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REVIEW ARTICLE

CHANGES IN THE DISTRIBUTION OF PENNSYLVANIA FISHES: THE LAST 100 YEARS[1]

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ABSTRACT

As a first step in documenting long-term changes in Pennsylvania fish assemblages, we used a geographic information system to develop a state-wide historical database for fishes. The database contains information on fish distribution over the past 100 years for rivers and streams. Initial analysis of these data indicate that 11 fishes have been extirpated from Pennsylvania rivers and streams, and six fishes that were previously considered extirpated are present in contemporary collections. Eighty-percent of the 102 watersheds experienced reductions in fish species richness over the last 100 years. Highest fish species richness occurred in the Allegheny River drainage, which also harbors the majority of state endangered, threatened, and candidate species. Our results suggest that further investigations into the mechanisms causing fish declines in specific Pennsylvania watersheds may lead to conservation of biodiversity.
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INTRODUCTION

The native fish fauna of Pennsylvania is a product of geographical and biological processes. The state's landscape has been shaped by several glacial advances and plate tectonic movements, which caused stream reversals and created barriers to fish dispersal. Today, the six major drainage basins that traverse Pennsylvania (Figure 1) harbor a diversity of fishes from six disjunct refugia: Atlantic Coastal Plain, Atlantic Coastal Uplands, Mississippi Valley, Gulf of St. Lawrence, Great Lakes, and Northeastern Coastal Refugia (Schmidt 1986).

Accounts of Pennsylvania's fishes have a long history. Early reports by Cope (1881) and Bean (1892), later

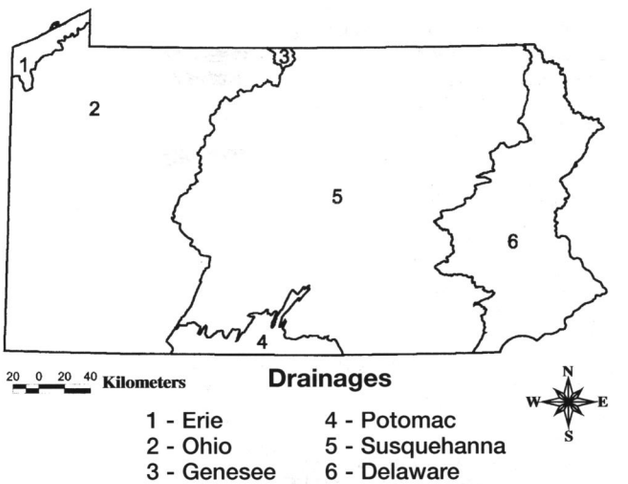

FIGURE 1. Pennsylvania's major drainage basins.

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revised by Fowler (1907), document nearly 100 species within Pennsylvania's waters. More recently published records document nearly 160 native and exotic species, among 24 (Cooper 1983) and 27 families (Denoncourt 1975). While an abundance of data are available for the state, assessment of changes in fish community composition through time has been limited, because data could not be easily synthesized, manipulated, or geographically represented.

With the advent of relational databases and geographic information systems (GIS), zoogeographic studies have become greatly simplified, because tabular and cartographic data can be combined, allowing for easy access, maintenance, and management. Moreover, digital geographic fish data can be easily integrated with other land-use data facilitating a wide range of investigations (Angermeier and Bailey 1992; Isaak and Hubert 1997).

To begin the documentation of fish distribution patterns, we assembled a database that covered approximately the last 100 years to (1) compare historical and extant patterns of native fishes in Pennsylvania's major drainages, (2) document changes in fish communities at the watershed scale, and (3) identify watersheds that are important to the maintenance of Pennsylvania's fish diversity.

MATERIALS AND METHODS

Several organizations permitted the use of their data for this project (Table 1). We condensed all data into the ARC/INFO® (ESRI 1995) geographic information system (GIS), which we used to create distribution maps and to relate fish data to landscape elements (e.g., watershed boundaries). In most instances, contemporary databases (i.e., post-1975; PFBC, RH, EPA, and MAHA, see Table 1) contained latitude and longitude bearings, so that we were able to easily produce these data points in ARC/INFO®. Historic databases (i.e., pre-1975, UMMZ, PSU, ELC, CU, SMITH, and ANSP) were assembled in ARC/INFO® by manually digitizing sites on screen, from site descriptions provided by collectors. We scrutinized all databases for accuracy of species identification and site locality by projecting species distribution points on a map and verifying their location with best available literature describing a given species distribution. Voucher specimens were available for all databases except the Pennsylvania Fish and Boat Commission and Robin Heard. We only used data for streams and rivers, because the majority (90%) of Pennsylvania's lentic systems are man-made (PDFW 1970) and the composition of these systems is largely the result of stocking programs.

The Office of Remote Sensing at the Pennsylvania State University, using 1:100,000 scale digital line graphs from U.S. Geological Survey (U.S.G.S.) stream maps and U.S.G.S. digital elevation models, generated a map delineating 102 Pennsylvania watersheds. We created distribution maps (at 25-year intervals) of all present species and analyzed them at the drainage scale using the map in Figure 1 and at the watershed scale using the map described above (Argent et al. 1997).

Because our largest database, the PFBC, contained only presence and absence data for non-sport fishes, we were unable to develop a measure of relative abundance. Therefore, we used species richness and species loss to better identify watersheds that may be important to the maintenance of Pennsylvania's fish diversity and that have experienced large changes in composition. We defined species loss as a reduction in the distribution of a given species over the last 100 years within the 102 watersheds.

TABLE 1. - Pennsylvania fishes databases.

Database or contact person	Years Covered	Number of Collection Sites
Pennsylvania Fish and Boat Commission (PFBC), William Frazier	1975-1995	10,780
Edwin L. Cooper (ELC)	1921-1983	1,500
The Academy of Natural Sciences in Philadelphia (ANSP), William Saul and Jon Gelhaus	1900-1989	530
The Pennsylvania State University (PSU), Jay R. Stauffer, Jr.	1974-1994	408
Cornell University (CU), Charles M. Dardia	1904-1989	404
The University of Michigan's Museum of Zoology (UMMZ), William L. Fink	1903-1974	165
The Smithsonian Institution (SMITH)	1900-1984	126
Environmental Protection Agency (EPA)	1993-1995	88
Robin Heard (RH)[1]	1994-1995	70
USEPA - National Exposure Research Laboratory (MAHA), Frank H. McCormick and Gary Smith	1994	58

[1]Robin Heard is a former graduate student at The Pennsylvania State University.

RESULTS

Our assessment of Pennsylvania's fishes yielded 33 families represented by nearly 200 native, exotic, and hybrid species (see Argent et al. 1997). Previous accounts by Denoncourt (1975) and Cooper (1983) did not include estuarine species found in the Delaware River or accidental introductions of the blue tilapia, *Oreochromis aureus*, to the Susquehanna River which occurred after Denoncourt's and Cooper's publications (Skinner 1984) (Table 2). Several exotic fishes (those of non-Pennsylvania origin: the rainbow trout, *Oncorhynchus mykiss*; Pacific salmon species, *Oncorhynchus sp.*; brown trout, *Salmo trutta*; common carp *Cyprinus carpio*; goldfish, *Carassius auritus*; and Amur pike, *Esox reicherti*) and transplanted fishes from other Pennsylvania drainages (Table 3) were collected, but were not used to calculate species richness because they were not of Pennsylvania origin or were not native to

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TABLE 2. Pennsylvania fish families not documented in Denoncourt (1975) and Cooper (1983). Refer to Table 1 for "Collector" acronyms.

Family	Species[1]	Collector	Date
Engraulidae - Anchovies	Bay anchovy	PFBC	1985
Belonidae - Needlefishes	Atlantic needlefish	ANSP	1900
Mugilidae - Mullets	Striped mullet	PFBC	1985
Gobiidae - Gobies	Naked goby	ANSP	1957
Bothidae-Lefteye flounders	Smallmouth flounder	PFBC	1985
Soleidae - Soles	Hogchoker	PFBC	1985
Cichlidae - Cichlids*	Blue tilapia	Skinner (1984)	1984

[1]Refer to Appendix A for scientific names.
*Data not included in our database.

TABLE 3. Exotic fishes and fishes transplanted among Pennsylvania's major drainage basins. Drainages where fish were transplanted are denoted by O=Ohio, E=Erie, D=Delaware, G=Genesee, P=Potamic, and S=Susquehanna.

Common Name	Scientific Name	Drainage transplanted
Pink salmon	*Oncorhynchus gorbuscha*	E
Coho salmon	*Oncorhynchus kisutch*	E
Rainbow trout	*Oncorhynchus mykiss*	O,E,D,G,P,S
Steelhead trout	*Oncorhynchus mykiss*	E
Sockeye salmon	*Oncorhynchus nerka*	D
Chinook salmon	*Oncorhynchus tshawytscha*	E
Atlantic salmon	*Salmo salar*	O,S
Brown trout	*Salmo trutta*	O,E,D,G,P,S
Brook trout	*Salvelinus fontinalis*	D,G,P,S
Lake trout	*Salvelinus namaycush*	E,S
Northern pike	*Esox lucius*	D,P,S
Muskellunge	*Esox masquinongy*	D,P,S
Amur pike	*Esox reicherti*	S
Rainbow smelt	*Osmerus mordax*	S
Central stoneroller	*Campostoma anomalum*	D
Goldfish	*Carassius auritus*	O,E,D,P,S
Grass carp	*Ctenopharyngodon idella*	O,E,D,G,P
Common carp	*Cyprinus carpio*	O,D,E,P,S
Cutlips minnow	*Exoglossum maxillingua*	O
River chub	*Nocomis micropogon*	D
Golden shiner	*Notemigonus crysoleucas*	O,E
Spottail shiner	*Notropis hudsonius*	O
Mimic shiner	*Notropis volucellus*	S
Fathead minnow	*Pimephales promelas*	D
Rudd	*Scardinius erythrophthalmus*	D
White catfish	*Ameiurus catus*	O
Channel catfish	*Ictalurus punctatus*	D
Mummichog	*Fundulus heteroclitus*	S
Mosquitofish	*Gambusia affinis*	D
Four-spined stickleback	*Apeltes quadracus*	S
White bass	*Morone chrysops*	S
Striped bass	*Morone saxatilis*	O,S
Rock bass	*Amploblites rupestris*	D,S
Green sunfish	*Lepomis cyanellus*	D,S
Bluegill	*Lepomis macrochirus*	D,S
Redear sunfish	*Lepomis microlophus*	S
Smallmouth bass	*Micropterus dolomieu*	D,S
Largemouth bass	*Micropterus salmoides*	D,S
White crappie	*Pomoxis annularis*	D,P,S
Black crappie	*Pomoxis nigromaculatus*	D,P,S
Blue tilapia	*Oreochromis aureus*	S
Greenside darter	*Etheostoma blennioides*	S
Fantail darter	*Etheostoma flabellare*	S
Banded darter	*Etheostoma zonale*	S
Walleye	*Stizostedion vitreum*	D,S

some Pennsylvania drainages. Other exotic fishes have been reported in Pennsylvania but were not present in these data (e.g., rudd, Scardinus erythrophthalmus).

We found that eleven species have been extirpated from Pennsylvania rivers and streams (Table 4), while six species previously considered extirpated by Cooper (1985) have been collected in recent years (Table 5). Among the major Pennsylvania drainages, the Ohio River drainage (Figure 1) contained the highest fish species richness (Figure 2), totaling 120 native species. Watersheds along the western portion of the Ohio drainage contributed largely to its fish diversity. The Susquehanna, Erie, and Delaware drainages supported moderate fish diversities totaling 84, 99, and 102 native fishes, respectively. Only 25 and 53 fishes were reported for the Pennsylvania portions of the Genesee and Potomac river drainages, both of which cover relatively small areas. Species listed by the state as endangered, threatened, or candidate (ETC) (as of January 1, 1998) occurred in 56% of Pennsylvania watersheds, the majority of which occur in the Ohio River drainage (Figure 3).

Over the past 100 years, reductions and extirpations of riverine fishes occurred in 80% of the 102 watersheds

TABLE 4. Species believed extirpated from Pennsylvania rivers and streams. Refer to Table 1 for "Source" acronym.

Species[1]	Last Collected	Drainage*	Source
Shovelnose sturgeon	1820	O	Rafinesque (1820)
Longjaw cisco	1957	E	Scott and Smith (1962)
Popeye shiner	1853	O	Baird (MCZ, Harvard University)
Northern redbelly dace	1862	S	Cope (1862)
Southern redbelly dace	1973	O	ELC database
Bigmouth buffalo	1925	E	ELC database
Blue catfish	1886	O	Evermann and Bollman (1886)
Pirate perch	1917	D	ANSP database
Mud sunfish	1935	D	Fowler (1938)
Swamp darter	1911	D	ANSP database
Sharpnose darter	early 1900s	O	Denoncourt (1977)

*O = Ohio, E = Erie, D = Delaware, S = Susquehanna
[1]Refer to Appendix A for scientific names.

TABLE 5. Species previously considered extirpated, but occurring in contemporary collections. Refer to Table 1 for "Collector" acronym.

Species[1]	Last Collected	Drainage*	Collector
Skipjack herring	1995	O	PFBC
Goldeye	1990	O	PFBC
Mooneye	1994	O,E	PFBC
Lake herring	1981	E	PFBC
Ironcolor shiner	1996	D	Jay R. Stauffer (pers. com.)
Longear sunfish	1979	O	PFBC

*O= Ohio, E = Erie, D = Delaware
[1]Refer to Appendix A for scientific names.

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(Figure 4). Of these watersheds, nearly 50% lost three or more species. Highest species loss occurred in two Delaware River drainages and two Ohio River drainages. Land use in these four watersheds varied from highly degraded to relatively unimpacted, but the combined total of developed land and agricultural land exceeded 50% in three of the four watersheds (Table 6) (USEPA 1993).

Reductions in the distribution of Pennsylvania fishes occurred among several families (Table 7). Within the Family Cyprinidae, the largest reductions occurred among the comely shiner (*Notropis amoenus*), the satinfin shiner (*Notropis analostanus*), the southern redbelly dace (*Phoxinus erythrogaster*), and the swallowtail shiner (*Notropis procne*). The southern redbelly dace has not been collected since 1973 and may in fact be extirpated.

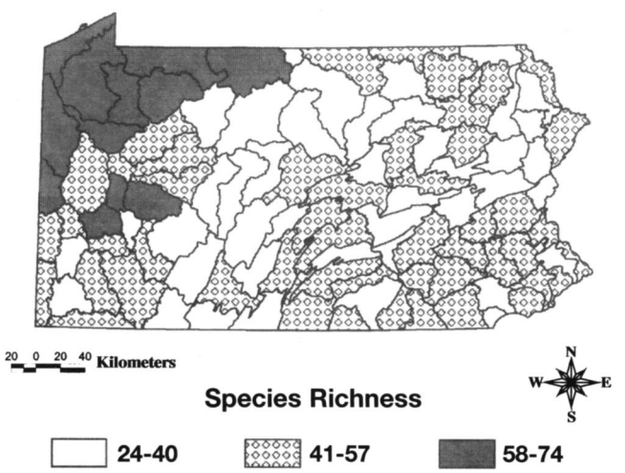

FIGURE 2. Fish species richness among 102 delineated Pennsylvania watersheds.

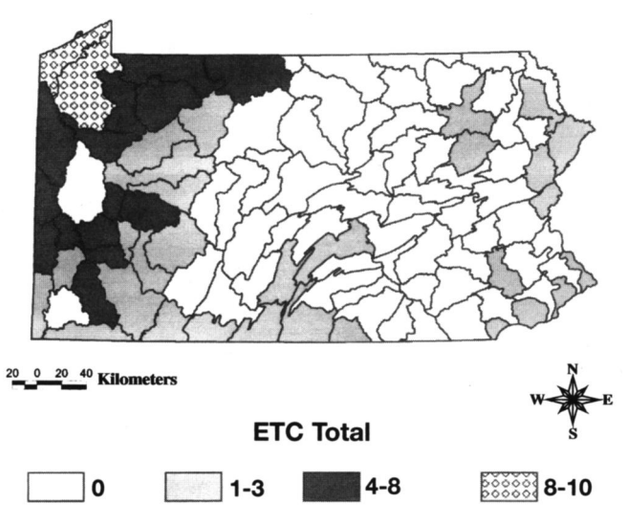

FIGURE 3. Distribution of Pennsylvania's endangered, threatened, and candidate fish species among 102 delineated watersheds.

Relatively large declines occurred in the Families Ictaluridae and Percidae, in the Ohio River drainage.

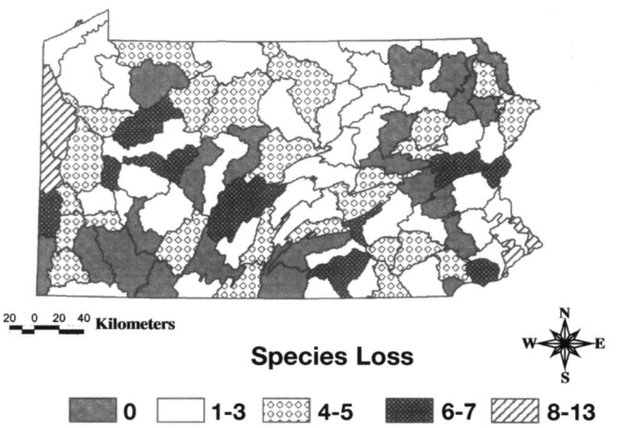

FIGURE 4. Fish species loss among 102 delineated Pennsylvania watersheds over the last 100 years.

TABLE 6. Percent land use in watersheds that experienced the highest fish species loss over the past 100 years.

	Land Use		
	Agriculture	Developed	Forest
Delaware Drainage:			
Lower Delaware River	25.7	24.4	35.4
Pennypack Creek	8.2	68.3	17.4
Allegheny Drainage:			
Shenango River	47.5	5.1	40.6
Beaver River	30.8	4.7	57.9

TABLE 7. Number of species in selected families that have experienced declines, in Pennsylvania drainages among the 102 watersheds we delineated, over the last 100 years.

Family	Drainage		
	Ohio	Susquehanna	Delaware
Petromyzontidae	3	1	1
Cyprinidae	15	15	14
Catostomidae	2	5	3
Ictaluridae	8	2	3
Centrarchidae	2	3	2
Percidae	6	3	2

DISCUSSION

Pennsylvania fish communities have changed over the last 100 years. While several species were absent from contemporary collections, several others were encountered for the first time. This result is not surprising, considering the increased sampling effort over the last 25 years by the PFBC and others (Table 1) and the more extensive use of electrofishing gear.

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The widespread loss of fishes at the watershed scale may be a reflection of Pennsylvania's changing landscape. Over the last 100 years many impoundments have been built (PDFW 1970), changing lotic systems to lentic ones and inhibiting the passage of anadromous and resident fishes (e.g., the Ohio and Delaware Basin watersheds in Table 6). Additionally, large urban centers have been developed that may alter stream ecosystems by contributing siltation (Taylor and Roff 1986), altering flow regimes (Karr et al. 1986), and increasing nutrient loading (McDonell and Pickett 1990). Perhaps the most pervasive pollutant in Pennsylvania is acid deposition, which has affected 4,100 km of streams (Frey 1990) and has been shown to reduce fish abundance and acid sensitive fishes from small streams in the northeastern United States (Baker et al. 1996, Heard et al. 1997).

Members of the Families Cyprinidae, Ictaluridae, Catostomidae, and Percidae all experienced reductions in distribution over the last 100 years. Such declines may be symptomatic of each species-specific habitat requirements and the introduction of exotic fishes, which may compete with these species for available habitat (Courtenay and Stauffer 1984). We found fishes not native to the state in all Pennsylvania drainages, fishes native to Pennsylvania that were transplanted from one drainage to another, and hybrid fishes that have been widely stocked to support sport fisheries. The specific role, that exotics and hybrids may have in displacing native fishes is not well understood.

We identified watersheds statewide that support diverse fish communities and rare species. While these findings are an important element to the maintenance of biodiversity, efforts should not stop here. Winston and Angermeier (1995) stated that a "conservation biologists' main goal should be preserving the viability of regional landscapes through maintaining their ecological integrity". To successfully accomplish this, we need a better understanding of how species and communities operate on larger spatial scales, such as the watershed scale. This analysis serves as a first step in meeting such a goal, but future work needs to focus on specific mechanisms responsible for the changes in fish communities we document here.

ACKNOWLEDGEMENTS

We thank the National Fisheries Research and Development Laboratory, U.S.G.S. Biological Resources Division, Wellsboro, Pennsylvania for providing financial support for this project. We also thank those individuals and organizations listed in Table 1 for providing the data used in this analysis and the students and staff at the Pennsylvania State University who contributed to this project. Ronald E. Hughey and an anonymous reviewer are thanked for their comments on an earlier draft of this manuscript.

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APPENDIX A. Scientific names of fishes in Tables 2-4.

Common Name	Scientific Name
TABLE 2	
Bay anchovy	*Anchoa mitchilli*
Atlantic needlefish	*Strongylura marina*
Striped mullet	*Mugil cephalus*
Naked goby	*Gobiosoma bosc*
Smallmouth flounder	*Etropus microstomus*
Hogchoker	*Trinectes maculatus*
Blue tilapia	*Oreochromis aureus*
TABLE 4	
Shovelnose sturgeon	*Scaphirlynchus platorynchus*
Longjaw cisco	*Coregonus alpenae*
Popeye shiner	*Notropis ariommus*
Northern redbelly dace	*Phoxinus eos*
Southern redbelly dace	*Phoxinus erythrogaster*
Bigmouth buffalo	*Ictiobus cyprinellus*
Blue catfish	*Ictalurus furcatus*
Pirate perch	*Aphredoderus sayanus*
Mud sunfish	*Acantharchus pomotis*
Swamp darter	*Etheostoma fusiforme*
Sharpnose darter	*Percina oxyrhyncha*
TABLE 5	
Skipjack herring	*Alosa chrysochloris*
Goldeye	*Hiodon alosoides*
Mooneye	*Hiodon tergisus*
Lake herring	*Coregonus artedii*
Ironcolor shiner	*Notropis chalybaeus*
Bullhead minnow	*Pimephales vigilax*
Blue sucker	*Cycleptus elongatus*
Blackbanded sunfish	*Enneacanthus chaetodon*
Longear sunfish	*Lepomis megalotis*

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