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Evaluation of Benthic Fish Communities in the Clinch and Duck rivers as Habitat Indicators for the Endangered Pygmy Madtom, *Noturus stanauli*

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Abstract

Identifying which species are associated with a specific endangered species can inform conservation managers about potential community associations and novel localities. The benthic fish community associated with the Pygmy Madtom (*Noturus stanauli*) in the Duck River has been documented through Index of Biotic Integrity (IBI) work at sites where the Pygmy Madtom has occurred by the Tennessee Valley Authority (TVA). To complement the Duck River data, we gathered benthic fish community data associated with the Pygmy Madtom in the Clinch River. We used Pflieger's metrics of constancy and fidelity to evaluate fish associations with the Pygmy Madtom. We also used and adapted Pflieger's approach to create a faunal index that will recognize potential Pygmy Madtom habitat. In the Clinch River, Mountain Madtom (*Noturus eleutherus*) and Golden Darter (*Nothonotus denoncourti*) had a constancy percentage of 100%, while the remaining associated species were each 60% or less. Bluebreast Darter (*Nothonotus camurus*) (50%) and Golden Darter (45.5%) had the most realistic fidelity to the Pygmy Madtom. The overall range of values for the resulting Pygmy Madtom Clinch River faunal index was -2 to 1, and Pygmy Madtom events only occurred at faunal index values of 0 to 1. In the Duck River, Banded Sculpin (*Cottus carolinae*), Duck Darter (*Etheostoma planasaxatile*), Logperch (*Percina carpodes*), Mountain Madtom, Redline Darter (*Nothonotus rufilineatus*), and Gilt Darter (*Percina evides*) had a constancy percentage of 100%, while the remaining associated species were at 80% or less. The Bluebreast Darter (100%) and Fringed Darter (*Etheostoma crossopterum*) (66.6%) had the strongest fidelity to the Pygmy Madtom in the Duck River. The overall range of values for Pygmy Madtom Duck River faunal index was -3 to 4 and Pygmy Madtom events only occurred at faunal index values from 1 to 4. The simplicity and usefulness of the Pygmy Madtom faunal indices for the Clinch and Duck rivers represent a valuable tool that field biologists and others could use to help identify additional sites potentially suitable for Pygmy madtoms throughout both rivers.

Keywords

Constancy, Fidelity, Faunal index, Pflieger

Cover Page Footnote

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INTRODUCTION

A comprehensive understanding of ecology and life history is a fundamental precursor to successful conservation and management of imperiled species. One important ecological aspect may be recognizing which species co-occur with imperiled species. These assemblage and community associations can inform conservation biologists about usable habitats for the species in question. Unfortunately, the conservation literature is limited on endangered species faunal associations, what these associations mean ecologically, and how to evaluate these interactions. From a practical management perspective, Pflieger's (1978) methods provide an easy approach to evaluate fish species associations. Pflieger's (1978) methods only require occurrence data associated with the focal species. However, various co-occurrence methods that are more analytical can be found in recent ecological literature. For example, in Veech (2014), emerging pairwise approaches analyzing species co-occurrence are discussed that may simplify analysis and understanding among paired species. Veech (2014) provides a table of analytical analyses (null models, network analysis, etc.) used to study co-occurrence from 1986–2013.

Pflieger (1978) evaluated species associations in his report on the status and life history of the Niangua Darter (*Etheostoma nianguae*) in the Osage River Basin, Missouri using the concepts of dominance (relative abundance of fishes collected with the focal species), constancy (the number of occurrences of a species with the focal species as a percentage), and fidelity (the number of occurrences of a species with the focal species as a percentage of total occurrences). Fifty-seven fish species were recorded at sites where Niangua darters were collected. The Niangua Darter is rare, localized and considered vulnerable to extinction (Pflieger 1978). Pflieger also created a Niangua Darter faunal index predicting possible sites of occurrence for the Niangua Darter in areas where it was previously unknown. Fidelity was used to calculate the Niangua Darter faunal index. The faunal index is a simple mathematical tool used to predict where a species might occur utilizing fidelity as the principal criteria. Steps for calculating the faunal index are provided in the methods.

Pflieger's methods have been adapted and applied to two recent studies on Blackside Dace (*Chrosomus cumberlandensis*) and Williams' Crayfish (*Faxonius williamsi*). Mattingly and Black (2013) examined Blackside Dace nest association and observed Creek Chub (*Semotilus atromaculatus*) in all Blackside Dace spawning events, which was consistent with their co-occurrence analysis. Wagner et al. (2010) focused on the status and distribution of the Williams' Crayfish and

discovered that Meek's Crayfish (*Faxonius meeki meeki*) was the most commonly associated species with Williams' Crayfish.

A specific example of another co-occurrence method slightly similar to Pflieger (1978) is by Peres-Neto (2004); however, it differs by employing a theoretical approach compared to Pflieger's (1978) practical approach. Peres-Neto (2004) introduced a series of null models that were developed to provide a more dynamic evaluation of species associations by clarifying different processes that may shape fish distributions and communities in Brazil. However, Peres-Neto (2004) concluded that species co-occurrences were driven by species-habitat relationships and that species interactions did not play a significant role in community structure in the Brazilian study.

Comprehensive or quantitative assessments of species co-occurrence do not exist for fishes associated with the federally endangered Pygmy Madtom (*Noturus stanauli*). However, Etnier and Jenkins (1980) and Starnes and Starnes (1985) did report that Mountain Madtom (*Noturus eleutherus*) was anecdotally associated with the Pygmy Madtom. If the Mountain Madtom or other species are strongly associated with the Pygmy Madtom, these fishes could serve as indicators for potential Pygmy Madtom sites.

The objectives of this study were to evaluate fish species associated with the Pygmy Madtom, and create a faunal index to recognize Pygmy Madtom habitat in the Clinch and Duck rivers. We used Pflieger's (1978) metrics of constancy and fidelity to evaluate fish associations with the Pygmy Madtom. We then adapted Pflieger's (1978) approach to create a faunal index that identified potential Pygmy Madtom habitat.

METHODS

Overview

Collection methods for Pygmy madtoms and other benthic fishes varied between the Clinch and Duck rivers. The collection methods for the Clinch River followed a protocol that we developed to measure environmental variables (depth, distance to bank, streambed roughness, temperature, and velocity) at the microhabitat scale by kick-seining a quadrat. The collection methods for the Duck River followed protocols that the Tennessee Valley Authority (TVA) adapted from Karr's (1981) Index of Biotic Integrity (IBI) for site monitoring. Comparable IBI collections by TVA in the Clinch River were not available for mainstem sites near the Frost Ford and Kyles Ford areas (Figure 1).

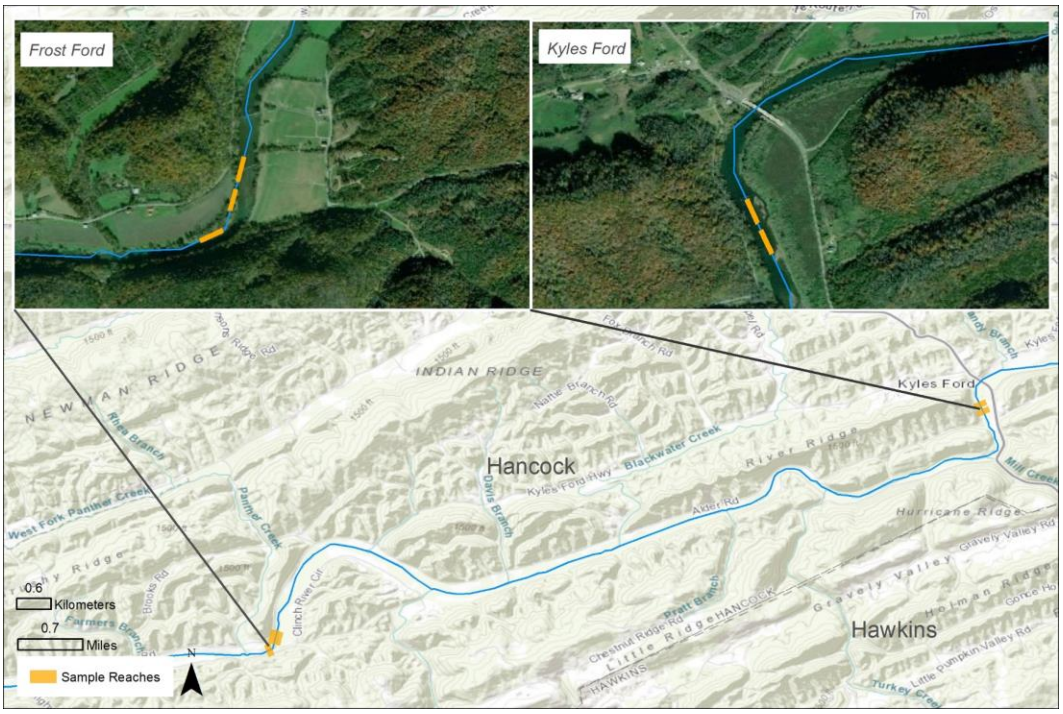

Figure 1. Map of sampling reaches described for the Frost Ford and Kyles Ford areas of the Clinch River, Tennessee.

All calculations to determine constancy and fidelity followed Pflieger (1978). The faunal index for benthic fishes associated with the Pygmy Madtom was adapted from Pflieger (1978). Microsoft Excel® for Mac 2011 was used for calculations and the creation of figures.

Clinch River sampling methods

Collection efforts during the 2017 season followed a strict protocol to measure microhabitat variables associated with Pygmy Madtom presence and absence. Simple kick-seining techniques were used to collect benthic fish species. A 1-m X 1.5-m quadrat was kick-seined twice, approximately every 10 m along a transect, within a 50-m or 100-m reach. One kick-seine set was near shore and the other was near mid-channel. A total of 20 kick-seine efforts were conducted in a 100-m reach and 10 kick-seine efforts were conducted within a 50-m reach. Electrofishing was not used. Three 100-m reaches and one 50-m buffer reach were sampled along the north bank, and one 100-m reach was sampled on the south bank of the Clinch River at Frost Ford. Two 100-m reaches were sampled at Kyles Ford during the fall of 2017. A total of 14 collection events occurred among these reaches at Frost Ford and Kyles Ford.

Duck River sampling methods

The TVA used IBI methodologies adapted from Karr (1981) to measure water quality based on fish assemblage composition, richness, and condition. The TVA methods were created to deplete habitats (i.e., pools, riffles, and runs) to maximize detection. Riffles and runs were sampled in a downstream direction with backpack electrofishers and stunned fish drifted into seines (6.1 m x 1.8 m), whereas pools were sampled by seine hauls (J.W. Simmons, TVA, unpubl. data). Every time a new species was encountered, three additional efforts were conducted until no new species were collected. Drainage areas >161 km^2 were boat electrofished to capture fishes in the non-wadeable pools and runs (J.W. Simmons, TVA, unpubl. data). The TVA sites in the Duck River were Hite Ford, I-40 bridge, Barren Hollow, and HWY-230 Bridge (Figure 2). Collection dates at these sites ranged from 1990–2014 (Table 1). We used a total of 18 sampling events from their IBI efforts. Hite Ford had the most collection events (n = 13) of all of these sites.

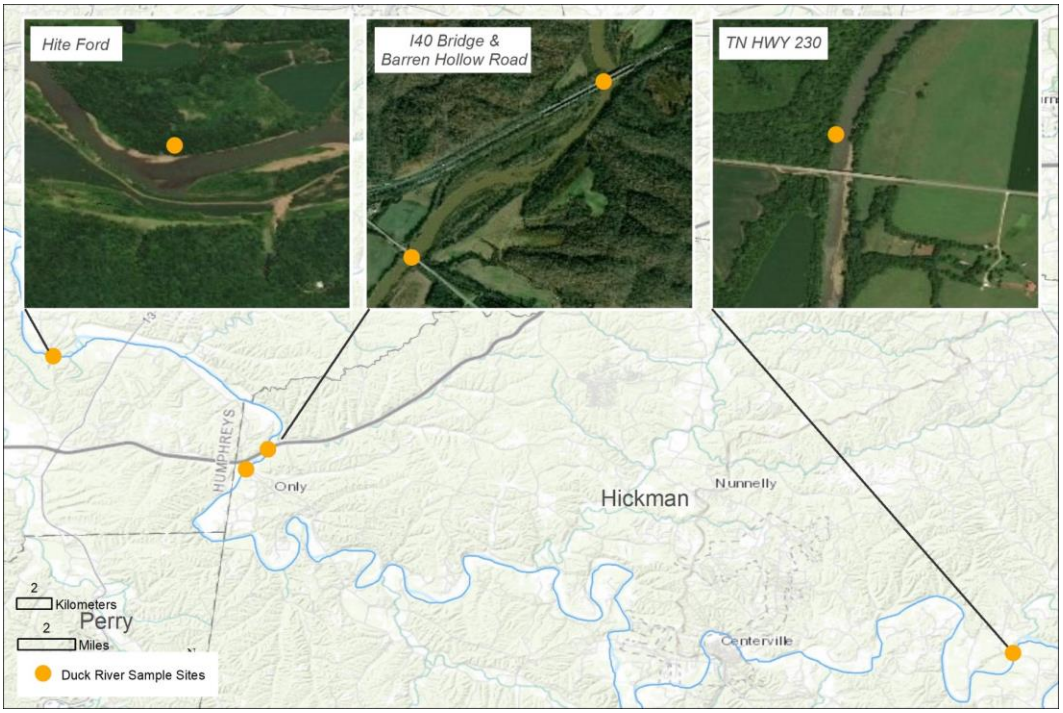

Figure 2. Map of TVA sampling sites for areas of the Duck River, Tennessee.

Table 1. Index of Biotic Integrity (IBI) collection sites and dates as events (n = 18) in the Duck River, Tennessee. Sampling was conducted by Tennessee Valley Authority between June 1990 and July 2014. GPS coordinates are given once for each site. Events are listed chronologically for the Pygmy Madtom present events and Pygmy Madtom absent events.

***Event*/Site name**	**GPS coordinates**	**Sampling Date**
Pygmy Madtom present events		
Interstate 40 bridge	35.880700, -87.694900	November 1993
Barren Hollow Road	35.870517, -87.706064	November 1993
Tennessee Highway 230	35.777800, -87.318100	August 2002
Tennessee Highway 230		August 2007
Hite Ford	35.927800, -87.803600	June 2008
Pygmy Madtom absent events		
Hite Ford		June 1990
Hite Ford		July 1991
Hite Ford		July 1992
Hite Ford		June 1993
Hite Ford		July 1994
Hite Ford		June 1996
Hite Ford		August 1998
Hite Ford		August 2004
Hite Ford		July 2010
Hite Ford		June 2012
Tennessee Highway 230		June 2012
Hite Ford		July 2012
Hite Ford		July 2014

Pflieger's (1978) calculation methods for constancy, fidelity, and faunal index

Pflieger (1978) defined constancy as "the number of occurrences of a species with the Niangua Darter as a percentage of total Niangua Darter occurrences." Constancy for Pygmy Madtom-associated species was calculated by summing the number of species' occurrences with the Pygmy Madtom and dividing that value by the total number of Pygmy Madtom occurrences and multiplying by 100. Pflieger (1978) defined fidelity as "the number of occurrences of the species with the Niangua Darter as percentage of total occurrences of the species at the stations where seine collections were made." Fidelity was calculated for the Pygmy Madtom by summing the number of occurrences of a species with the Pygmy madtom, dividing that value by the total number of occurrences (including occurrences without Pygmy Madtom), and then multiplying by 100. Lastly, Pflieger (1978) proposed a simple faunal index that would (1) recognize Niangua Darter habitat, (2) evaluate locations/events where Niangua Darter had been collected with a range of values from the index, and (3) apply the index to sites/events that indicate stream segments capable of supporting Niangua darters.

The Pygmy Madtom faunal index was adapted from Pflieger's (1978) faunal index, which included the groups, "large, nektonic, and benthic" fishes. We only used benthic species in the Pygmy Madtom faunal index. We used our best professional judgment to designate percentages for positive and negative indicators from testing several percentage possibilities. Because we only used benthic fishes, this contributed to higher cutoffs. Cutoffs may be adjusted as needed for future index work. Fidelity was the metric Pflieger (1978) used to create the faunal index and was the only metric used in this study for the Pygmy Madtom faunal index. Fish species in the Clinch River that had a fidelity of 40% or greater were designated as positive indicators and species that had a fidelity of 30% or less were designated as negative indicators. Pflieger (1978) used fidelities of 25% or greater for positive indicators and 5% or less for negative indicators; however, these cut offs were never described. In the Duck River, fish species that had fidelity of 50% or more were designated as positive indicators and species that had fidelity of 25% or less were designated as negative indicators. The faunal index was calculated for 14 events in the Clinch River and for 18 events in the Duck River by subtracting the number of negative indicators from the number of positive indicators for each event.

RESULTS

Clinch River species associations and faunal index

The Clinch River had three positive indicator fishes [Banded Sculpin (*Cottus carolinae*); Bluebreast Darter (*Nothonotus camurus*); and Golden Darter (*Nothonotus denoncourti*)] and three negative indicator fishes [Gilt Darter (*Percina evides*); Redline Darter (*Nothonotus rufilineatus*); and Snubnose Darter (*Etheostoma simoterum*)]. The Mountain Madtom and Golden Darter had a constancy percentage of 100% and the remaining associated species were each 60% or less (Table 2). Banded Sculpin had the strongest fidelity to Pygmy Madtom; however, this may be an outlier because we only collected one with the Pygmy Madtom and none in the absent sites and, as a result, its fidelity was 100%, which may be misleading. The Bluebreast Darter (50%) and Golden Darter (45.5%) had the most realistic, in terms of sample size, fidelity to the Pygmy Madtom (Table 3). The remaining species had fidelities of 38.5% or less. The range of values for Pygmy Madtom faunal index was -2 to 1, and Pygmy Madtom events only occurred at faunal index values of 0 to 1 (Table 4).

Table 2. Clinch River constancy = occurrences of benthic fishes with the Pygmy Madtom as a percentage of total Pygmy Madtom occurrences.

Species	Common Name	Constancy (%)
Nothonotus denoncourti	Golden Darter	100
Noturus eleutherus	Mountain Madtom	100
Nothonotus camurus	Bluebreast Darter	60
Percina evides	Gilt Darter	60
Nothonotus rufilineatus	Redline Darter	40
Etheostoma zonale	Banded Darter	20
Cottus carolinae	Banded Sculpin	20
Etheostoma meadiae	Bluespar Darter	20

Table 3. Clinch River fidelity = occurrences of benthic fishes with the Pygmy Madtom as a percentage of total occurrences for the Pygmy Madtom.

Species	Common Name	Fidelity (%)
Cottus carolinae	Banded Sculpin	100.0
Nothonotus camurus	Bluebreast Darter	50.0
Nothonotus denoncourti	Golden Darter	45.5
Noturus eleutherus	Mountain Madtom	38.5
Etheostoma zonale	Banded Darter	33.3
Etheostoma meadiae	Bluespar Darter	33.3
Percina evides	Gilt Darter	30.0
Nothonotus rufilineatus	Redline Darter	22.2
Etheostoma simoterum	Snubnose Darter	0.0

Table 4. Frequency distribution of the faunal index for 14 collecting events during the 2017 sampling season in the Clinch River.

	Frequency distribution (number of events)	
Index value	All events	Pygmy Madtom events
-2	1	0
-1	4	0
0	5	1
1	4	4
Total	14	5

Duck River species associations and faunal index

The Duck River had five positive indicator fishes [Blackfin Darter (*Etheostoma nigripinne*), Bluebreast Darter, Dusky Darter (*Percina sciera*), Fringed Darter (*Etheostoma crossopterum*), and Saffron Darter (*Etheostoma flavum*)] and seven negative indicator species [Fantail Darter (*Etheostoma flabellare*), Golden Darter, Harlequin Darter (*Etheostoma histrio*), Saddleback Darter (*Percina vigil*), Saddled Madtom (*Noturus fasciatus*), and Spangled Darter (*Etheostoma obama*)]. The Banded Sculpin, Duck Darter (*Etheostoma planasaxatile*), Logperch (*Percina caprodes*), Mountain Madtom, Redline Darter, and Gilt Darter had a constancy percentage of 100% and the remaining associated species were at 80% or less (Table 5). The Bluebreast Darter (100%) and Fringed Darter (66.6%) had the strongest fidelity to the Pygmy Madtom in the Duck River (Table 6). The remaining species had fidelity percentages of 50% or less. The range of values for Pygmy Madtom faunal index was -3 to 4, and Pygmy Madtom events only occurred at values of 1 to 4 (Table 7).

Table 5. Duck River constancy = occurrences of benthic fishes with the Pygmy Madtom as a percentage of total Pygmy Madtom occurrences.

Species	Common Name	Constancy (%)
Cottus carolinae	Banded sculpin	100
Etheostoma planasaxatile	Duck Darter	100
Percina evides	Gilt Darter	100
Noturus eleutherus	Mountain Madtom	100
Nothonotus rufilineatus	Redline Darter	100
Percina caprodes	Logperch	100
Etheostoma zonale	Banded Darter	80
Nothonotus aquali	Coppercheek Darter	80
Etheostoma blennioides	Greenside Darter	80
Etheostoma caeruleum	Rainbow Darter	80
Etheostoma flavum	Saffron Darter	60
Noturus miurus	Brindled Madtom	60
Etheostoma blennius	Blenny Darter	40
Nothonotus camurus	Bluebreast Darter	40
Percina sciera	Dusky Darter	40
Etheostoma crossopterum	Fringed Darter	40
Percina phoxocephala	Slenderhead Darter	40
Etheostoma nigripinne	Blackfin Darter	20
Etheostoma bison	Buffalo Darter	20

Table 6. Duck River fidelity = occurrences of benthic fishes with the Pygmy Madtom as a percentage of total occurrences for the Pygmy Madtom.

Species	Common Name	Fidelity (%)
Nothonotus camurus	Bluebreast Darter	100.0
Etheostoma crossopterum	Fringed Darter	66.7
Etheostoma nigripinne	Blackfin Darter	50.0
Percina sciera	Dusky Darter	50.0
Etheostoma flavum	Saffron Darter	50.0
Etheostoma blennioides	Greenside Darter	44.4
Noturus miurus	Brindled Madtom	42.9
Etheostoma blennius	Blenny Darter	40.0
Nothonotus aquali	Coppercheek Darter	40.0
Percina evides	Gilt Darter	38.5
Etheostoma caeruleum	Rainbow Darter	36.4
Etheostoma zonale	Banded Darter	36.4
Etheostoma planasaxatile	Duck Darter	35.7
Etheostoma bison	Buffalo Darter	33.3
Cottus carolinae	Banded Sculpin	29.4
Percina phoxocephala	Slenderhead Darter	28.6
Percina caprodes	Logperch	27.8
Noturus eleutherus	Mountain Madtom	27.8
Nothonotus rufilineatus	Redline Darter	27.8
Etheostoma flabellare	Fantail Darter	0.0
Nothonotus denoncourti	Golden Darter	0.0
Etheostoma histrio	Harlequin Darter	0.0
Percina shumardi	River Darter	0.0
Percina vigil	Saddleback Darter	0.0
Noturus fasciatus	Saddled Madtom	0.0
Etheostoma obama	Spangled Darter	0.0

Table 7. Frequency distribution of the faunal index for 18 collecting events by TVA in the Duck River.

	Frequency distribution (Number)	
Index value	All events	Pygmy Madtom events
-3	2	0
-2	1	0
-1	4	0
0	4	0
1	4	3
2	1	0
3	1	1
4	1	1
Total	18	5

DISCUSSION

The Pygmy Madtom faunal indices for the Clinch and Duck rivers are practical, rapid survey tools that researchers could use to find additional sites throughout both rivers. TVA biologists recorded a much more speciose benthic fish community in the Duck River (n = 26) than we encountered in the Clinch River (n = 9). This could be partially due to sampling over decades in the Duck River versus one season in the Clinch River. However, the higher species richness is probably a result of depletion techniques in addition to their sampling of all habitats (pools, riffles, and runs). The techniques and protocol used in the Clinch River targeted benthic fishes in runs, which represented the majority of habitat types, and riffles associated with channel bars and other wadeable habitats. This most likely explains the lower species richness associated with the Pygmy Madtom in the Clinch River.

Clinch River species associations and faunal index

Etnier and Jenkins (1980) and Starnes and Starnes (1985) reported finding the Mountain Madtom associated with the Pygmy Madtom in the Clinch River. This association was also observed in our study. The Mountain Madtom's constancy was 100% and its fidelity was 38.6%. However, the Mountain Madtom was neither a positive nor a negative indicator in the faunal index. In addition to these strong association metric values, the Mountain Madtom did show increased numbers in collections during late September–November, as did the Pygmy Madtom. In Burr and Stoeckel's (1999) monograph on the natural history of madtoms, they report on winter aggregations of Margined Madtom (*Noturus*

insignis), Brindled Madtom (*Noturus miurus*), and Yellowfin Madtom (*Noturus flavipinnis*). The winter aggregation phenomenon needs to be further studied to better understand madtoms and improve detection techniques that would help inform conservation agency decisions.

The Golden Darter is another strong associate of the Pygmy Madtom discovered in the Clinch River. It had constancy of 100% and fidelity of 45.5%. Unlike the Mountain Madtom, the Golden Darter was a positive indicator along with the Bluebreast Darter and Banded Sculpin based on the faunal index. The Golden Darter is considered extremely localized and locally common and occurs mostly in the Clinch and Duck rivers like the Pygmy Madtom (Page and Burr 2011). Page and Burr (2011) mentioned that the Golden Darter occurs in "shallow gravel riffles of small to medium-sized rivers"; however, we found the Golden Darter in shallow runs. Habitat-association data on the Golden Darter and other ecological aspects of its life history would be helpful in understanding any niche overlap between the Golden Darter and Pygmy Madtom. Interestingly, the Golden Darter ended up being a negative indicator for Pygmy Madtom faunal index in the Duck River.

Duck River species associations and faunal index

The constancy of the Banded Sculpin, Duck Darter, Gilt Darter, Logperch, Mountain Madtom and Redline Darter was 100%. Unlike Mattingly and Black (2013), who used constancy and fidelity as indicators of nest interactions between Blackside Dace and other species, fidelity was the only useful criterion for detecting the Pygmy Madtom in the Duck River. None of the previously mentioned species had a strong fidelity or were positive indicators in the faunal index. The species with the strongest fidelity were the Bluebreast Darter and the Fringed Darter, which are both positive indicators. Collections from sites with the Bluebreast Darter and Fringed Darter together or separately should be considered potential sites for the Pygmy Madtom, or at a minimum, considered for additional sampling. The practicality of the Duck River faunal index, which uses fidelity for calculations, leads us to conclude that the faunal index is a useful tool for currently predicting Pygmy Madtom sites in the Duck River until more data has been collected and analyzed.

Summary of faunal associations

Since Pflieger's (1978) publication on the Niangua Darter, his methods have been used or adapted to evaluate nest associations of the Blackside Dace by Mattingly and Black (2013), distributional analysis of Williams' Crayfish by Wagner et al. (2010), and our findings on Pygmy Madtom associations in the Clinch and Duck rivers. The three case (including the Pygmy Madtom) studies we

have presented on faunal associations using Pflieger's (1978) methods show the usefulness of his approach for evaluating species interactions. Understanding faunal associations can play an important role in the conservation management of a species. We realize the theoretical community ecology literature has many useful examples of testing species associations, but the purpose of our work was to highlight Pflieger's (1978) approach and creation of a faunal index as useful management tool. The index could be used to conduct a rapid survey of potential sites for a species, such as the Pygmy Madtom, that has no habitat measurements or models, with only limited occurrence data over a wide range.

Conservation Concerns

The Pygmy Madtom faunal indices for the Clinch and Duck rivers are valuable tools that field biologists and others could use to find additional sites throughout both rivers. However, as a precaution, the faunal index may not be applicable in seasons other than when the faunal indices were developed. Bluebreast Darter habitat should be studied because of this darter's strong fidelity to the Pygmy Madtom in both rivers, which could indicate a comparative ecological relationship. The faunal index approach has proven to be successful with describing ecological aspects of other species such as the Niangua Darter, Blackside Dace, and Williams' Crayfish. The ecological associations discovered by applying Pflieger's (1978) metrics of constancy and fidelity provides insight into the communities to which the Pygmy Madtom belongs. Of particular interest was the high fidelity displayed between the Bluebreast Darter and the Pygmy Madtom in both rivers. These preliminary advances in conservation and ecological knowledge will be useful to future Pygmy Madtom management and research.

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