate from neotropical South America, and this species is common in the ornamental fish trade. There seems little doubt that the captured individual was released by a pet owner at a convenient location. This fish will most likely not survive the low winter temperatures within the assessment area, but the species has established populations in Florida and probably Texas (Fuller et al. 1999).

Red-bellied pacu, *Piaractus brachypomus* [Serrasalmidae]

Piaractus is native to South American freshwaters and serves as a valuable food fish and a significant part of the ornamental fish trade. Since 1993, Southern Illinois University at Carbondale has obtained specimens representing this species from several lakes within the assessment area, yet they know of no fish farms in the vicinity that raise this species or of any State or Federal agency that would be releasing this exotic into public waters. Apparently, humans have released their aquarium pets, which were probably too large for their aquaria, into nearby lakes rather than euthanizing them. Pacu almost certainly winterkill at this latitude, and there is no reason to expect it to become established in north temperate waters. A single fish taken on a trotline, Mississippi River, south of Chester, Randolph County, Illinois, September 1988 (Chester Herald Tribune 1988), was reported as a piranha, but the accompanying photograph shows it to be *Piaractus*. An additional newspaper account (Anonymous 1994) of an angler catch of this fish (reported as a 14-inch piranha) in September 1994 is from Lake Baldwin (Kaskaskia River drainage), Randolph/St. Clair Counties, a power-plant cooling lake that

maintains relatively warm water throughout the year. It is possible that this species could survive and become established in lakes of this type. Because the species strongly resembles some species of piranha (e.g., *Serrasalmus* and *Pygocentrus*), the capture of specimens by anglers often is reported in newspaper accounts and causes undue alarm among swimmers and boaters.

Red piranha, *Pygocentrus nattereri* [Serrasalmidae]

In fall 2000, a student at Southern Illinois University caught a red piranha on hook and line in Campus Lake. This record and others in newspaper accounts are apparently the result of aquarium releases. As noted above, piranhas are most frequently confused with the seed and fruit-eating pacus. The introduction of a pair of piranhas into one of the power-cooling lakes in the assessment area could result in an ecological disaster because the species'potential for survival, reproduction, and recruitment would be formidable in a warm-water lake.

Introduction of Native Species

Stocking is a long-standing approach to aquatic resource management within the assessment area. Initially, most fish stockings were undertaken to improve recreational or commercial opportunities, with little or no consideration given to the effect of introduced species on the ecosystem. As our knowledge and understanding of the effects of stocking programs on fishes and aquatic systems have expanded, questions related to fish stocking have become increasingly complex (Li and Moyle 1993, Moyle et al. 1986). Factors such as biodiversity, genetic conservation, and interspecific and intraspecific interactions are now increasingly major components of stocking programs. Within the assessment area, numerous exotic and native species have been introduced and become a vital component of aquatic systems. Although species native to the area are frequently released into water bodies, the stock supplied is often not from local populations. The following species are consistently stocked in the assessment area, but the stock may not be native and could affect genetic level biodiversity.

Pumpkinseed, *Lepomis gibbosus* [Centrarchidae]

This species is present in ponds on the Crab Orchard National Wildlife Refuge, Illinois, where at least one population has been established for many years. Pumpkinseeds, native to more northern waters, have appeared in a small number of samples from other ponds in the assessment area and provide a localized fishery. Neither Federal nor State biologists have regularly stocked this species in the assessment area; its origin in the area is not accurately known.

Bluegill, *Lepomis macrochirus* [Centrarchidae]

A native species, bluegills have been stocked every year into numerous ponds, lakes, reservoirs throughout much of the assessment area since at least the mid-1950s. Bluegills are native to the Midwest but may become stunted in small ponds and are known to limit recruitment of largemouth bass (Heidinger 1999).

Redear sunfish, *Lepomis microlophus* [Centrarchidae]

Similar to the bluegill, redear sunfish have been extensively stocked throughout the assessment area in farm ponds, city lakes, reservoirs, pay lakes, and other standing water bodies. The historical range of this species apparently included much of the assessment area; this species is supplementally stocked into aquatic systems where it occurs naturally.

Smallmouth bass, *Micropterus dolomieu* [Centrarchidae]

This species is native to the assessment area in Illinois, Indiana, Kentucky, and Missouri. It has been stocked into reservoirs in southern Illinois and into the Patoka Reservoir in southern

Indiana. A fishery has never developed in southern Illinois. Smallmouth bass stocking is included in the management plans for small ponds in the Hoosier National Forest, Indiana. Natural stream fisheries are known in both the Green River, Kentucky, and a number of streams in southern Indiana.

Spotted bass, *Micropterus punctulatus* [Centrarchidae]

Native populations of spotted bass are known from selected stream systems in the assessment area, including southern Illinois, southern Indiana, and western Kentucky. Some stocking of this species has occurred in the past in southern Illinois and probably other parts of the assessment area. Unintentional stockings of hybrids between largemouth and spotted bass have also occurred within the assessment area.

Largemouth bass, *Micropterus salmoides* [Centrarchidae]

Probably the most popular sport fish in the assessment area, largemouth bass are native to the region and virtually ubiquitous. They have been stocked consistently every year since at least the mid-1950s into nearly every kind of standing water body available, either officially by both State and Federal agencies or by otherwise well-meaning anglers. The largemouth bass is a major predator in lentic systems and competes with other sport and non-sport fishes for space and food. It is no longer possible to understand the ecological place of this species in natural fish communities because its size, numbers, food base, and space have been manipulated by humans in too many locations for over 50 years.

White crappie, *Pomoxis annularis* [Centrarchidae]

White crappie are common and widespread throughout the assessment area, and they are among the most popular of native sport fishes. They have been sporadically stocked into some reservoirs and farm ponds, but they often overpopulate and show poor recruitment (Heidinger 1999). Unintentional stocking of hybrids between the white and black crappie has occurred in some reservoirs.

Black crappie, *Pomoxis nigromaculatus* [Centrarchidae]

There are few records of deliberate stocking of black crappie in the assessment area. Black crappie, like white crappie, are native to the region but tend to occur in lower numbers where the two are syntopic. Most crappie anglers pursuit white crappie, but a fishery exists for the black crappie as well.

Golden shiner, *Notemigonus crysoleucas* [Cyprinidae]

Golden Shiners are native to the assessment area but are also the most commonly sold bait minnow in the region. The species is commercially produced in ponds and sold as bait throughout the Midwest and as forage for sport fish in farm ponds. Adults may compete for food and space with young sunfish and bass species.

Fathead minnow, *Pimephales promelas* [Cyprinidae]

The fathead minnow is a commonly produced bait minnow sold throughout much of the Eastern Unites States. In Midwestern States, it is native to riverine and lacustrine habitats primarily north of the assessment area. Historical, prestocking era records are largely lacking (Burr and Warren 1986, Gerking 1945, Pflieger 1997, Smith 1979) for the assessment area, and the presence of this species may even be the result of bait-bucket release. Illinois State hatchery records indicate that the species has been stocked periodically as forage in reservoirs since at least the 1960s. Fathead minnows are commonly released into fishing waters by anglers who empty their bait buckets after finishing their daily angling.

Northern pike, *Esox lucius* [Esocidae]

In the 1970s, northern pike were stocked in a few reservoirs in southern Illinois (i.e., Cedar

Lake, Kinkaid Lake) and southern Indiana (i.e., Monroe Reservoir, Indian Lake) for sport fishing. Reproduction apparently occurred in Kinkaid Lake for the first couple of years, but recruitment was negligible. Some stock has been released in privately owned strip-mine lakes in southern Illinois and western Kentucky. Since the 1970s, there have been no more deliberate State or Federal stockings in Illinois; the authors are unaware of an established population in the assessment area. This species is native to northern Indiana and Illinois in both lakes and streams and is a major predator on other fishes.

Muskellunge, *Esox masquinongy* [Esocidae]

Historically, the muskellunge occurred in the Ohio River basin, and a few native populations still exist in the Green River, Kentucky (Burr and Warren 1986). McComish and Brown (1980) indicate that anglers may have taken this species within the Hoosier National Forest boundaries and nearby areas into the 1960s. Stocking programs exist within all the States in the assessment area, but in most cases native Ohio basin muskellunge have not been used as stock.

Black bullhead, *Ameiurus melas* [Ictaluridae]

In the 1950s and 1960s, this species was occasionally stocked into farm ponds, city reservoirs, and other urban fishing sites. The black bullhead is native to the Midwest, but in artificial settings it may overpopulate, reproduce at small sizes (15 cm), and develop stunted individuals (Heidinger 1999). Within the assessment area, no known stocking programs are maintained by State or Federal agencies for this species.

Blue catfish, *Ictalurus furcatus* [Ictaluridae]

Over the past decade, blue catfish have been stocked in reservoirs within the assessment area. The species is native to the region, and large natural populations are known in the Ohio, Mississippi, and Wabash Rivers where a fishery has developed for anglers and commercial fishers. The success of these stocking programs is not adequately known, and a notable fishery for this species in reservoirs has not yet developed.

Channel catfish, *Ictalurus punctatus* [Ictaluridae]

The channel catfish is easily the most widely stocked catfish species in the assessment area. Each year, this catfish has been deliberately released throughout the assessment area into ponds, reservoirs, city lakes, pay lakes, and other sites since at least the 1950s. The recent growth of the aquaculture industry in southern Illinois and southern Missouri now supports hundreds of acres of ponds for channel catfish culture, and cultured stock is often sold in restaurants throughout the region. Channel catfish are native to the assessment area, and many established riverine and lacustrine populations are known.

Walleye, *Stizostedion vitreum* [Percidae]

Since the mid-1970s, walleye have been stocked as eggs, fry, or fingerlings into several reservoirs in the assessment area. They continue to be stocked as of this writing, although a notable fishery has not been established in any of the reservoirs (e.g., Kinkaid Lake, Illinois; Patoka Lake, Indiana) that have received continued releases. The species is considered native to the region, but stocked walleyes originated from lakes in Pennsylvania and States other than the Midwest. Adult walleye prey on fishes and crayfishes and may reduce the forage base in large reservoirs or consume the young of other desirable species.

Western mosquitofish, *Gambusia affinis* [Poeciliidae]

The western mosquitofish is native to the assessment area and is often abundant in lowland water bodies. The species' reputation for consuming larvae of various mosquito species has resulted in introductions around the world. It has been released annually into urban and rural ponds to help reduce mosquito

populations in cities and to provide some forage for predatory fishes. Western mosquitofish have been deliberately released into ponds in the assessment area, but official releases have been minimal. Undocumented introductions have undoubtedly occurred and may account in part for the current abundance of this species.

Hybrids

At least five hybrid combinations (bluegill x green sunfish, silver carp x bighead carp, northern pike x muskellunge [tiger muskellunge], striped bass x white bass [sunshine bass & palmetto bass], sauger x walleye [saugeye]) of fishes have been stocked or deliberately released into the assessment area or now occur in the assessment area due to dispersal of individuals stocked in other locales. All of these species except for the carp hybrid have been released to improve sport fishing. The bluegill x green sunfish hybrid was released for many years during the 1960s and 1970s into farm ponds and some reservoirs but rarely has been stocked in the past decade. The tiger muskellunge was released into a reservoir in the 1970s, but the success of that stocking is not known and no other deliberate releases have been reported. The sunshine and palmetto bass hybrids have been most successful in the Ohio River and a few reservoirs where large numbers have been released for many years since the mid-1970s. This combination is potentially fertile and will backcross. The saugeye has been released primarily into the Ohio River. Adults are fertile and will backcross (Heidinger 1999). This hybrid may produce a fishery where walleye stocking has failed to do so. Because the hybrid phenotype cannot always be distinguished from the parentals, identification of hybrids to establish fishing records has been problematical, usually involving the taking of tissue samples for genetic analysis. The occurrence of a single carp hybrid is only a report, and there is no indication that more have been released or that this hybrid is established and spreading.

EXOTIC TERRESTRIAL VERTEBRATES

Exotic terrestrial vertebrates can affect ecosystem-level changes that alter water, nutrient, and energy cycles; productivity; and biomass. Ecosystem-level consequences may directly affect human health. One estimate places the cost of environmental damage and associated control of exotic mammal and bird species in the U.S. at over $36 billion annually (Pimentel et al. 1999). This figure may underestimate the true cost, because this analysis included only the direct "losses and damages" and "control costs;" not the lost ecosystem services. Also, the costs related to invasive species control are increasing as nonindigenous species continue to spread at accelerating rates.

In addition to these economic impacts, ecological impacts such as competition are serious problems associated with exotic species. Nonindigenous species may compete with native species for many things including food and nesting sites. For example, Muscovy ducks introduced into the range of wood ducks may displace them from their tree cavity nests (Bolen 1971). Exotic terrestrial species may also degrade habitat for native wildlife and introduce diseases, pathogens, or parasites that can spread to native wildlife

European Starling (*Sturnus vulgaris*)

The European starling was intentionally introduced into North America during the 19th century from Europe. Although several early attempts failed, the introduction of approximately 100 birds in Central Park in the 1890s was extremely successful (Laycock 1966). Population growth and range expansion for this species were explosive, and the population of starlings has grown to about 200 million (Cabe 1993). Starling populations now appear to be leveling off or even decreasing throughout most areas of the country (Robbins 2001). The spectacular success of this species is linked to anthropogenic

landscape changes. Due to their highly plastic foraging and nesting habits, starlings successfully nest and roost in urban areas and they are also taking greater advantage of agricultural areas than most native birds. In fact, the total agricultural loss due to starlings in the U.S. is estimated at $800 million/year (Pimentel et al. 1999).

Economic losses associated with starling depredation of agricultural crops is only one problem associated with this species. Starlings also compete with native species for food and nesting cavities. The displacement of native bird species by European starlings has been documented in areas of the country with limited nest sites (Weitzel 1988). Starlings aggressively compete with other cavity nesters including woodpeckers, buffleheads, great crested flycatchers, tree swallows, purple martins, eastern blue birds, and others (Cabe 1993). Starlings frequently use nest cavities recently excavated by woodpeckers, driving flickers, red-headed woodpeckers, and red-bellied woodpeckers from their nests. The lower reproduction and fecundity of red-bellied woodpeckers due to nest cavity competition with starlings have been documented (Ingold 1994, 1996). Starlings also usurp nest cavities from native secondary cavity nesting species; the nesting habits of starlings have been linked to declines in bluebird populations (Zeleny 1976).

The spread of disease by starlings is a potential threat within the assessment area. European starlings can carry diseases that are transmissible to livestock and to people, including transmissible gastroenteritis (a swine disease), blastomycosis, and salmonella. Gautsch et al. (2000) found that European starling droppings contained *Campylobacter jejuni*, *Listeria monocytogenes*, and *Chlamydophila psittaci*, all of which are human pathogens. However, the study concluded that the starling droppings were not a significant source of human infection. Within the U.S., starling droppings provide a growth medium for *Histoplasma capsulatum*, the fungus that causes histoplasmosis in humans. Spread of disease among wildlife is another facet of this problem that has not been adequately explored.

The European starling first became established in the assessment area in the 1930s (Cabe 1993). Initially exhibiting explosive population growth, the population levels have been stabilized in the area since the beginning of the Breeding Bird Survey in 1966 (table 3, Sauer et al. 2001). The assessment area falls within the region with the highest number of starling detections per survey route (Sauer et al. 2001). The population levels are most likely due to the high interspersion of agriculture and forests: ideal conditions for breeding starlings.

House Finch, *Carpodacus mexicanus*

Although the house finch is native to western North America, it is considered an exotic species in the Eastern United States. In fact, the spread of the house finch in the eastern part of its current range has been termed “one of the most notable ornithological events of the twentieth century” (Hill 1993). Shipped from California, a few illegally captured birds were released on Long Island, New York, in 1940 (Elliot and Arbib 1953). The house finch has quickly spread throughout the East, becoming a common bird of urban and suburban areas.

Currently, the exotic house finch breeds throughout most of the Eastern United States in addition to its native range west of the prairies (Hill 1993). In the East, the species is seldom found away from human habitation and is a common sight at back yard bird feeders. The house finch has experienced phenomenal population growth in the assessment area since 1966 with annual increases averaging between 20 and 40 percent (table 3). This remarkable growth rate has been possible due to the fecundity of the species. In addition, house finches have benefited from human alteration of the landscape (Hill 1993). Within its native range, the house finch prefers early successional and edge

Table 3. Entry mechanisms and population trends for exotic bird species of the Hoosier-Shawnee Ecological Assessment Area based on Breeding Bird Survey (Sauer et al. 2003) results for two physiographic regions that broadly overlap the assessment area. The number in parentheses is the estimated percent change per year for the entire time period.

Species	Mechanism	Population trends		
		1966-1979	1980-2000	1966-2000
European starling				
Highland Rim	Introduction (I)	Decrease[3]	Increase[2]	Stable[4] (0.6)
Lexington Plain	Introduction (I)	Stable	Stable	Stable (0.9)
House finch				
Highland Rim	Introduction (I)	---	Increase[2]	Increase[2] (29.6)
Lexington Plain	Introduction (I)	---	Increase[2]	Increase[2] (15.0)
House sparrow				
Highland Rim	Introduction (I)	Stable	Decrease[3]	Decrease (-2.5)
Lexington Plain	Introduction (I)	Decrease[3]	Decrease[3]	Decrease[3] (-4.2)
Rock dove				
Highland Rim	Introduction (I)	Increase[2]	Decrease[3]	Stable (-0.8)
Lexington Plain	Introduction (I)	Increase[2]	Decrease[3]	Stable (-1.5)
Cattle egret				
Highland Rim	Dispersal	---[1]	Increase[2]	Increase[2] (4.2)
Lexington Plain	Dispersal	---	---	---
Eurasian collared-dove				
Highland Rim	Dispersal	---[1]	Increase[2]	Increase[2] (48.0)
Lexington Plain	Dispersal	---	---	---

[1] Indicates insufficient data to determine trend.
[2] Indicates significant positive trend during the time period.
[3] Indicates significant negative trend during the time period.
[4] Indicates no significant change in relative abundance.

habitats (Salt 1952). This landscape feature is extremely common around human settlements in the East.

Because of their fidelity to human-dominated landscapes, house finches seldom compete with native species away from feeding stations. They dominate American goldfinches at bird feeders; however, this interaction does not appear to impact goldfinch populations in the assessment area (Hamilton and Wise 1991). Interestingly, for house finches, the greatest number of interspecific interactions occurs with another exotic, the house sparrow. House sparrows actively take over house finch nests and dominate back yard feeders (Bergtold 1913, Evenden 1957)

A postscript to the exotic house finch's success in the Eastern United States: a form of conjunctivitis, first reported in eastern populations in 1994, had spread throughout the eastern range of the species by 1997 (Fischer et al. 1997). The gregarious nature of the house finch at feeding stations and its migratory habits in the Eastern United States have been listed as contributing factors in this epizootic (Roberts et al. 2001). The disease is severe and can ultimately lead to death of the infected individual. In fact, the rapid spread of the disease has led to recent declines in eastern house finch populations (Sauer et al. 2001). To date, the only native bird species that appears to be significantly

susceptible to this form of conjunctivitis is the American goldfinch, although the disease has been observed much less frequently in this species (Ley et al. 1997). The ultimate implications of this disease for the house finch and native passerines have not yet been determined.

House Sparrow, *Passer domesticus*

Much like the European starling, the house sparrow was introduced to the U.S. from England. Unlike the starling, the house sparrow, first introduced in 1851 in New York, was aided in its expansion across North America by additional introductions and translocations from established populations (Robbins 1973). By 1910, this species was well established across the continent. The house sparrow now has a nearly global distribution, although in many parts of its range it is seldom seen far from humanmade structures (Lowther and Cink 1992). In North America, some of the highest population levels for house sparrows are attained in the Midwestern U.S. including Illinois and Indiana (Summers-Smith 1988).

The North American population of house sparrows was estimated at 150 million in 1943 (Wing 1943). Yet, the population currently appears to be stable or even decreasing in most areas of the country (Robbins 2001). This decline is also evident within the assessment area (table 3). Lowther and Cink (1992) suggest that the decline of house sparrows is linked to changes in farming practices after World War II from small plots surrounded by hedgerows to large monocultures and clean farming, a change that has also impacted native wildlife.

Many problems associated with the starling are also a concern with house sparrows. House sparrows have been documented to usurp cavities from red-bellied and red-headed woodpeckers (Ingold and Densmore 1992). In addition to native woodpeckers, house sparrows have been known to harass a wide variety of native birds, including robins, Baltimore orioles, yellow-billed cuckoos, and black-billed cuckoos. However, the propensity to displace native bluebirds, wrens, purple martins, and cliff swallows from their nesting sites is perhaps of greater importance (Laycock 1966, Long 1981, Roots 1976).

Rock Dove, *Columba livia*

The rock dove, a native of Africa and Eurasia, was first domesticated around 4,500 BC with domestics transported around the world by humans (Soccinka 1982). The species was first introduced in North America at Port Royal, Nova Scotia, in 1606 and quickly became established as feral populations (Schorger 1952). Rock doves have flourished in human-dominated areas throughout the world including North, Central, and South America, the Hawaiian Islands, and parts of the West Indies. The rock dove is common throughout the assessment area and is found primarily nesting in or on human structures in human-dominated areas. The rock dove was not included in any formal population census until the BBS began in 1966. In the sixties, the population experienced an increase, but the rock dove population has been stable within the region over the last four decades (table 3).

The primary concern with regard to the rock dove is competition with native cliff nesting species. In addition, their acidic feces eats away gutters and other metal structures, erodes stone buildings, and burns lawns. Rock dove droppings harbor a variety of diseases and parasites that can spread to native wildlife and humans. Amongst the many diseases they carry are aspergillosis, equine encephalitis, influenza, chlamidiosis, toxoplasmosis, and tuberculosis (Schnurrenberger and Hubbert 1981).

Cattle Egret, *Bubulcus ibis*

Cattle egrets are native to Africa and Asia, and the nature and success of their almost worldwide range expansion has been well documented. Cattle egrets spread from the west coast of Africa in the late 1800s across the Atlantic

Ocean to the coastal area of northeastern South America (Telfair 1994). The species then spread northward into North America. In the United States, cattle egrets were first sighted in southern Florida in 1941 (Owre 1973). Since that time, the species has been observed in all 50 States. Within the assessment area, Indiana is the only State that does not have confirmed breeding. A reasonable explanation for the recent and rapid expansion of the cattle egret in the Western Hemisphere is human conversion of large pasture for livestock production along with the dispersal abilities of the species (Telfair 1994).

Cattle egrets are named because of their habit of feeding on insects disturbed by grazing host animals such as cattle (Telfair 1994). Because of this distinct niche, they do not compete with native wading birds for food. There is potential for nest site competition at breeding colonies, however, especially in the northern part of their range where cattle egrets and native ardeids breed around the same time (Burger 1978). Despite this, cattle egrets may attract other colonial waterbirds to formerly unused inland breeding sites (Telfair 1980), thus expanding potential nesting resources for native species. However, within nesting colonies, the deposition of cattle egret guano changes soil chemistry. Although some plant species such as hackberry (*Celtis occidentalis*) can survive the changes, others such as oak (*Quercus* sp.) are killed.

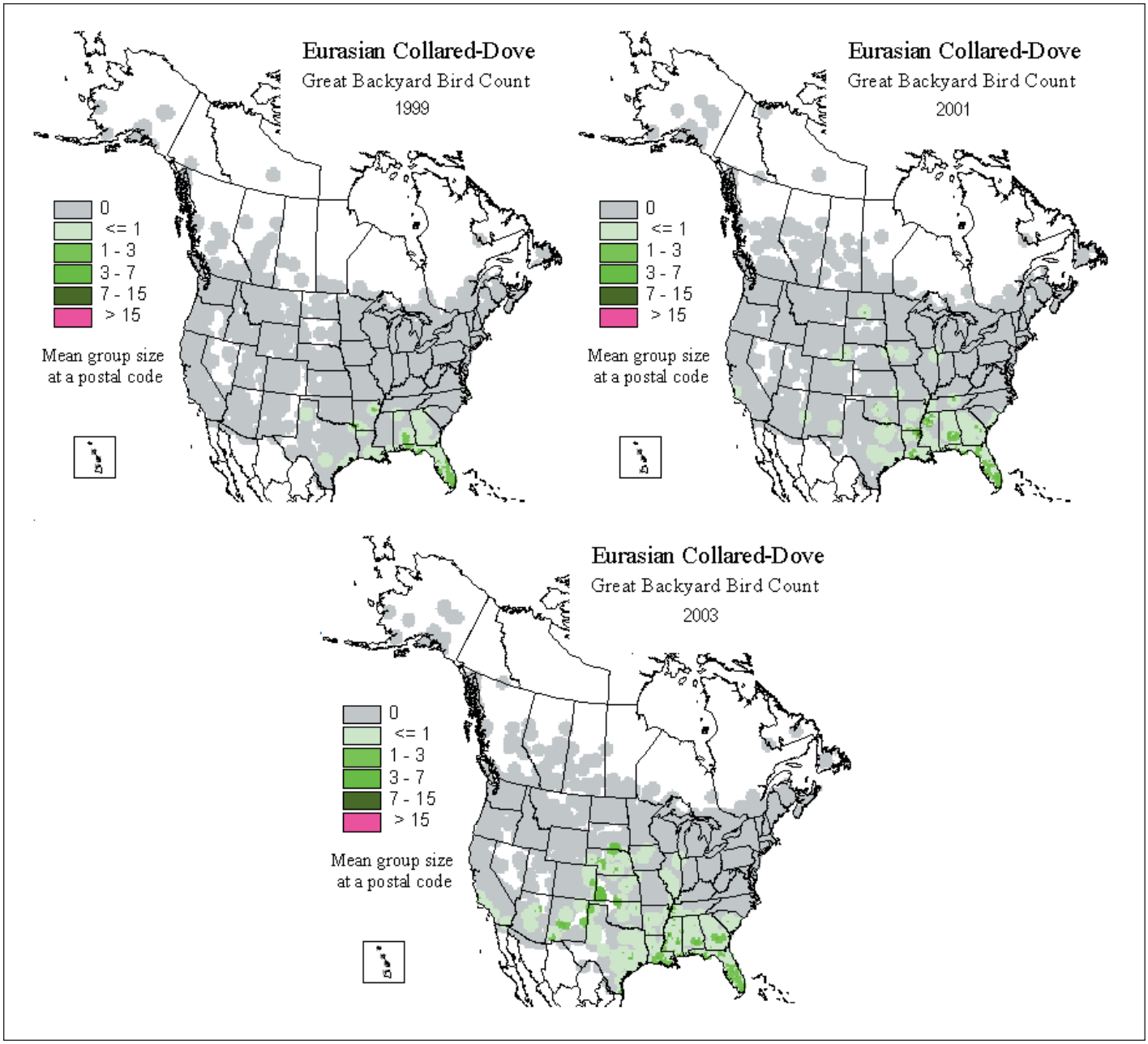
The cattle egret's diet may be of great economic benefit to cattlemen. There is substantial anecdotal evidence that cattle egrets reduce the numbers of certain species of cattle-associated biting flies thus reducing the incidence of cattle diseases such as bovine anaplasmosis (Telfair 1994). Yet, cattle egrets may propagate the tropical bent tick (*Amblyomma variegatum*), which is a vector of heartwater, a rickettsial disease of cattle and other ruminants (Barre et al. 1995).

Regionally, cattle egrets nest primarily along the Mississippi River, although confirmed breeding has occurred in Williamson County, Illinois, and Trigg County, Kentucky. Although cattle egrets have been detected only on a few survey routes (n=3), the population is generally increasing in the region according to BBS results (Sauer et al. 2001, table 3); however, trends are not significant. Given the history of the species in North America, it will likely continue to extend its range and increase in number.

Eurasian Collared-Dove, *Streptopelia decaocto*

A native of Asia, the Eurasian collared-dove was apparently imported into the Bahamas during the 1970s; approximately 50 of these doves were released in 1974 as a result of an aviary break-in. The population increased to at least 10,000 birds in less than 10 years, and the population started to spread to other islands. The species reached Florida by the mid-1980s where it continued its rapid range expansion. Populations are now well established in many Eastern and Midwestern States. Nesting records and sightings of the Eurasian collared-dove have occurred throughout the assessment area (fig. 3).

The Eurasian collared-dove was documented in southern Illinois in the mid-1900s and was recently added to the official State checklist (Geiser 2000). The species was first located in Hickman, Kentucky, in late May 1999. The first state record for the Eurasian collared-dove in Indiana was spotted during June 1999 (Gorney 2001). Trend results have been compiled by the BBS only for the Highland Rim physiographic region (table 3) indicating an enormous population increase. The Great Backyard Bird Count, one of the largest citizen-science projects in the world, indicates that the species is increasing and spreading quickly northwestward (fig. 3). The impact of this species has yet to be determined, and it is possible that the



species will compete with the native mourning dove (*Zenaida macroura*). In Georgia, where the Eurasian collared-dove is well established, the species appears to occupy a niche in the well-developed suburbs somewhere between the rock dove in the city and the mourning dove in open country. The Eurasian collared-dove will provide a unique opportunity to observe the impact of this exotic species on populations of native birds and to learn what ecological/geographical barriers, if any, finally limit their range expansion.

Feral Cats and Dogs, *Felis domestica* and *Canis familiaris*

The chief characteristic that separates feral cats and dogs from their domestic counterparts is their lack of reliance on humans. Free-roaming pets certainly cause significant ecological damage, most often in fulfilling natural predatory instincts rather than pursuing life requirements. Feral cats and dogs, however, do not directly depend on humans for survival; they must acquire their own food and shelter, often at the expense of native wildlife.

Figure 3. Great Backyard Bird Count maps (created by BirdSource) showing the northwestward range expansion of the Eurasian collared-dove from 1999 to 2003 (Great Backyard Bird Count Results 2003).

Feral dogs have broad dietary preferences. In addition to scavenging for human garbage, they are known to prey on small and large animals including white-tailed deer and domestic livestock. In a survey, resource managers cited damage to wildlife populations as the primary problem associated with feral dogs (Denny 1974). The impacts of feral dogs on wildlife populations are variable, however, and depend on food availability, number of dogs in an area, and competition with other predators (Green and Gipson 1994).

The size of the feral cat and dog population is unknown, complicated by differing interpretations of the terms, "feral," "unowned," and "stray." There are also no reliable estimates available on the status and trends of feral cat and dog populations, but most agree that cats represent a greater threat to wildlife than dogs. In fact, Ebenhard (1988) found that worldwide, introductions of domestic cats into areas are twice as likely to cause damage as other introduced predators. There are little data on the impact of feral cat predation on wildife, and this is an area that desperately needs to be evaluated. Within the U.S., it is estimated that over a billion small mammals and birds are killed by free ranging rural and feral cats (Ogan and Jurek 1997). This predation by cats may be endangering several bird species including the least tern, piping plover, and logger head shrike (Coleman et al. 1997). In addition to small mammals and birds (especially ground nesting and roosting species), the diets of feral cats include insects, amphibians, and reptiles (Ogan and Jurek 1997). Feral cats compete with natural predators and transmit several diseases including toxoplasmosis (Roelke et al. 1993). In a landmark study in California, Crooks and Soule (1999) determined that habitat fragmentation, coupled with increases in predation pressure from mid-size predators such as feral cats, could quickly drive native prey species locally extinct.

The long-term solution to most problems associated with feral cats and dogs centers on public education that promotes owner responsibility. Programs are needed like the American Bird Conservancy's Cats Indoors! (http://www.abcbirds.org/cats/), which seek to teach cat owners, decisionmakers, and the general public that free-roaming cats pose a significant risk to birds and other wildlife, suffer themselves, and threaten human health. Preventing domestic pets becoming feral is essential and can be accomplished by confining pets and sterilizing them. One study conducted in Massachusetts indicated that 91.5 percent of female cats were spayed and 90 percent of male cats were neutered. Yet, 15 percent of the sterilized females had had an average of two litters before sterilization (Manning and Rowan 1998). When feral populations are significant enough to generate community complaints, targeted control of existing populations may be warranted and many methods exist for this purpose (Green and Gipson 1994). Traditionally, there have been four approaches to controlling feral populations: trap, remove, and euthanize; trap, remove and relocate; trap, neuter, and return to the original site; and wait and see.

Feral Hog, *Sus scrofa*

Feral hogs descended from domestic farm animals that were first introduced by colonist to North America about 400 years ago (Frankenberger and Belden 1978). In addition, European wild boars were released into Tennessee and North Carolina early in the 20th century for hunting (Jones 1959). Feral hogs within the assessment area are progeny of domestic and wild varieties, as well as their hybrids. Although historically feral hogs have been confined to the Southern United States, they are expanding northward and are found regionally in Illinois and Indiana (Gipson et al. 1998). Throughout the U.S. the feral hog population is estimated to be around 4 million.

Currently, an assessment is underway to determine the status of feral hogs in southern Illinois (G. Feldhammer, personal communication).

Feral hogs are omnivorous, consuming a variety of plants and animals. They directly impact wildlife communities by preying on many species including rodents, birds, amphibians, and invertebrates (Challies 1975, Everitt and Alanis 1980, Henry and Conley 1972, Wood and Roark 1980). Feral hogs carry several important diseases including brucellosis and pseudorabies, which represent a risk to domestic livestock and native wildlife (Peline and Lancia 1990, Van der Leek et al. 1993). This species also hosts a wide variety of parasites that impact native wildlife. In addition, feral hogs potentially compete for food (especially acorn mast) with many wildlife species including white-tailed deer, wild turkey, squirrels, and a variety of waterfowl. The rooting and wallowing of feral hogs are also of consequence. These activities seriously threaten rare plant species, generally disrupt vegetative communities (Tate 1984), increase soil erosion and siltation of aquatic habitats, and may enhance conditions for exotic and invasive plants (Spatz and Mueller-Dombois 1975). Rooting and wallowing also tear up rotten logs that provide habitat for many amphibians and reptiles. During April through August, wild hogs invade high-elevation hardwood communities. A study in the Great Smoky Mountains National Park reported that understory plant cover was reduced by up to 87 percent and that up to 77 percent of all logs and branches were moved in heavily rooted areas (Singer 1981). Red-backed voles and shrews that were normally common in pristine stands were absent in rooted areas.

DISCUSSION

Exotic aquatic and terrestrial species have changed the structure of eastern forests within the assessment area, as well as the density and composition of wildlife associated with them.

Invasive exotic species have disastrous effects on native flora and fauna. In a new environment, exotic species may have fewer predators or diseases, and population growth can be explosive. Since exotic species are self-perpetuating, they can be more permanent problems than other threats to biodiversity including overexploitation and habitat loss. Although the Office of Technology Assessment estimates that 4 to 19 percent of exotic species cause great harm, another 6 to 53 percent are estimated to have neutral or unknown effects. These species, however, should not be viewed as benign biota. For example, purple loosestrife (*Lythrum salicaria*) existed in relatively low numbers for over a century before populations exploded, displacing valuable native wetland plants. Today, more than 190,000 hectares of wetlands are taken over by this invasive nonindigenous plant annually (Thompson et al. 1987). The spread of noninvasive species replaces healthy, diverse ecosystems with biologically impoverished, homogenous landscapes.

Nonindigenous aquatic and terrestrial species found in the assessment area come from varied sources. Of the aquatic species reported here, four (rainbow smelt, grass carp, silver carp, and bighead carp) dispersed after having been introduced into other States. At least five species (e.g., bull shark, threadfin shad, inland silverside, atlantic needlefish, striped mullet) have dispersed upriver from Gulf coastal waters subsequent to presumed changes in environmental conditions (i.e., warming, drought) that allowed their movement northward in the Mississippi River. Others (e.g., goldfish) introduced to the assessment area originally as food fishes or for aquaculture studies, appear to have become more widely distributed after the record 1993-94 Mississippi River flooding. Still other species (e.g., grass carp. silver carp, and bighead carp) have become established after earlier introductions for other purposes (i.e., weed control, improvement of water quality in

culture ponds). Three species (fathead minnow, golden shiner, brook stickleback) were introduced via bait bucket, and four others (red bellied pacu, red piranha, oscar, Amazon sailfin catfish) probably through release of aquarium stock. White perch has spread rapidly from the Great Lakes to southern Illinois due to its tolerance for varying ecological conditions. Perhaps the largest contingent of nonindigenous species/stocks and cultured hybrids has been released to enhance and restore sport fishing. At least 19 species and 5 hybrids have been intentionally released, several on an annual basis, into the reservoirs, city lakes, pay lakes, and recreational and farm ponds of the assessment area. Only 11 of these species are native to the area, and the source of brood stock often originates from widely disparate geographic sources. The other eight species are native to either northern North America or originated from either the Atlantic or Pacific slopes of North America.

Many of the terrestrial exotic species present within the assessment area were deliberately introduced for aesthetic, hunting, or livestock purposes. Of the terrestrial species examined in this chapter, only two species—cattle egret and Eurasian collared-dove—have dispersed naturally into the assessment area. Two species of birds (European starling, house sparrow) were introduced by European settlers to help them acclimate to their new setting. The house finch is the only terrestrial exotic discussed here which is native to North America, and the species was introduced from the Western U.S. Four species (rock doves, feral cats, dogs, and hogs) were introduced as pets or livestock and subsequently escaped to establish feral populations.

It is evident that both purposeful and unintentional introductions can lead to undesirable results, especially in terms of sportfishing/hunting, economics, human welfare, and ecological interactions. Moyle et al. (1986) introduced the concept of the "Frankenstein Effect" suggesting that if broad consequences of each introduction are not considered, the introductions may ultimately cause more problems than they solve. Li and Moyle (1999) present ecological concepts important for understanding the effects of introductions, suggest some management alternatives to introducing new species, and provide guidelines for evaluating proposed introductions. Several researchers have published recommendations for dealing with the issue of exotic plants and animals (Campbell 1997, Miller 1997, Stein and Flack 1996). These recommendations include

1. Development of more effective ways to prevent new introductions.
2. Early detection and eradication of new exotics.
3. Better control and management of established invaders.
4. Protection and recovery of native species and ecosystems.
5. Better public education and support for controlling exotics.
6. Better integration of control efforts by responsible government and nongovernmental entities.
7. Support for research aimed at identifying invasive species that could potentially damage our forests.
8. Support for further research aimed at developing effective ways to control exotics.

Changes in values, an expanding human population, and a decline in natural habitats provide an opportunity for reconsidering of old policies and values. And, there is now much public concern for protecting endangered species, maintaining water quality, preserving natural areas and biodiversity, and protecting the limited wild areas we have left in the region. The assessment area could become a model for the Nation by adopting a proactive

and progressive set of policies and protocols for introductions.

As highlighted here, many introduced vertebrates were successful, largely due to human alteration of the landscape. This suggests that land management practices may at least limit the impacts of exotic wildlife. Indeed, it appears that broad changes in land use have led to declines in house sparrow populations throughout North America. In addition, management of habitats specifically for native wildlife, may enable native species to better cope with threats presented by exotics. In some circumstances, where the objective is to reduce the population of an exotic species, targeted population control of exotic wildlife may be necessary. However, unless the underlying ecological factors that favor exotic wildlife are addressed, targeted control may not be enough.

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