BioInvasions Records (2015) Volume 4, Issue 2: 125–132
doi: http://dx.doi.org/10.3391/bir.2015.4.2.09

Research Article

Occurrence of the Asiatic weatherfish, *Misgurnus anguillicaudatus* (Cantor, 1842), in Alabama, USA

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Received: 2 September 2014 / Accepted: 14 February 2015 / Published online: 5 March 2015

Handling editor: Vadim Panov

Abstract

The Asiatic weatherfish, *Misgurnus anguillicaudatus*, is a generalist species that has invaded numerous physiographic niches worldwide. Asiatic weatherfish populations have been observed to compete with native fish populations in Hawaii and are of major concern in Australia due to the concomitant introduction of an exotic parasite. Asiatic weatherfish populations have been observed in 16 of the contiguous United States (US) since the 1940s. Alabama is the most recent US state to report sustaining Asiatic weatherfish populations. Asiatic weatherfish were first observed by local fishermen in 2000, but reported established in Alabama in 2009 and, more recently, in 2012. From 2013 to 2014, surveys were conducted in NE Alabama on the Coosa River near Logan Martin Reservoir, as well as the surrounding watershed on the eastern side of the reservoir, specifically investigating for Asiatic weatherfish. Sites were surveyed using standard protocols for the surveying of wadeable streams using a backpack electrofisher and seine nets. Weatherfish were collected at 5 of 15 sites surveyed between 2013 and 2014. A total of 112 fish were collected, comprising 15% (112/738) of total catch. At 2 of the 5 sites, weatherfish occurrence was >50% of the total species observed. Weatherfish were collected in numerous habitats including lentic pools, lotic riffles, as well as in dense vegetation. Numerous size class individuals were collected (27–114mm SL) indicating populations are reproducing. Based on its occurrence in Logan Martin Reservoir and surrounding tributaries, the species appears to be expanding its range utilizing Logan Martin Reservoir as a "stepping stone" for migration. Little is known about competition between Asiatic weatherfish and native US fishes although many conservationists suggest competition is inevitable. Currently, Asiatic weatherfish co-occur in Alabama springs alongside a rare endemic fish species (coldwater dater, *Etheostoma ditrema*) and it is likely to encounter other sensitive species as it expands its range.

Key words: Cobitidae, weatherloach, competition, exotic, invasive, distribution, surveys

Introduction

Alabama is one of the many southeastern states in the United States (US) with an abundant diversity of native freshwater fish species yet Alabama also ranks highest among states with freshwater species extinctions (Lydeard and Mayden 1995; Stein 2002). Habitat loss and destruction are considered primary causes of aquatic species loss, although another, often unassuming, contributing factor may be competition with introduced species (Davis 2003). Whether accidentally or intentionally, Alabama has been subjected to at least 61 species introductions into its waterways (Boschung and Mayden 2004). For example, rainbow trout, *Oncorhynchus mykiss* (Walbaum, 1792) were introduced to support the sportfish industry. Grass carp, *Ctenopharyngodon idella* (Valenciennes, 1844) and mosquitofish, *Gambusia affinis* (Baird and Giard, 1853) were introduced as a means of biologically controlling unwanted aquatic nuisance species (i.e., vegetation/ mosquitos). More often, however, introductions have occurred through the release of aquarium pets such as goldfish, *Carassius auratus* (Linnaeus, 1758) and through release of aquaculture species such as common carp, *Cyprinus carpio* (Linnaeus, 1758) (Nico et al. 2015). While relatively few native freshwater fish species have become extinct after the introductions of exotics, the debate continues over the impacts of such introductions, which in worst-case scenarios the introduced species is detrimental and depresses or displaces imperiled endemic species (Sax and Gaines 2008; Davis 2003). In the US, such a species is often given the status category “injurious” (Pimentel et al. 2004).

The Asiatic weatherfish, *Misgurnus anguillicaudatus* (Cantor, 1842) (Figure 1), is a member of the family Cobitidae, or spined loaches (Kottelat and Freyhof 2007). Native to Eastern Asia, the Asiatic weatherfish is a common food staple in its native region but is also regularly exported as an ornamental species (Amano and Katayama 2009; Kim et al. 1994). The Asiatic weatherfish is anguilliform in shape and typically occurs in low gradient, shallow water streams and springs (Kottelat and Freyhof 2007). In its native range, Asiatic weatherfish occur in paddy fields and is considered beneficial as a consumer of nuisance aquatic weeds and mosquito larvae. Asiatic weatherfish are considered omnivorous scavengers, feeding mostly on small benthic invertebrates and detritus (Kottelat and Freyhof 2007). Asiatic weatherfish are considered hardy, reportedly tolerating temperatures ranging from below zero to nearly 30°C and oxygen tensions below 2 mg/L (Urquhart and Koetsier 2014; Rixon et. al. 2005; McMahon and Burggren 1987).

Australia, Europe, and North Africa have reported naturalized populations of Asiatic weatherfish for decades (Van Kessel et al. 2013). In the US, the species has been observed in Hawaii since the 1800s and on the mainland US since the 1940s (Maciolek 1984; Nico et al. 2014). In the contiguous US, Asiatic weatherfish have been collected in California, Idaho, Illinois, Indiana, Maryland, Michigan, New Jersey, New York, North Carolina, Oregon, Tennessee, and Washington (St. Amant and Hoover 1969; Simon et al. 2006). In 2009, Asiatic weatherfish were collected in Goray Spring along Poorhouse Branch, a small tributary of the Coosa River in Northeast Alabama (Fluker et al. 2010). In 2012, Asiatic weatherfish were collected in Blue Eye Spring near Blue Eye Creek, another tributary of the Coosa River, approximately 20 km from the Goray Spring site in Alabama (Meade and White, unpublished). Due to the relatively low number of species inhabiting Goray Spring and Blue Eye Creek, invasion potential to these sites could be high (Capers et al. 2007). Although Goray Spring and Blue Eye Spring contain few species, these springs each contain unique endemic fishes of Alabama. Furthermore, these springs/creeks are neighboring systems to the Choccolocco Creek watershed, one of the most biodiverse watersheds in Alabama and home to numerous imperiled species including the federally-listed blue shiner, *Cyprinella caerulea* (Jordan, 1877), and pygmy sculpin, *Cottus paulus* (Williams, 2000), as well as the state-listed holiday darter, *Etheostoma brevirostrum* (Suttkus and Etnier, 1991), and coldwater darter, *Etheostoma ditrema* (Ramsey and Suttkus, 1965) (Boschung and Mayden 2004).

Because Asiatic weatherfish utilize aquatic insects as a major food source, they may compete and have an immediate biotic impact on native US fish populations (Tabor et al. 2001). Asiatic weatherfish contribute to poor water quality, which could further have an impact on native species (Keller and Lake 2007). At the locations where Asiatic weatherfish have been collected in Alabama, the species co-occurs with the coldwater darter, *Etheostoma ditrema*, as well as with the banded pygmy sunfish, *Elassoma zonatum* (Jordan, 1877) both considered unique spring species. Because of its occurrence alongside rare species, as well as its proximity to the Choccolocco Creek watershed, environmental managers are concerned over the presence of Asiatic weatherfish in Alabama. Before management decisions regarding its presence can be made, however, the extent of the species range must be determined. The objective of this study was to determine the range of Asiatic weatherfish populations in NE Alabama and if species composition has changed at sites where weatherfish occur based on comparisons with historical data.

Methods

Surveys for Asiatic weatherfish were conducted using a combination of techniques including electrofishing, dip-netting and seining. Where possible, surveys followed US EPA rapid bioassessment protocols (Barbour et. al. 1999), including two-pass surveys of any site. Further, when all habitats (riffle, run, and pool) were present at any site, the USGS 30 + 2 method was employed to ensure the sites were thoroughly surveyed (O’Neil and Chandler 2005). Fish were identified on site (Genus/species) and enumerated. Any Asiatic weatherfish collected were further measured (SL, standard length in mm), digitally photographed, and then vouchered and placed in the JSU museum collection. Water quality parameters including temperature (C), pH, conductivity (μS), and TDS (total dissolved solids, ppm) were also recorded for sites where Asiatic weatherfish were collected.

Sites surveyed were those where Asiatic weatherfish had previously been collected as well as sites in the region containing potential suitable habitat to support Asiatic weatherfish populations. In general, most sites surveyed were tributaries (ephemeral and perennial) to the east of Logan Martin Reservoir, many including springs where lentic conditions were prevalent. Surveys were performed predominantly during cooler months to reduce stress to captured individuals. Additionally, many ephemeral sites along Logan Martin reservoir were inundated with water during winter months and dry during warm summer months. Upon collection of Asiatic weatherfish at any site, resurveys were performed to confirm establishment. A total of 15 sites were surveyed between February 2013 and November 2014 including: Cropwell Branch on Logan Martin Reservoir (site 1), Blue Eye Spring on Blue Eye Creek (site 2), an unnamed Choccolocco Creek tributary on Springhill Road in Lincoln, AL (site 3), Goray Spring on Poorhouse Branch (site 4), an unnamed Choccolocco Creek tributary adjacent to Highway 77 near Morgan Springs Road in Lincoln, AL (site 5), Choccolocco Creek at Highway 77 (site 6), Flynn Spring (site 7), Stoney Branch (site 8), Eastaboga Creek (site 9), Plum Spring (site 10), Everett's Spring (site 11), Dill's Spring (site 12), Cheaha Creek (site 13), Fayne Creek (site 14), and Dry Branch (site 15) (Table 1) (Figure 2).

Shannon indices were calculated for each site surveyed. Shannon indices and/or Jaccard's index were also calculated for historical data, when available. Shannon indices were compared for significance using Hutcheson significance (H test) ($\alpha = 0.05$) (Hutcheson 1970; Zar 1999).

Results

Asiatic weatherfish were collected at 5 of the 15 sites surveyed. Those sites included Cropwell Branch (site #1), Blue Eye Spring (site #2), an unnamed Choccolocco Creek tributary on Springhill Road (site #3), Goray Spring (site #4), and an unnamed Choccolocco Creek tributary on Highway 77 (site #5). The numbers of species collected at each site ranged from 0 to 11 (mean 5.1 ± 3.5 species/site) and a total of 27 species were collected overall (Supplementary material Table S1). Asiatic weatherfish were predominately observed in silty substrate or in dense milfoil, *Myriophyllum spicatum* (Linnaeus, 1753). Overall, however, weatherfish were collected in a variety of habitats, including lentic and lotic habitats, within a single site.

Return surveys were performed on sites 1–5. During one survey of Blue Eye Spring (11/5/13), no Asiatic weatherfish were collected; however, during a survey in early 2014 (1/25/14), Asiatic weatherfish were collected. Asiatic weatherfish were collected during all return surveys of Goray Spring and Cropwell Branch during the study period. The unnamed tributaries on Springhill Road and Morgan Springs Road are ephemeral sites, only inundated during cooler months, thus weatherfish were not always observed at those sites. Data for any site includes the most complete list of species found during any survey attempt.

When collected, abundance of weatherfish ranged from 5 to 40 specimens/site and comprised from 10 to 79% of total fish catch at any site. Weatherfish made up greater than 50% of the catch in silty substrate sites with minimal or no canopy. Further, the abundance of weatherfish increased at sites closer to Logan Martin Reservoir. Weatherfish co-occurred with coldwater darters (22 specimens, 14.6% catch) in Goray Spring and with banded pygmy sunfish (15 specimens, 14.3% catch) in Blue Eye Spring, both species also occurring in dense milfoil with Asiatic weatherfish. Sizes of weatherfish varied ranging from 28–147mm SL with a mean SL of 90.5±22.7 mm. Multiple size classes were present at all sites where weatherfish were present (Table 2).

Water quality parameters for sites where Asiatic weatherfish were present varied (Table 3). In brief, temperatures at each site were below 18°C with pH values in the neutral to basic range (>7.3). Conductivity and TDS values varied from site to site ranging from 60 – >300 uS and 43–>200 ppm, respectively.

Shannon indices for sites with complete survey data are listed in Table S1. Sites excluded from Table S1 were either ephemeral sites or mere presence/absence survey data that was merely performed to document general species composition. In summary, Blue Eye Spring had the highest diversity (H = 1.98) for the sites surveyed, however there was no significance among Shannon indices ($p = 0.86$) among any site. No historical data on species composition for any site was available except for Blue Eye Spring. A Shannon index was calculated for Blue Eye Spring based on a 1964 survey including numbers and species observed (H = 1.36), whereas Jaccard coefficients were calculated for surveys comparing years 1964, 1990, and 2013 based on species occurrence only (Table 4).

Figure 1. Male (A) and female (B) specimens of Asiatic weatherfish, *Misgurnus anguillicaudatus*, collected in Alabama during 2013-2014 surveys (photograph by Lindsay White).

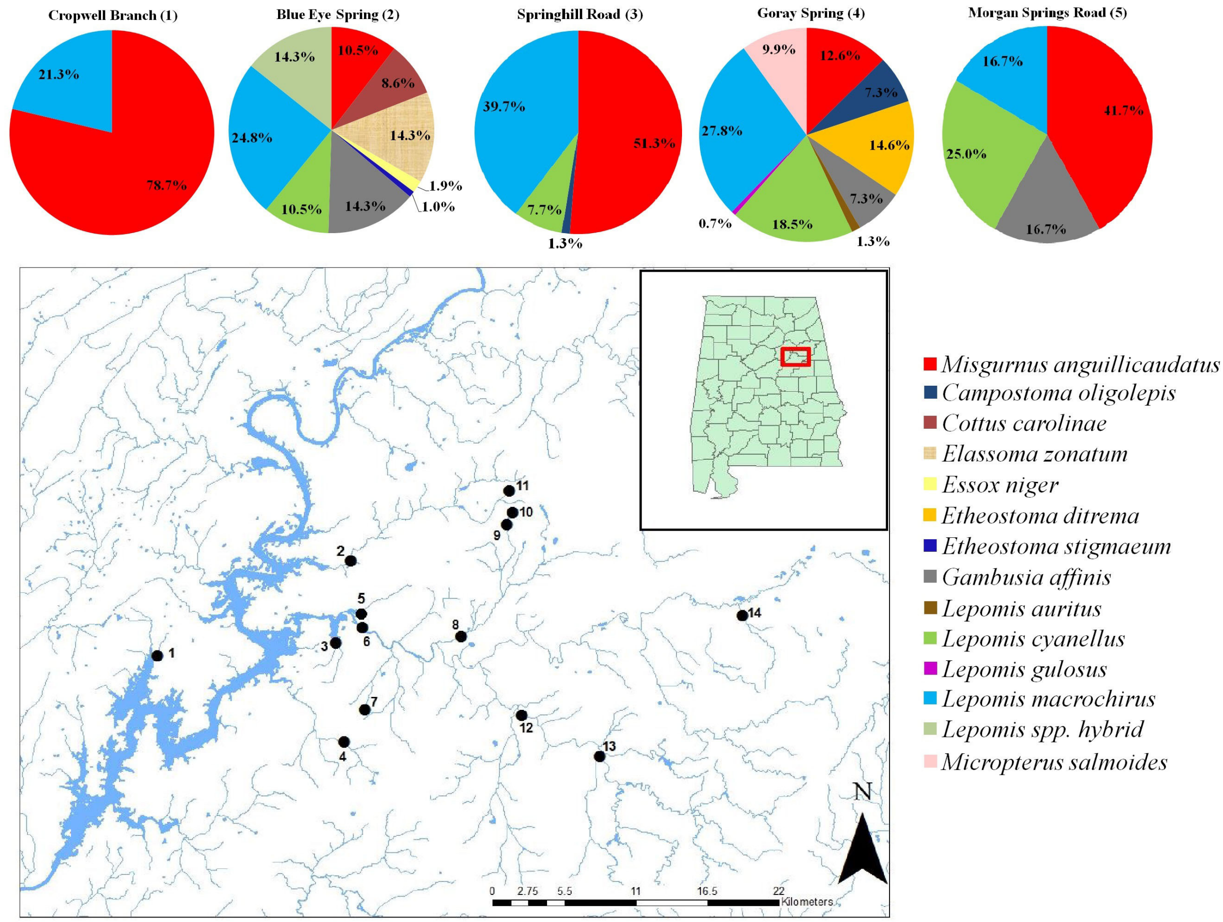

Figure 2. Locations surveyed on Logan Martin Reservoir (Coosa River) and surrounding tributaries showing species composition at sites where Asiatic weatherfish were collected: Cropwell Branch on Logan Martin Reservoir (1), Blue Eye Spring on Blue Eye Creek (2), unnamed Choccolocco Creek tributary on Springhill Road in Lincoln, AL (3), Goray Spring on Poorhouse Branch (4), unnamed Choccolocco Creek tributary adjacent to Highway 77 near Morgan Springs Road in Lincoln, AL (5), Choccolocco Creek at Highway 77 (6), Flynn Spring (7), Stoney Branch (8), Eastaboga Creek (9), Plum Spring (10), Everett's Spring (11), Dill's Spring (12), Cheaha Creek (13), Fayne Creek (14), and Dry Branch (15).

Table 1. GPS coordinates for 15 sites surveyed for Asiatic weatherfish in the Coosa River drainage of Northeast Alabama. Sites were surveyed from February 2013 to March 2014.

Site #	Site	Coordinates		Date
		Latitude	Longitude	
1	Cropwell Branch	33°32'43.4"	-86°16'06.1"	1/24/2014
2	Blue Eye Spring	33°36'06.5"	-86°08'06.2"	4/18/2013
3	Springhill Rd Tributary	33°33'10.8"	-86°08'43.2"	2/20/2014
4	Goray Spring	33°29'38.9"	-86°08'22.3"	10/22/2013
5	Morgan Springs Rd Tributary	33°34'13.0"	-86°07'38.5"	2/26/2014
6	Choccolocco at Hwy 77	33°33'42.9"	-86°07'37.6"	2/21/2014
7	Flynn Spring	33°30'47.5"	-86°07'30.9"	2/28/2013
8	Stoney Branch	33°32'58.5"	-86º06'26.4"	3/27/2014
9	Eastaboga Creek	33°33'24.7"	-86°03'31.0"	11/19/2013
10	Plum Spring	33°37'23.2"	-86°01'38.2"	2/28/2013
11	Everetts Spring	33°37'48.4"	-86°01'22.9"	10/2/2013
12	Dills Spring	33°38'35.1"	-86°01'32.1"	10/1/2013
13	Cheaha Creek	33°30'36.1"	-86°01'00.3"	4/9/2013
14	Fayne Creek	33°29'08.4"	-85°57'46.5"	3/21/2013
15	Dry Branch	34°34'08.7"	-85°05'50.7"	3/14/2013

Table 2. Total percent catch, percent catch of adults, percent catch of juveniles, and standard length (SL) range of Asiatic weatherfish at sites where collected (Urquhart and Koetsier 2011).

Site	% Total Catch	% Adult (>100mm)	%Juvenile (<100mm)	Range SL (mm)
Cropwell Branch	78.7	3.9	96.2	28–106
Blue Eye Spring	10.5	100.0	0.0	110–128
Springhill Rd Tributary	51.3	18.2	81.8	50–130
Goray Spring	12.6	71.4	28.6	84–147
Morgan Springs Rd Tributary	41.7	25.0	75.0	60–112

Table 3. Water quality parameters including temperature, pH, conductivity (Cond.), and total dissolved solids (TDS) at the sites were Asiatic weatherfish populations were collected.

Site #	Site	T (°C)	pH	Cond. (µS)	TDS (ppm)
1	Cropwell Branch	9.50	8.76	122.10	100
2	Blue Eye Spring	17.10	7.30	313.00	222.00
3	Springhill Rd Tributary	13.20	8.01	60.10	43.50
4	Goray Spring	18.00	7.70	315.00	217.00
5	Morgan Springs Rd Tributary	10.50	7.80	118.10	83.10

Table 4. Species occurrence and calculated Jaccard coefficients from historical data obtained from Blue Eye Creek survey years 1964, 1990, and 2013.

Species	**1964**	**1990**	**2013**
Campostoma oligolepis Hubbs & Greene, 1935	-	P	-
Cottus carolinae (Gill, 1861)	P	P	P
Cyprinella venusta Girard, 1856	P	-	-
Elassoma zonatum Jordan, 1877	-	-	P
Essox niger Lesueur, 1818	-	-	P
Etheostoma stigmaeum (Jordan, 1877)	P	-	P
Gambusia affinis (Baird & Girard, 1853)	P	P	P
Hemitremia flammea (Jordan & Gilbert, 1878)	-	P	-
Lepomis cyanellus Rafinesque, 1819	-	P	P
Lepomis macrochirus Rafinesque, 1819	-	-	P
Lepomis miniatus (Jordan, 1877)	P	-	P
Misgurnus anguillicaudatus (Cantor, 1842)	-	-	P
Notemigonus chrysoleucas (Mitchill, 1814)	P	-	-
Notropis chrosomus (Jordan, 1877)	P	-	P
Semotilus atromaculatus (Mitchill, 1818)	-	P	-

Jaccard	**1964**	**1990**	**2013**
1964	-	0.18	0.42
1990	0.18	-	0.21
2013	0.42	0.21	-

Discussion

Although not currently considered an invasive species by U.S. Fish and Wildlife Service (USFW), Australia placed a ban on import of Asiatic weatherfish in 1986 and labeled it a "noxious" species under the Victoria Fisheries Act of 1995 (Lintermans 2007; Department of Agriculture, Fisheries, and Forestry 2006). Part of the reasoning behind this listing was due to the rapid expansion of the species range in Australia. Researchers suggested that Asiatic weatherfish were expanding their ranges in Australia at a rate of 7 km/yr (Lintermans 2007). Observations of populations in the US (Michigan) indicate the species was expanding its range more slowly, possibly moving 1km/yr (Tabor et al. 2001). Although the method of initial introduction into the Coosa River watershed is unknown (possibly through aquarium release), the sites in Alabama where Asiatic weatherfish have been collected indicate the species is expanding its range, moving from Logan Martin Reservoir into the surrounding watersheds. Indeed, reservoirs often facilitate exotic introductions acting as "stepping stones" to expansion (Havel et al. 2005). Although not substantiated, Alabama Department of Conservation and Natural Resources managers suggest that local fisherman reported Asiatic weatherfish in Logan Martin Reservoir around the year 2000 (Fluker et al. 2010). Based on current survey data to the east of the reservoir, this would suggest the population became established in the reservoir and has moved at least 1km/yr since that time.

The flexible and adaptive feeding behavior of Asiatic weatherfish further raises concern over the presence of the species outside its native range (Simon et al. 2006). Tabor (2001) observed that Asiatic weatherfish prey extensively on benthic invertebrates and copepods. Researchers have also observed Asiatic weatherfish feeding on *Gambusia affinis* fry and commercially prepared salmon eggs when held in aquaria (Logan et al. 1996; Simon et al. 2006). Due to its burrowing behavior in silty or heavily vegetated areas, and its feeding behavior, Asiatic weatherfish may further affect benthic egg laying species. Such interaction could be devastating to numerous Alabama families of fishes including endemic Centrarchids, Percids, and Cyprinids (Boschung and Mayden 2004).

Other than direct biotic competition, Asiatic weatherfish may have an abiotic advantage, compared to native species, that facilitates its exploitation of non-native habitats. The Asiatic weatherfish is considered a hardy species, tolerating temperatures ranging from below zero up to 30°C (Logan et. al. 1996; Van Kessel et.al. 2013; Urquhart and Koetsier 2014). Asiatic weather-fish also employ facultative air breathing when oxygen tensions are low (Nico et. al. 2014; McMahon and Burggren 1987). Further, Tsui et al. (2004) have shown that Asiatic weatherfish are capable of tolerating high ammonia (NH_3) concentrations and may thrive in areas containing pollutants known to harm other species. If the Asiatic weatherfish is more of a generalist species, tolerating a wide range of environmental conditions, it may have an advantage over native Alabama fish species that are more specialized, often having narrower tolerances to environmental conditions (Boschung and Mayden 2004). Despite the cooler temperatures in this study, Asiatic weatherfish were collected in springs/streams that typify water quality conditions within the region. Notably, weatherfish were found in habitats where nutrient loading due to agricultural practices is often high (i.e., Goray and Blue Eye Spring) and apparently such conditions did not deter their presence.

Mosquitofish, *G. affinis*, and the basket clam, *Corbicula fluminea* (O.F. Müller, 1774), are both Asian species that are ubiquitous to NE Alabama streams. When found, both of these species typically occur in high densities, however, they appear to have minimal impact on native species. Numerous studies, however, have shown that mosquitofish can have a negative impact on native southwestern fishes (Archdeacon et al. 2008). Recent evidence also suggests that mosquitofish may have a negative impact on southeastern minnows (Laha and Mattingly 2007).

The impact of Asiatic weatherfish on Alabama native fishes has not been investigated; however, comparisons of past and current fish assemblages at Blue Eye Spring/Creek suggest changes have occurred in species composition (Sizemore and Howell 1990). At many sites, throughout the year, fish assemblages fluctuate, particularly ephemeral sites in drier months. Due to the vast differences in assemblage data, however, which could be attributed to survey methods or survey intention (i.e. complete surveys vs. presences/absence surveys and the inclusion of species collected in adjacent creeks into spring species lists, etc.), comparisons with the data collected in this study have been difficult. For example, the flame chub, *Hemitremia flammea*, a unique spring species, was collected in Blue Eye Spring in 1962 and 1986, however the species has not been observed since 1986. In addition, the banded pygmy sunfish, *Elassoma zonatum*, was not reported in Blue Eye Spring in any historical survey data yet occurs in high densities at the site currently. Interestingly, in 1999 Honda Manufacturing of Alabama LLC began construction of a facility adjacent to Blue Eye Spring. This was also the approximate time when local fishermen first observed Asiatic weatherfish in Logan Martin Reservoir. Whether or not one or both of these events resulted in the change in fish assemblages at Blue Eye Spring is not known, however, both may have been contributing factors.

Blue Eye Spring and Goray Spring have relatively high diversities for spring habitats, according to calculated Shannon indices, and both rank similarly to other creeks surveyed in the region. Difficulty interpreting Shannon and Jaccard indices extends to all sites, however, where, in many cases, only species presence or absence data was reported. In addition, data from Cropwell Branch and many of the other ephemeral sites surveyed in close proximity to Logan Martin Reservoir (Springhill Road and Morgan Springs Road) is likely not representative of assemblages within the lake itself. Overall, comparisons from past and present surveys give no clear indication of changes in fish assemblages at the sites. For example, Jaccard's suggests that Blue Eye Spring had more similarity in species composition between years 1964 and 2013 compared to year 1990. Overall, no definitive evidence exists to conclude whether the populations have changed considerably at Blue Eye Spring and, if they have changed, whether or not the introduction of Asiatic weatherfish contributed to that change.

The presence of exotic species in any aquatic system is a major concern for environmental managers. In many cases, exotics or nuisance species can be controlled or eradicated, however many of the methods used to remove nuisance species can also result in the loss or harm to native species (Britton et al. 2011). In many cases natural barriers, such as waterfalls, and even man-made barriers such as dams, can limit the spread of exotic species. Asiatic weatherfish, however, have been observed to "walk" in mud bogs and may not be impeded by the presence of natural or man-made obstacles (Kottelat and Freyhof 2007). Indeed, in this study, numerous Asiatic weatherfish populations were collected upstream of potential culvert barriers at road crossings. Further complicating any issues with removal or eradication of any exotic is simply verifying the presence or absence of the exotic at any site. Due to its elusive nature of burrowing into the sediments or dense vegetation, Asiatic weatherfish often go undetected. In our surveys over the years and in many discussions with Alabama regional environmental managers regarding their surveys, Asiatic weatherfish were not always collected at sites where populations had previously been confirmed. Whether a population at any site had been extirpated or had migrated to another site is not known. Further, whether the populations collected at any site were the result of multiple or a single introduction is not known. The use of eDNA may help to fully elucidate the range of Asiatic weatherfish in Alabama as well as whether or not numerous introductions have occurred.

Acknowledgements

This project was funded in part by Jacksonville State University and USFW. We would like to thank Dr. Bernie Kuhajda for his expertise and comments on the manuscript. We would also like to thanks the science staff and students of Munford High School for their aid in collecting survey data: Mrs. Kim Murray, Mrs. Beth Bowers, Miss Kayla Sarro, Miss Jerrica Lindsey, Miss Kelley Foster, Miss Heather Mayfield, Miss Tabitha Hood, and Mr. Trey Roberson. Finally, we offer a sincere thank you to the reviewers of this manuscript.

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Supplementary material

The following supplementary material is available for this article:

Table S1. List of species collected at each of the 15 sites surveyed from February 2013 to March 2014 reporting surveys with the greatest occurrence of species at any given site, including Shannon Indices for each site surveyed from which data was sufficient.

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