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Status of Spring Cavefish (*Forbesichthys agassizii*) in Southern Illinois

[1]Brian A. Metzke, [2]Ginny Adams, and [2]S. Reid Adams
[1]University of Illinois, Prairie Research Institute, Illinois Natural History Survey
1 Natural Resources Way, Springfield, IL 62702, 217-557-9251, Brian.Metzke@illinois.gov
[2]Department of Biology, University of Central Arkansas, Conway, AK 72035, gadams@uca.edu

ABSTRACT

Spring Cavefish (*Forbesichthys agassizii*) inhabit springs, streams and subterranean aquatic habitats from Missouri to Tennessee. In Illinois, most fisheries survey programs do not sample habitats in which Spring Cavefish can be found, and therefore, its distribution and ecology are poorly understood in the state. We reviewed records of the species within Illinois fisheries databases and museum collections and performed targeted surveys for the species in both 2003 and 2013 to better evaluate distribution status and trends. At a coarse spatial resolution, Spring Cavefish distribution appears stable; however, temporal variability in its presence at individual locations suggests the species may be vulnerable to local extirpation. Evaluation of environmental setting relative to Spring Cavefish distribution suggests water quality may influence presence more than physical characteristics. This study highlights the need for targeted surveys to monitor the status of this species.

INTRODUCTION

Spring Cavefish (*Forbesichthys agassizii*) is a small (usually <9cm) brown or tan, salamander-like fish that inhabits caves, springs and clear streams (Smith 1979, Page and Burr 2011). Like other species within Amblyopsidae, it has rudimentary eyes, many sensory papillae, a broad, flat head and is adapted for subterranean or low light environments (Robison and Buchanan 1988, Etnier and Starnes 1993, Niemiller and Poulson 2010, Page and Burr 2011); however, Spring Cavefish exhibit transitional adaptation in that they move into caves or other sheltered environments during daytime hours and emerge at night to feed (Smith and Welch 1978). The species is primarily an invertivore (Weise 1957), although cannibalism has been recorded in adults (Hill 1969).

Recorded Spring Cavefish distribution includes southeastern Missouri, southern Illinois, southwestern Kentucky and central Tennessee (Smith and Welch 1978, Niemiller and Poulson 2010, Page and Burr 2011), and the species' inhabited waters are often associated with the karst regions of these states (Burr et al. 2004). The earliest known account of the species in Illinois comes from Forbes and Richardson (1920), where they describe specimens collected in 1870's and 1880's from caves and springs in Union and Pope Counties. Although most abundant in the LaRue-Pine Hills Research Natural Area in Union County, Spring Cavefish have been found in springs, headwaters originating from springs and streams in and around the Shawnee Hills natural division of southern Illinois (Weise 1957, Smith and Welch 1978, Smith 1879, Page and Burr 2011).

Spring Cavefish in Illinois may suffer from the same stressors as other amblyopsids, including habitat degradation or loss through pollution, landscape changes and hydrologic alterations, over-collection, habitat fragmentation and loss of genetic variation (Willis and Brown 1985, Niemiller et al. 2013). In Illinois, Spring Cavefish are included as a Species in Greatest Need of Conservation (IDNR 2005) with habitat availability and fragmentation listed as the primary stresses to the species. Global conservation status for the species is listed as G4 – Apparently Secure, but the Illinois state conservation status is S1S2 – Imperiled or Critically Imperiled (NatureServe 2015). Jelks et al. (2008) concludes Spring Cavefish are declining and vulnerable across their range and habitat destruction or modification is the primary cause.

Spring Cavefish habitats are under-sampled by ongoing monitoring programs within Illinois (e.g., Illinois Department of Natural Resources [IDNR] basin surveys), and as a consequence, evaluation of the species' spatial and temporal distribution patterns is difficult. The Illinois Natural History Survey (INHS) and Southern Illinois University – Carbondale (SIUC) fish museum collections contain Spring Cavefish specimens, but collection efforts for the species are irregular in their frequency and spatial extent.

In this study, we use existing records and two focused surveys (one in 2003 and another in 2013) to evaluate the distribution and ecological status of Spring Cavefish in Illinois. Our objective is to provide insight into the species' temporal and spatial distribution patterns within the state and further evaluate its habitat associations.

METHODS

INHS, SIUC and IDNR collection databases and VertNet were queried for Spring Cavefish records to evaluate the species' known distribution. To supplement the spatial and temporal extent of these records, two survey efforts to collect Spring Cavefish were conducted, one in 2003 and one in 2013. The 2003 survey revisited many of the historic locations Spring Cavefish had been collected, but also included springs not previously surveyed. Unsurveyed springs were identified using geologic records of springs from southern Illinois. Surveys were conducted between April and June 2003, which corresponds to the time of year that Spring Cavefish are most likely to be active at the surface (Smith and Welch 1978) and each location was surveyed once. Spring Cavefish were collected using a small aquarium net or a D-frame dip net and placed into a bucket for enumeration. Cobble and large organic material were lifted in order to displace hiding individuals. Sampling concluded when efforts failed to collect additional individuals (i.e., sampled to exhaustion) with a minimum effort of one hour.

Survey locations for the 2013 effort were selected from both historic records and those from the 2003 survey, with an emphasis on places where Spring Cavefish had recently (approximately 10 years) been collected. Surveys were completed in April and May of 2013 and locations were surveyed once. Spring Cavefish were collected using dip netting and hand grabbing at smaller sites (e.g., springheads) and with backpack electrofishing units at stream sites. Number of individuals collected was noted, but no attempt was made to fully enumerate a population. Sample effort ranged from approximately one half hour to one hour per location.

During the 2013 survey, several in-stream, riparian, watershed and water quality variables were recorded at each 2013 location to characterize environmental setting. Instream and riparian features related to substrate, flow, channel units, bank composition and vegetation were estimated during each survey (Table 1), and recorded values for these characteristics represent the average condition throughout the surveyed areas. Watershed and stream segment variables for each survey location were derived from GIS-based attributions (Holtrop et al. 2005, Holtrop et al. 2006; Table 1). A portable multimeter (HQ40d Portable Meter, Hach Company) was used to measure pH, dissolved oxygen, specific conductance and temperature. Water quality variables were not measured at two sites (9 and 14) where hydrology was limited.

We used Principal Components Analysis (PCA) to ordinate physical (instream and watershed) and water quality variables at 2013 survey locations. PCA distills multivariate data into composite variables, which can be used to visualize differences amongst survey locations and determine which variables are driving that variation. Physical and water quality variables were transformed to a 0-1 scale prior to ordination, and two PCAs (one for physical and one for water quality variables) were conducted as water quality information was lacking from two locations. PCAs were conducted using PC-ORD (McCune and Mefford 1999).

Table 1. Physical and water quality variables (and subcategories) and summary statistics recorded during the 2013 survey for spring cavefish.

Attribute (units)	Mean	SD	Range
Substrate Composition (proportion)			
- Muck/Silt	0.10	0.23	0 - 0.9
- Organic	0.08	0.15	0 - 0.5
- Wood	0.01	0.05	0 - 0.2
- Claypan	0.11	0.26	0 - 0.8
- Sand	0.07	0.20	0 - 0.8
- Gravel	0.09	0.18	0 - 0.9
- Cobble	0.38	0.35	0 - 1.0
- Boulder	0.01	0.04	0 - 0.2
- Bedrock	0.14	0.23	0 - 0.8
Mean Width (meters)	2.10	1.60	0.5 - 5.0
Mean Depth (meters)	0.34	0.27	0.1 - 1.0
Flow (qualitative, 1-4 scale)[1]			
Channel Unit Composition (proportion)			
- Riffle	0.34	0.34	0 - 1.0
- Run	0.26	0.33	0 - 0.9
- Pool	0.40	0.35	0 - 1.0
Channel Vegetation (proportion)			
- Emergent	0.05	0.06	0 - 0.2
- Submergent	0.01	0.03	0 - 0.1
- Overhanging	0.01	0.01	0 - 0.1
Bank Composition (proportion)			
- Bare	0.44	0.35	0 - 1.0
- Herbaceous	0.34	0.29	0 - 0.8
- Woody	0.01	0.02	0 - 0.1
- Trees	0.04	0.07	0 - 0.2
- Bedrock	0.09	0.16	0 - 0.5
Riparian Width (meters)[2]			1 - >100
Dominant Riparian Vegetation (1-4 scale)[3]			
Channel Shading (proportion)	0.69	0.32	0 - 1.0
Land Use (proportion)			
- Agriculture	0.26	0.22	0.03 - 0.58
- Forest	0.53	0.25	0.08 - 0.92
pH	7.97	0.30	7.41 - 8.55
Dissolved Oxygen (mg/L)	8.17	1.77	5.05 - 10.57
Conductivey (μS/cm)	255	131	113 - 662
Temperature (°C)	15.6	4.2	11.1 - 24.0

[1]categories were "none, very low, low and moderate"
[2]riparian width at most (13/21) locations could not be estimated (i.e., extended beyond visibility)
[3]categories were "none, tree, herbaceous and wetland"

RESULTS

An examination of the INHS and SIUC museum collections yielded 40 records of Spring Cavefish within Illinois, only eight of which occurred since 2000, and the most recent of which was 2005 (Figure 1). No records of the species were present in the IDNR Fisheries Analysis System (FAS) database. Spring Cavefish have been collected from four HUC8 watersheds (Cache River, Big Muddy River, Ohio River-Bay Creek and Mississippi River-Cape Girardeau unit) and six counties (Jackson, Union, Pulaski, Johnson, Pope and Hardin).

During the 2003 survey, 31 springs were surveyed within four HUC8s (Figure 2). Spring Cavefish were collected at eleven locations, five of which represented new records. A mean of 30.9 individuals were collected when the species was present (range 2 – 81).

Twenty-one locations were surveyed during the 2013 effort, including five novel locations that (to our knowledge) had not been surveyed before. Ten survey locations were streams and the remaining were springs. Spring Cavefish were collected at nine of the surveyed locations (Figure 2), one of which was a new record for the species. The mean number of Spring Cavefish collected when observed was 3.7 (range 1 – 17). Nine locations were surveyed in both 2003 and 2013. At five of these locations Spring Cavefish were collected during both surveys, at three locations they were not collected during either survey, and at one location they were collected in 2003, but not in 2013. Two other locations where Spring Cavefish were collected in 2003 were dry in 2013 (i.e., there was no surface water present so no survey could be conducted). There was no evidence of recent surface water at either of these two locations, and one had been converted into row crop agriculture.

Thirty variables were utilized during PCA of physical variables. The percent sampled area with floating vegetation variable was dropped from the analysis as none was observed at survey locations. Principle Component 1 (PC1) explained 14.8% of the variation within the ordination and variables with the strongest loadings include three channel morphology variables (% riffle, % run and mean depth), riparian width and percent clay substrate (Table 2). PC2 explained 13.6% of the variation and two variables related to surficial bedrock density, two to watershed land use and the last to channel shading (Table 2). Survey locations where Spring Cavefish were present overlap considerably within the PCA ordination space with those where the species was not detected (Figure 3).

PCA of water quality variables (all variables were utilized) resulted in 51.6% of the variation explained

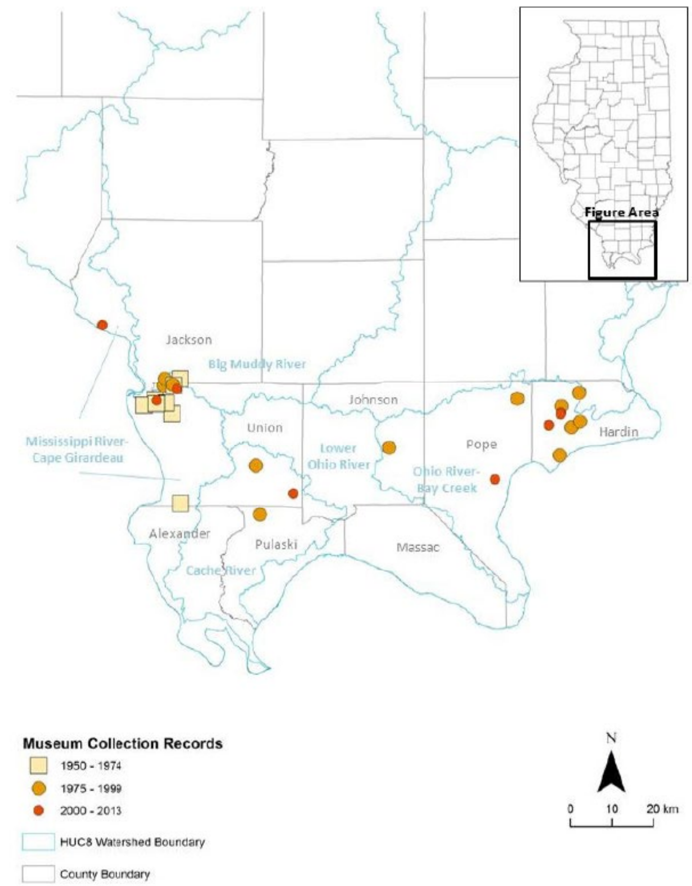

Figure 1. Spring Cavefish records within the Illinois Natural History Survey and Southern Illinois University – Carbondale museum collections. Spring Cavefish have been recorded in six counties and four HUC8 watersheds.

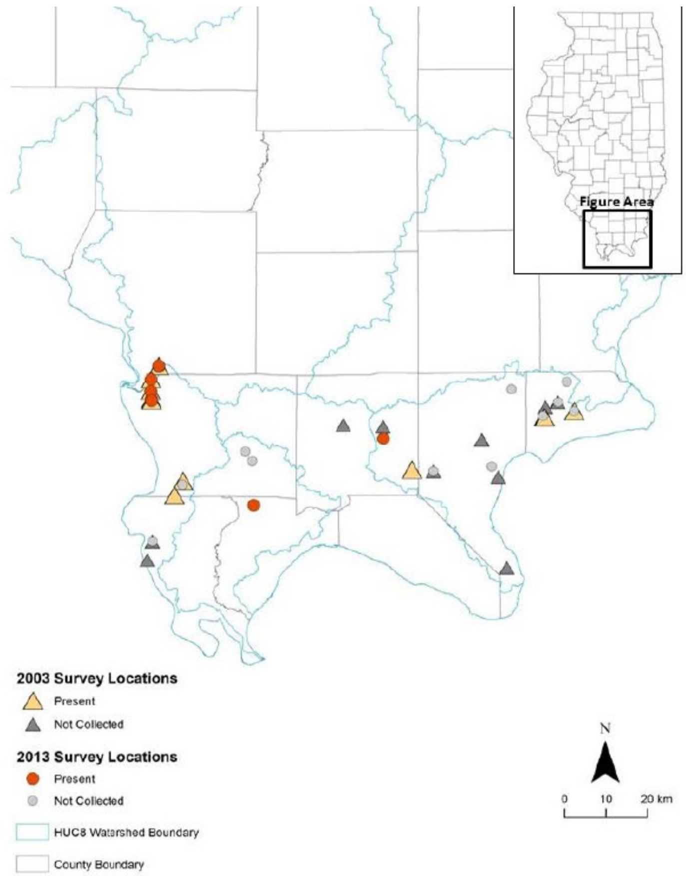

Figure 2. Spring Cavefish survey locations for the 2003 (triangles) and 2013 (circles) efforts.

by PC1 and 22.9% by PC2. Dissolved oxygen and temperature loaded most strongly in PC1, while conductivity and pH in PC2 (Table 3). Within the PCA ordination space survey location where Spring Cavefish are present grouped to the right of the plot, while those where the species was not detect are mostly on the right of the plot (Figure 4).

DISCUSSION

The 2003 and 2013 surveys for Spring Cavefish confirmed the presence of the species at four recorded locations (i.e., locations with museum records) while discovering six locations where the species had not previously been recorded. During these surveys Spring Cavefish were collected from a range of habitats, including springheads, headwaters originating from springs and third-order streams. Conversely, the hydromorphological characteristics (e.g., volume, hydrologic isolation, lack of water) of three surveyed locations where Spring Cavefish were not detected suggests with high certainty that the species has been extirpated at these locations where it had previously been recorded.

Physical variables were of limited use for detecting differences amongst 2013 survey locations with Spring Cavefish and those where it was not detected (Figure 3). There are several possible explanations for this pattern. First, many of the sites where we did not collect Spring Cavefish were locations where historic records exist, suggesting these have characteristics within the tolerance range of the species. The reason(s) why we did not detect presence are not always known, so it is possible these historic locations are still inhabitable for

Table 2. Top five strongest variable loadings for Principal Components 1 and 2 of Principal Components Analysis with physical variables.

Principle Component 1:	
Attribute	**Eigenvector**
% riffle	0.337
mean depth	-0.332
% run	-0.325
% clay substrate	-0.311
riparian width	0.305
Principle Component 2:	
Attribute	**Eigenvector**
% watershed agriculture	0.352
% bank bedrock	-0.339
% channel shading	0.309
% bedrock substrate	-0.296
% watershed forest	-0.281

Table 3. Variable loadings for Principal Components 1 and 2 of Principal Components Analysis with water quality variables.

Attribute	**Eigenvector**	
	PC1	**PC2**
pH	0.472	0.568
dissolved oxygen	0.614	0.221
conductivity	-0.354	0.748
temperature	-0.525	0.265

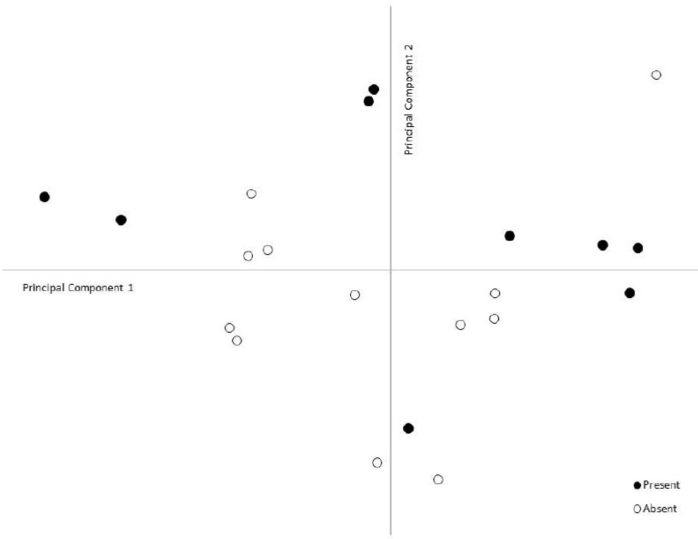

Figure 3. Principal Components Analysis (PCA) plot of environmental variables at 2013 spring Cavefish survey locations. Principal Component 1 describes 14.8% of the variation, Component 2 describes 13.6%. Shaded circles indicate locations where spring Cavefish were collected and hollow circles are those where the species was not detected.

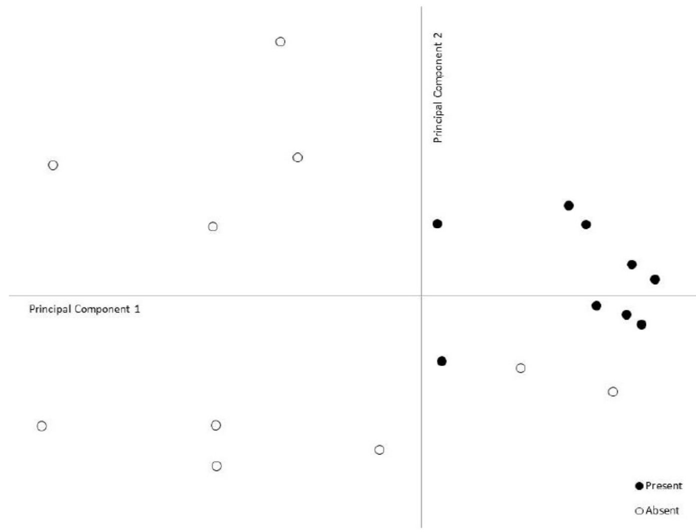

Figure 4. Principal Components Analysis (PCA) plot of water quality variables at 2013 spring Cavefish survey locations. Principal Component 1 describes 51.6% of the variation, Component 2 describes 22.9%. Shaded circles indicate locations where spring Cavefish were collected and hollow circles are those where the species was not detected.

Spring Cavefish. Second, it is possible that the physical variables most important for determining Spring Cavefish distribution were not evaluated. For instance, temperature stability, solar irradiance, flow regime, availability of prey or presence of predators may all influence presence or abundance of Spring Cavefish, and none of these were evaluated during the survey. Third, Spring Cavefish may have a wider breadth of environmental tolerance than expected from a facultative subterranean species. Its presence in aquatic habitats with a broad range of physical and watershed characteristics suggests either a wide realized niche breadth or that only a few conditions limit distribution (e.g., dissolved oxygen concentration or temperature regime). Finally, PCA maximizes distance of survey locations within ordination space by emphasizing those variables which best account for variation within the multivariate dataset; however, the variables most important to differentiating points within the PCA might not be those most influential to Spring Cavefish distribution. Certainly, additional studies focused on describing the relationship between Spring Cavefish and environmental setting might refine our understanding of the species' ecology. Contrary to physical variables, water quality variables did exhibit some relationship with Spring Cavefish distribution (Figure 4). Spring Cavefish tended to be present at locations that had higher dissolved oxygen concentration and lower temperature (PC1). Hill (1968) found that Spring Cavefish exhibited avoidance behavior at dissolved oxygen concentrations less than 6mg/L; the mean concentration at locations with Spring Cavefish was 9.4mg/L and 7.1mg/L where the species was not recorded. The pattern suggested by our PCAs is that physiochemical characteristics of aquatic habitats may more greatly influence Spring Cavefish distribution than physical characteristics.

At a broad spatial scale (i.e., HUC8 watershed), Spring Cavefish distribution has been stable since at least the 1970's when the extent of its range had been surveyed (Figures 1 and 2). Site specific or small scale distribution is more difficult to evaluate given the species' narrow habitat range and the difficulty in collecting it at locations where density is low. The 2003 and 2013 surveys indicate Spring Cavefish populations may become extirpated over a relative short period of time, as suggested by the failure to collect the species at several locations with occurrence records. As it is more difficult to prove absence than presence, it is possible that Spring Cavefish may still be extant at historic locations, especially if they had retreated to subterranean habitats; however, two of 2003 survey locations no longer contain water (i.e., subsurface hydrologic changes have caused them to run dry) and another was small enough that a false determination of absence is unlikely. On the other hand, several unrecorded and recently formed springs were discovered during the 2013 survey (one of which yielded a new Spring Cavefish record). Local extirpations and the emergence of potential habitat suggest stochastic events may be important in understanding the long-term distribution patterns of this species.

One of the largest concerns for the persistence of Spring Cavefish in Illinois is the ability of individuals to disperse or immigrate to sink populations, colonize novel locations or recolonize locations where extirpation has occurred. Their propensity for springs and small streams suggests long dispersal events through river networks, especially from one HUC8 to another, might be unlikely. The suggestion that individual clusters of Spring Cavefish in adjacent watersheds are necessarily connected (Burr et al. 1996) lacks evidence. Therefore, potential connectivity of the species' metapopulation (if the population dynamics behave as such) may depend upon subterranean movement across watershed boundaries and around non-traversable aquatic habitats, like large rivers. It is clear Spring Cavefish utilize subterranean habitats (Smith and Welch 1978, our observations), but their ability to use these as dispersal pathways depends, in part, upon the connectedness of subterranean environments they inhabit. Webb, et al. (1993) surveyed 35 caves within the distribution boundaries of Spring Cavefish in Illinois and observed the existence of significant subterranean structure (although they did not note the presence of the species). But, the dispersal potential for Spring Cavefish through these subterranean systems is unknown. The fragmented nature of Spring Cavefish populations in Illinois makes this species a good candidate for a more focused evaluation of functional connectivity.

SUMMARY

Our study suggests Spring Cavefish distribution is stable at a coarse spatial scale, but its persistence at a local scale (e.g., spring, stream segment) may be unstable over periods of less than a decade. Because the species may use both surface and subterranean pathways, it is difficult to evaluate dispersal potential and therefore recolonization potential. The species' apparent association with water quality may make it vulnerable to alteration of subsurface hydrology related to anthropogenic activities or climate change. Given standardized sampling programs rarely detect Spring Cavefish, we suggest continued monitoring of this species with a focus on evaluation of fine scale distribution and further refinement of ecological status.

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