Journal of the Pennsylvania Academy of Science 74(1):3-12, 2000

A METHOD TO IDENTIFY AND CONSERVE RARE FISHES IN PENNSYLVANIA[1]

DAVID G. ARGENT*[2], ROBERT F. CARLINE[2]
and JAY R. STAUFFER, JR.[3]

[2]*USGS Biological Resources Division*
Pennsylvania Cooperative Fish and Wildlife Research Unit
The Pennsylvania State University
113 Merkle Laboratory
University Park, PA 16802

[3]*The School of Forest Resources*
The Pennsylvania State University
2 Ferguson Building
University Park, PA 16802

ABSTRACT

Three designations are given to rare fishes in Pennsylvania: endangered, threatened, and candidate, but no standard method exists to appropriately classify fishes among these designations. The purpose of this study was to develop a method that classifies Pennsylvania's rare fishes and identifies communities harboring rare fishes. We used the overall distribution and abundance of a given species over a 32-year period as the criteria to evaluate fish species' rarity status. Results of our analysis indicate that 54 of Pennsylvania's fishes could be considered rare at some level: 28 endangered, 15 threatened, and 11 candidate. These species represent nearly 35% of Pennsylvania's native fish fauna. The Ohio River drainage, which contains over 69% of these rare fishes, constitutes 30% of Pennsylvania's total land area. Less than 10% of the land in the Ohio River drainage is publicly owned, and little of that supports rare fishes. These results suggest that future conservation efforts (e.g., land acquisition or new management strategies) may need to be implemented to preserve Pennsylvania's rare fishes.
[J PA Acad Sci 74(1):3-12, 2000]

[1]Received for publication 10 October 1999; accepted 7 February 2000.
*Corresponding author

INTRODUCTION

A primary goal of conservation biology is to provide principles by which biological diversity can be preserved in the face of increasing anthropogenic impacts (Soulé 1985). Observing and documenting the loss of native fauna is often difficult, because it is rarely cataclysmic and often occurs on small scales (Angermeier 1995). Accordingly, numerous state and federal agencies have developed conservation programs to protect and enhance rare species, but many of the existing conservation programs tend to be reactive rather than proactive (Scott et al. 1988; Angermeier and Schlosser 1995), are often costly, and offer little assurance of success. Moreover, conservation efforts have been hindered by the lack of consolidated data describing the distribution of rare animals (Doremus 1991), by the inadequacy of current conservation policy (Angermeier and Schlosser 1995), and by the lack of an objective method with which to identify rare species.

Several species traits have been used to describe patterns of rarity: geographic range, habitat specificity, and local population size (Rabinowitz et al. 1980). Using these traits in combination Rabinowitz et al. (1980) described a hierarchical continuum of "seven forms of rarity". For example, species may be locally abundant, but geographically rare or they may be widespread but occupy specific habitat types. Most rare fishes in Pennsylvania occur at the periphery of their overall range and can be thought of as diffusively rare (Schoener 1987) at the national scale. Within Pennsylvania, many fish species occupy small geographic areas in low numbers, but do not receive protection appropriate for their degree of rarity within the state.

Currently (as of July 19, 1999) in Pennsylvania, nine fishes are state endangered, nine are state threatened, and 27 are state-candidate species (Table 1) (collectively called ETC species). These species account for approximately 30% of Pennsylvania's native fish species diversity. Although the terms endangered, threatened, and candidate have been clearly defined (PBTC 1995; Steiner 1997), criteria to meet these definitions have been lacking and fall largely to expert opinion (A. Shiels, *personal communication*, Pennsylvania Fish and Boat Commission). Currently, Pennsylvania's ETC fish list is the result of subjective inputs made by members of the Pennsylvania Fish and Boat Commission's (PFBC) Fish Advisory Committee, ichthyologists, fisheries biologists, and representatives of user groups (A. Shiels, *personal communication*, Pennsylvania Fish and Boat Commission).

It is our contention that a more objective framework to identify and classify rare fishes can be established with a better compilation of species records and of species' distribution mapping. Moreover, these data can be used to identify specific geographic areas where large concentrations of rare species occur. Once this system is in place, preventative (proactive) management strategies that use geographic representations of fish distribution patterns may be developed to aid conservation biologists in curbing biodiversity loss.

Our objectives were to (1) review current classifications of Pennsylvania's ETC species to ensure they are appropriately categorized and consider other species that should be added to the ETC species listing, (2) determine whether species in each fish family are over or under-represented in ETC designations, and (3) identify areas within Pennsylvania that support rare fish assemblages.

METHODS

We assembled fish records (Argent et al. 1998a) from several sources (Table 2) into the [1]Arc/Info® geographic information system (GIS; ESRI 1995) and the [1]Microsoft Office database [1]Access® (Microsoft 1995). Fish surveys conducted by the PFBC included 300-m stream reaches and were electrofished with one pass at each site. Fish surveys conducted by Heard et al. (1997), using electrofishing gear, typically included 90 to 125-m stream lengths. The Environmental Protection Agency (EPA) used similar techniques to sample fishes (EPA database). By contrast, surveys conducted by researchers at the Pennsylvania State University and Cooper (1983) used a variety of sampling gear (e.g, rotenone, multiple-pass electrofishing, or seines) over differing stream lengths (typically greater than 100 m). Once these databases were assembled, we elected to utilize only those collections made during the past 32 years (1965-1997). We selected this time period because it encompassed a substantial portion of Cooper's (1983) statewide survey, Jay R. Stauffer's survey of fishes in eastern and western Pennsylvania (1985-1989; MUSE database), and the complete records of the PFBC (1976-1995 for streams and 1976-1997 for lakes). While varying in spatial extent, sampling intensity, and sampling effort, these records spanned a wide range of available stream types and sizes, represent the only available collections of some species, and represent the most intensive sampling effort in Pennsylvania's recent history (Table 2).

Data were first analyzed by associating all fish collections with watershed boundaries derived by the Pennsylvania State University's Office of Remote Sensing (ORSER), using U.S. Geological Survey stream maps at a 1:100,000 scale. In total, 104 Pennsylvania watersheds were delineated (Figure 1). Watersheds ranged in size from 7 to 271,914 ha. We generated separate frequency histograms for both species presence within a watershed and local abundance across all watersheds, to derive two measures of geographic range (Gaston and Lawton 1990). Using these histograms, it became evident that several natural breaks existed. We elected to assign a rank to each species based on their presence in a certain number of watersheds: 1 = 0 - 2, 2=3 - 4, 3 = 5 - 10, and 4 > 10 watersheds. Using these data, a species that was present in seven watersheds, for example, would be assigned a rank of three.

As a second criterion, we used the total catch of a species across all sampled sites as a measure of relative abundance. For example, if 17, 20, and 11 specimens of a species were collected at three different sites, then an overall abundance of 48 was given to that species. This additive approach was used because not all sites contained abundance data; therefore, proportional abundance measures (e.g., relative abundance) could not accurately be calculated. If abundance data were not available, we assumed that at least one individual was collected to document its presence at a given site. This is a rather conservative approach, but given the fact that we are interested in rare fishes, we thought it best to err on the more conservative side. We ranked the abundance data as follows: 1 = 10 or less, 2 = 11 - 30, 3 = 31 - 120, and 4 > 120 fish (total catch).

We assumed that both (distribution within watersheds and site abundance) ranks were equally important in determining rarity and as such we used averages of these ranks to categorize fishes as endangered, threatened, or candidate. We interpreted an average rank of one or one-and a half as corresponding with an endangered fish. Endangered fish, using this scheme would have a very limited geographic distribution occurring in as many as four watersheds and having an abundance of as many as 30 individuals statewide. Average ranks of two or two-and a half corresponded to a threatened fish. These fishes have limited geographic distributions occurring in one to

TABLE 1. - Current (Cs) and proposed (Ps) status (as of July 19, 1999) of Pennsylvania fishes, using this methodology. Wr denotes watershed rank and Cr denotes catch rank. E = endangered, T = threatened, C = candidate, X = extirpated, UL = unlisted, and D = delisted.

Common name	Scientific name	Cs	Ps	Wr	Cr
Ohio lamprey	*Ichthyomyzon bdellium*	T	C	3	4
northern brook lamprey	*Icthyomyzon fossor*	E	E	1	1
mountain brook lamprey	*Ichthyomyzon greeleyi*	T	T	3	2
silver lamprey	*Ichthyomyzon unicuspis*	C	X	0	0
least brook lamprey	*Lampetra aepyptera*	UL	C	3	4
American brook lamprey	*Lampetra appendix*	UL	C	3	4
shortnose sturgeon	*Acipenser brevirostrum*	E	E	1	1
lake sturgeon[2]	*Acipenser fulvescens*	E	E	N/A	N/A
Atlantic sturgeon	*Acipenser oxyrhynchus*	T	E	1	1
spotted gar	*Lepisosteus oculatus*	C	E	1	1
longnose gar	*Lepisosteus osseus*	C	C	3	3
bowfin[1]	*Amia calva*	C	C	2	4
skipjack herring	*Alosa chrysochloris*	C	T	2	2
hickory shad	*Alosa mediocris*	C	E	1	1
goldeye	*Hiodon alosoides*	C	T	2	2
mooneye	*Hiodon tergisus*	C	T	3	2
cisco	*Coregonus artedi*	UL	E	1	1
central mudminnow	*Umbra limi*	UL	C	3	3
eastern mudminnow	*Umbra pygmaea*	UL	C	3	3
silver chub	*Macrhybopsis storeriana*	C	E	2	1
gravel chub	*Erimystax x-punctatus*	E	E	2	1
hornyhead chub	*Nocomis biguttatus*	C	C	3	3
bridle shiner[2]	*Notropis bifrenatus*	C	E	3	4
river shiner	*Notropis blennius*	UL	E	2	1
ghost shiner	*Notropis buchanani*	C	E	1	1
ironcolor shiner	*Notropis chalybaeus*	X	E	1	1
bigmouth shiner	*Notropis dorsalis*	UL	T	1	3
blackchin shiner	*Notropis heterodon*	C	E	1	1
redfin shiner	*Lythrurus umbratilis*	C	E	1	2
Southern redbelly dace	*Phoxinus erythrogaster*	UL	T	2	2
longnose sucker	*Catostomus catostomus*	E	E	1	2
smallmouth buffalo	*Ictiobus bubalus*	C	T	3	2
bigmouth buffalo	*Ictiobus cyprinellus*	UL	E	1	2
spotted sucker	*Minytrema melanops*	C	T	1	4
river redhorse	*Moxostoma carinatum*	C	C	4	3
black bullhead	*Ameiurus melas*	C	E	1	1
mountain madtom	*Noturus eleutherus*	T	E	1	2
tadpole madtom	*Noturus gyrinus*	C	E	2	1
brindled madtom	*Noturus miurus*	C	T	2	2
northern madtom	*Noturus stigmosus*	T	E	1	1
burbot	*Lota lota*	T	E	1	2
brook silverside	*Labidesthes sicculus*	UL	C	4	3
threespine stickleback	*Gasterosteus aculeatus*	UL	E	1	1
brook stickleback	*Culaea inconstans*	UL	C	2	4
banded sunfish	*Enneacanthus obesus*	C	E	1	1
warmouth	*Lepomis gulosus*	C	E	1	2
longear sunfish	*Lepomis megalotis*	C	E	2	1
Eastern sand darter	*Etheostoma pellucidum*	E	E	1	1
bluebreast darter	*Etheostoma camurum*	T	T	2	2
Iowa darter	*Etheostoma exile*	C	E	1	1
spotted darter	*Etheostoma maculatum*	E	T	2	3
tippecanoe darter	*Etheostoma tippecanoe*	E	T	2	3
channel darter	*Percina copelandi*	T	T	2	2
gilt darter	*Percina evides*	T	T	3	2
longhead darter	*Percina macrocephala*	E	T	3	2
Potomac sculpin[2]	*Cottus girardi*	C	D	3	4
spoonhead sculpin	*Cottus ricei*	C	X	0	0
deepwater sculpin	*Myoxocephalus thompsoni*	C	X	0	0

[1] Inland populations only.
[2] Determined by expert opinion.

TABLE 2. - Databases used to identify rare fishes in Pennsylvania. Number of sites denotes the total number of collection events contained within the respective database and Number of sites used denotes the number of sites within a database that contained rare fishes.

Database	Years covered	Number of sites	Number of sites used
Pennsylvania Fish and Boat Commission	1975-1995	10,780 (streams)	424
Pennsylvania Fish and Boat Commission	1975-1997	10,019 (lakes)	403
Edwin L. Cooper	1932-1983	1,500	253
The Pennsylvania State University	1974-1994	408	116
Robin Heard	1994-1995	70	6
Environmental Protection Agency[a]	1993-1995	88	12
The U.S. National Museum	1800-1984	126	1

[a]Data available through the Internet at:
http://www.biology.alberta.ca/jackson.hp/iwr/museums.html

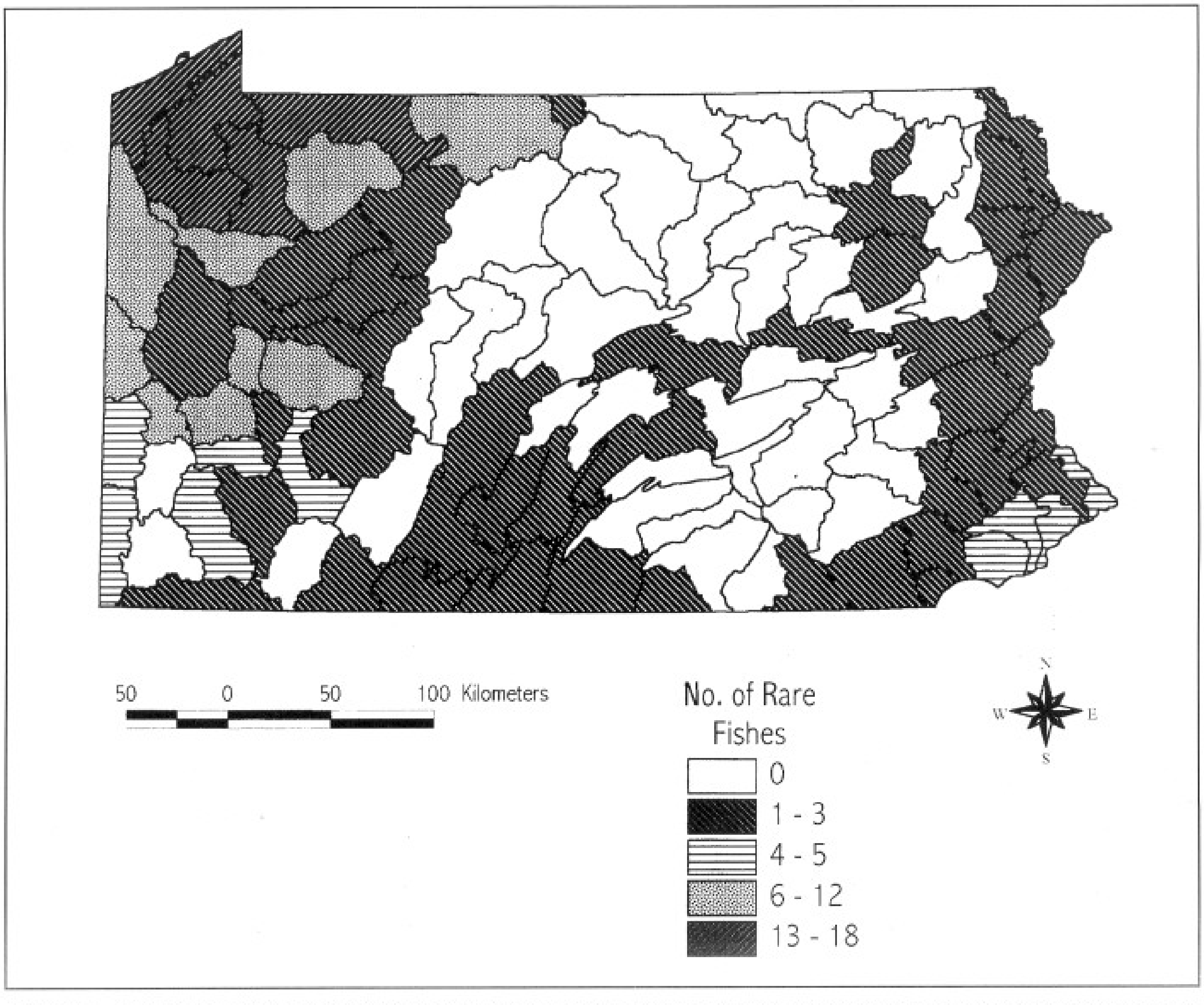

FIGURE 1. - Watershed boundaries derived for Pennsylvania from 1:100,000 digital line graphs. Watersheds that harbor Pennsylvania's rare fishes have been shaded to denote total number of rare species in a watershed.

nine watersheds and are moderately abundant in local sites.These fishes may not be locally rare, but may be geographically rare. Average ranks of three- and a half corresponded to a candidate species. These fishes occurred in four to ten watersheds statewide and were somewhat locally abundant. Fishes with average ranks of four were considered common.

Once rankings were applied, individual distribution maps were derived for each species identified among the three classifications. Using the GIS, we intersected these distribution maps with our watershed data layer to identify specific streams and watersheds that support these rare species. We also used other existing GIS data layers (i.e., state parks, state forests, national parks, national forests, and wild areas), housed at ORSER, to determine whether areas containing rare fishes were associated with publicly owned lands. Data layers representing publicly owned land were derived using standard methods at a 1:100,000 scale.

To determine whether species in each fish family are over or under-represented in ETC designations, we used a chi-square analysis to test a 30% expectation of rarity for each fish family (Minitab 1994). Fisher's exact test was used for contingency table analysis in cases where expected frequencies in one or more cells were fewer than five (Sokal and Rohlf 1969). A 30% expectation was selected because Pennsylvania's current rare species account for approximately 30% of the native fish species diversity. Using this test, we did not distinguish among endangered, threatened, or candidate species.

RESULTS

Classification assessment

Of nearly 23,000 collections reviewed, only 1,215 or 5% contained fishes identified as rare using this methodology. Using our classification scheme, 28, 15, and 11 fishes would be classified as endangered, threatened, or candidate in Pennsylvania, respectively (Table 1). This represents approximately 35% of Pennsylvania's total native fish fauna. The family Cyprinidae had the largest number of rare fishes, but one of the lowest proportions of rare fishes by family (Table 3). Contingency table analysis, testing a 30% expectation of rarity among fish families, revealed that all families were not significantly over represented in the rarity category at $\alpha = 0.05$, applying our classification method.

Endangered fishes

Of the nine fishes that are currently listed as endangered, only six would be retained if our classification scheme were applied (Table 1). Four fishes would be moved from threatened to endangered status and 11 would be moved from candidate to endangered status. In addition to these changes, we recommend that three additional species be added to Pennsylvania's endangered fish species list. Of those species that we determined to be endangered, at lease one, the ghost shiner (*Notropis buchanani*) should be sampled further to verify its presence in Pennsylvania because the collections we reviewed are over 20 years old. Two species that were proposed to have endangered status were determined using expert opinion. Surveys, between 1989 and 1996 in Lake Erie by the Ohio Division of Wildlife, Sandusky Fisheries Research Station documented 74 lake sturgeon (*Acipenser fulvescens*), but no sturgeon have been collected in the Pennsylvania portion of Lake Erie (R. Kenyon, *personal communication*, The Pennsylvania Fish and Boat Commission). Restoration efforts are underway in Pennsylvania in cooperation with other agencies that manage the fisheries of Lake Erie (R. Keynon, personal communication, The Pennsylvania Fish and Boat Commission) and we believe that the protection afforded to endangered species will aid these restoration efforts. Criswell (1998) resampled many of the locations we used to rank the bridle shiner (*Notropis bifrenatus*). His results indicated severe declines in this species throughout its historic range, to two remaining locations. Therefore, we believe this species requires the endangered status rather than the candidate status we determined.

Threatened fishes

Only four of the nine fishes included in Pennsylvania's current threatened fish list were so classified by our analysis (Table 1). Both the spotted (*Etheostoma maculatum*) and tippecanoe (*Etheostoma tippecanoe*) darters would be downgraded from endangered to threatened status. This change was due in large part to recent collection efforts made by Jay R. Stauffer, Jr., in northwestern Pennsylvania (MUSE database). In addition to these changes, six fishes could be moved from candidate to threatened status and two fishes could be added to the threatened list.

Candidate fishes

Of the 27 fishes that are currently listed as candidate (Table 1), five would be retained using our scheme. Only one species, the Ohio lamprey (*Ichthyomyzon bdellium*), previously classified as threatened, would be reclassified as a candidate species. Six additional fishes would be given candidate status. Collections made in 1998 of the Potomac sculpin (*Cottus girardi*) indicate that this species is now secure in Pennsylvania and that populations are stable (Robert Criswell, *personal communication*); therefore, we recommend that it be removed from Pennsylvania's ETC list. Distribution maps are available in Argent et al. (1998b) for all species reviewed.

TABLE 3. - Total number of Pennsylvania's rare fishes proposed by this methodology, and the total number of native state fishes within each family. Expectation of rare fishes, denotes a 30% expectation by family of rarity used for Chi-square and Fisher's exact test analysis.

Fish family	Total no. rare fishes	Expectation of rare fishes	Total no. native fishes	No. rare/ total no.
Petromyzontidae	5	2	6	0.83
Acipenseridae	3	1	3	1.00
Lepisosteidae	2	1	3	0.66
Amiidae	1	0	1	1.00
Clupeidae	2	2	7	0.29
Hiodontidae	2	1	2	0.50
Salmonidae	1	1	3	0.33
Umbridae	2	1	2	1.00
Cyprinidae	11	13	43	0.26
Catostomidae	5	5	16	0.31
Ictaluridae	5	4	12	0.42
Gadidae	1	0	1	1.00
Atherinidae	1	1	2	0.50
Gasterosteidae	2	1	3	0.66
Centrarchidae	3	5	16	0.19
Percidae	8	7	22	0.36

Fishes that are currently state listed, but now believed extirpated from Pennsylvania

Three fishes currently listed as candidate in Pennsylvania could be considered extirpated: the deepwater sculpin (*Myoxocephalus thompsoni*), spoonhead sculpin (*Cottus ricei*), and silver lamprey (*Lehthyomyzon unicuspis*) (Table 1). Attempts to collect deepwater sculpin reinforce the notion that it is currently extirpated from Lake Erie (Parker 1988). The only Pennsylvania collections of this species were reported in Cooper (1983) from Fowler's early work. While the spoonhead sculpin has not been collected in Pennsylvania since the early 1900s (Cooper 1983), several populations appear to thrive in Canada (Houston 1990). Continued listing of this species as candidate is unsubstantiated by the collections we reviewed. The silver lamprey is currently listed as candidate in Pennsylvania, threatened in Ohio, and status undetermined in West Virginia (Schmidt 1996). Records from the Cornell University database and those reported in Cooper (1983) document probable accounts of this species from Lake Erie.

Centers of rarity and publicly owned land

Overlaying individual species' distribution maps in Arc/Info® allowed us to determine where rare and endangered fish communities reside. These results indicate that most of Pennsylvania's rarest fishes occur in the northwestern and western region of the state (Figure 1; Table 4). The Allegheny River, French Creek, and Ohio River contained the highest numbers of rare fishes. In addition, several other important watersheds exist in eastern Pennsylvania. These include the Delaware River, which historically and presently supports two sturgeon species in addition to other anadromous fishes and Marshalls Creek, which presently supports the only Pennsylvania populations of the ironcolor shiner (*Notropis chalybaeus*).

This spatial analysis also revealed that several species are known from only one or two geographic locations and appear as relict populations. Elk Lick Creek and Flaugherty Creek, Casselman River watershed, support the only known populations of the longnose sucker (*Catostomus catostomus*) in Pennsylvania. Pymatuning Reservoir harbors the brook silverside (*Labidesthes sicculus*) and central mudminnow; it also supports Pennsylvania's only known spotted sucker (*Minytrema melanops*) populations.

Overlaying rare species richness (Figure 1) with publicly owned land data layers indicates that only 6% of those watersheds harboring rare fishes contain land that is publicly owned (Figure 2). The Ohio River drainage, which constitutes 35% of Pennsylvania's total land area and contains 69% of the rare fishes we identified, has less than 10% of its land in public ownership.

DISCUSSION

Our classification scheme provided an objective method to identify Pennsylvania's rare fishes and a quantitative estimate of overall distribution and population size. This technique removed much of the subjectivity associated with classifying rare fishes, utilized current and historical fish collection records and helped to identify diverse communities of rare fishes.

TABLE 4. - Pennsylvania streams that support diverse communities of endangered, threatened, and candidate fishes. For a complete listing refer to Appendix C in Argent et al. 1998b, available from the authors.

Stream/river	No. of rare fishes	Stream/river order
Allegheny River	21	4 - 5
French Creek, Crawford Co.	11	3 - 5
Lake Erie, Presque Isle Bay, Erie Co.	9	NA
Conneaut Creek, Crawford Co.	8	3 - 4
Ohio River	8	8
Delaware River	8	4 - 5
Delaware Estuary	6	5
Monongahela River	6	4 - 5
Potato Creek, McKean Co.	6	3 - 4
Brokenstraw Creek, Warren Co.	5	3 - 4
E. Branch Oil Creek, Crawford Co.	5	3 - 4
Fishing Creek, Potter Co.	5	2
Mill Creek, Potter Co.	5	2- 3
Oil Creek, Crawford Co.	5	3 - 4
Sandy Creek, Venango Co.	5	3 - 4
Elk Creek, Erie Co., trib. to Lake Erie	4	3 - 4
W. Branch French Creek, Crawford Co.	4	2
Marshalls Creek, Monroe Co.	4	2
Pymatuning Lake, Mercer Co.	3	NA

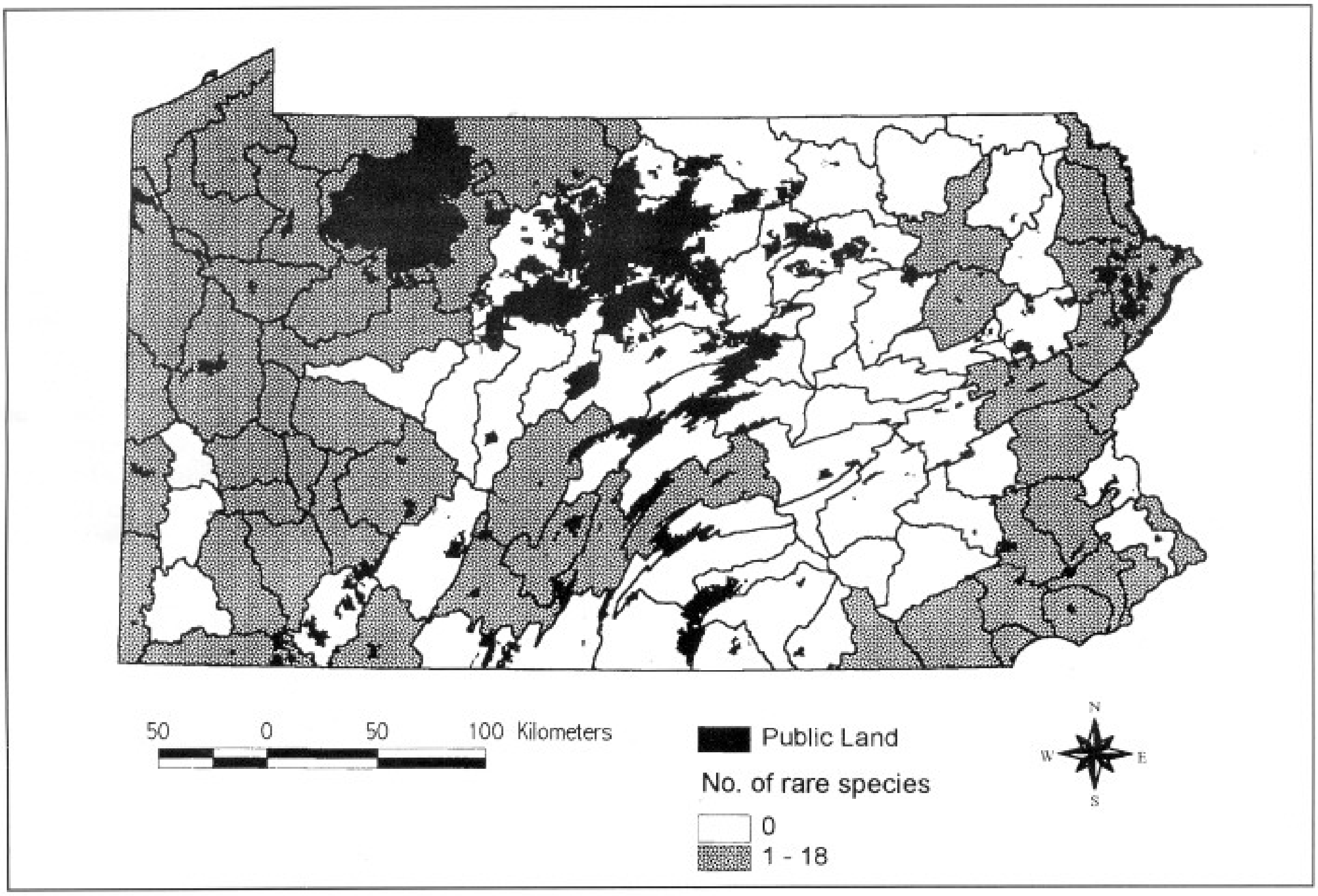

FIGURE 2. - Overlay of watersheds that harbor rare fishes with publicly owned land. Publicly owned land, denoted with black polygons, includes state parks, state forests, national parks, national forests, and conservancy areas. Watersheds that are shaded contain between one and eighteen rare fishes. Those that are white contain no rare fishes.

Our classification scheme identified 41 of 45 fishes currently (as of July 19, 1999) classified as rare by expert opinion as rare based on distribution and abundance data (Table 1). This indicates that there is a high degree of agreement between the objective criteria we used and the subjective criteria used by experts in determining what constitutes rarity. However, of these 41 fishes only 14 were similarly classified using expert opinion among Pennsylvania's endangered, threatened, and candidate species designations. This suggests that experts can identify rarity on a large spatial scale using subjective criteria, but cannot systematically and objectively assess varying degrees of rarity or have insufficient information regarding the distribution of certain species. Moreover, our results suggest that experts do not weight distribution and abundance data as heavily as we did in determining the status of rare fishes, because our method resulted in the identification of 12 fishes (for a total of 54 species) not currently listed that could be included in Pennsylvania's ETC list. Experts can now use the results we generated to reflect upon other criteria that may be important in determining imperilment.

Ranking schemes and frequency distributions have been applied to assess patterns of rarity among fishes in the past (McAllister et al. 1986; Minns 1987). Additionally, various weighting measures have been applied to these schemes that emphasize the importance of certain species' characteristics in determining their status. Minns (1987) states that weighting factors give ranking methods considerable versatility. We elected not to weight our variables because we believe that both local abundance and geographic dispersion play equally important roles in determining a species' rarity and its level of imperilment. Other factors like habitat and life history characteristics may need to be included in future assessments to more accurately classify species, especially those families in which the majority of species were classified as rare.

The three fishes that we believe are extirpated from Pennsylvania may have declined for several reasons. Throughout their range, deepwater sculpins have been limited by declining water quality, loss of suitable habitat, and predation and competition from lake trout and burbot (Parker 1988). Houston (1990) indicated that the key-limiting factor for spoonhead sculpins is the availability of deep coldwater lakes. Because Lake Erie has its deepest locations outside the political boundary of Pennsylvania, it is unlikely that these sculpins will be found in Pennsylvania's portion of the lake. Historical accounts of the silver lamprey document this species throughout the upper Mississippi River drainage and as a probable inhabitant of Lake Erie, but in small numbers (Lee et al. 1980). Given the number of blockages in the Ohio River drainage, it is possible that the silver lamprey is unable to expand its range eastward into Pennsylvania (Lee et al. 1980). Moreover, as this species typically inhabits large river systems and lakes, it is likely that inefficiencies in sampling gear have resulted in a paucity of collections.

Traits of fishes identified as rare

Unlike other states, some of Pennsylvania's fishes are rare because of locality, but others are rare because of pollution and habitat degradation. For example, those fishes we identified as rare in the northwestern portion of the state reflect the historical zoogeography of the region that was once covered with glaciers (Cooper 1983). Most fishes in this area represent relict fish populations with widespread distributions to the west and north of Pennsylvania's political boundary (Lee et al. 1980). Therefore, Pennsylvania constitutes the fringe of many of these species' overall distribution. However, species like spotted (*Etheostoma maculatum*) and bluebreast darters (*Etheostoma camurum*) and northern madtoms (*Noturus stigmosus*) are extirpated from the Shenango drainage because of pollution and habitat loss, while other big river forms like lake sturgeon, blue sucker (*Cycleptus elongatus*) and paddlefish (*Polyodon spathula*) declined when dam building became acute and water quality declined (R. Criswell, *personal communication*).

While geographic distribution is an important factor, the general patterns we observe in Pennsylvania with respect to rarity occur elsewhere and have been described using life history traits. Within Pennsylvania the families Petromyzontidae, Acipenseridae, Cyprinidae, Catostomidae, Ictaluridae, and Percidae contained the majority of rare fishes as we identified them (Table 3). Williams and Miller (1990) reported similar patterns of rarity among North American fish families, with members of the families Acipenseridae, Catostomidae, Cyprinidae, and Percidae having the most imperiled species. Most of the species within Cyprinidae, Percidae, and Ictaluridae are short-lived, have relatively low fecundity, and occupy small stream areas within the Commonwealth, whereas members of the families Petromyzontidae, Acipenseridae, and Catostomidae are quite fecund and can live 5 to 60 years (Smith 1985). Recent studies indicate that a species' probability of being at risk increases if it is late to mature, non-piscivorous, inhabits streams, and does not breed in streams over gravel or pebble beds (Parent and Schriml 1995). In Virginia, Angermeier (1995) reports that most extirpated fishes occur in all sizes of water, represent all length classes, and are restricted to a single physiographic province. Given the wide variability in species' traits, future conservation efforts should be robust enough to provide adequate habitat for fishes exhibiting these characteristics.

Conservation districts

While our findings may be an important component to the maintenance of Pennsylvania's biodiversity, further conservation efforts are still needed. Winston and Angermeier (1995) stated that a "conservation biologist's 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 these rare fishes and their communities operate at larger spatial and temporal scales, such as the watershed scale.

In general, Pennsylvania's public land is comprised of areas that had historically been logged or were of little agricultural or commercial value. Thus, most of this land occurs in the mountainous areas of the state forming headwater reaches that do not flow through watersheds important to those fishes we identified as rare (Figure 2). However, the value of headwater watersheds is well documented in the literature and their continued existence is vital to many downstream processes (e.g., energy flow). But the lack of overlap between the publicly owned land and the watersheds harboring rare fishes suggests that the future of these fishes lies in the ability of private landowners to responsibly manage their lands and protect these fishes habitats.

Frissell and Bayles (1996) argue that the establishment of reserve networks at the watershed scale can effectively provide the greatest protection to threatened biota when limited resources are available for protection. Given the geographic distribution of Pennsylvania's rare fishes and the nature of landownership (i.e., they are largely clustered within streams and across the state), reserve networks may provide a viable conservation opportunity. Such networks can foster a conservation ethic between private landowners and local conservation groups (Frissell and Bayles 1996).

Future considerations

Because species restoration efforts are expensive, time consuming, and lack assurance of success, we believe that the application of this technique can aid in conservation planning. By considering communities of fishes rather than single species, it can serve as a proactive management tool, aiding in the identification of conservation districts. This technique could be used in conjunction with other conservation tools to readily identify areas of declining diversity and areas of high species richness of rare fishes.

One of the shortcomings of this study is the difference in sampling methods used in recent and historic surveys. Electrofishing a standard length of stream was used to collect the majority of fishes in this study. Angermeier and Smogor (1995) indicate that more representative fish collections can be made when sampling effort is adjusted to reflect a stream length that includes a variety of fish habitats. They suggest that researchers could maintain a cumulative list of species encountered and stop sampling when a predetermined number of additional sampling units fail to yield additional species. Moreover, because many of these fishes were found in large order streams and rivers (Table 4), improved sampling techniques will need to be developed to acquire more representative samples.

In Pennsylvania, a systematic monitoring and inventorying program should be developed and maintained by a single organization. The monitoring approach needs to include specific collection methods, precise site descriptions, voucher specimens, abundance data, verified species identifications, and a sampling protocol that uses a variety of gears. Second, new collections need to be made to verify the existence of those fishes whose records appear to be in question (e.g., ghost shiner) and those fishes that have not been collected for at least the last 10 years (e.g., Atlantic sturgeon). Such collections will help to refine the list of rare fishes and provide needed abundance data for other fishes. Last, species classifications need to be reviewed at some specified time interval and appropriate measures should to be outlined with regards to the conservation or restoration of imperiled species and their habitats. More research will need to be done on several species to document their specific habitat requirements and to assess the suitability of available habitat. The future success of these species is dependent on our ability to protect the remaining natural communities in the face of an ever-expanding human population.

ACKNOWLEDGEMENTS

We thank the USGS National Fisheries Research and Development Laboratory (Research Work Order #47) and The Wild Resource Conservation Fund for providing financial support. We also thank those institutions, agencies, and individuals listed in Table 2 for providing their data. Andrew Shiels and PFBC Area Fisheries Managers are thanked for reviewing the proposed species list. We wish to thank Paul Angermeier, Gary Meffee, and five anonymous reviewers for comments on earlier drafts of this manuscript.

ENDNOTES

[1]Use of trade names does not infer endorsement by the U.S. Government.

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