2010

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Recommended Citation
Smith, Kurt T. and Whitledge, Gregory. "Fin Ray Chemistry as a Potential Natural Tag for Smallmouth Bass in Northern Illinois Rivers." *Journal of Freshwater Ecology* 25, No. 4 (Jan 2010): 627-635. doi:10.1080/02705060.2010.9664412.

Fin Ray Chemistry as a Potential Natural Tag for Smallmouth Bass in Northern Illinois Rivers

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ABSTRACT

Natural chemical markers in otoliths and fin rays have proven useful for describing environmental history of fishes in a variety of environments. However, no studies have evaluated smallmouth bass (*Micropterus dolomieu*) pectoral fin ray chemistry as a non-lethal alternative to otolith chemistry. We evaluated the trace element composition of smallmouth bass fin rays collected from northern Illinois rivers and determined the accuracy with which fish could be classified to their environment of capture using pectoral fin ray strontium:calcium (Sr:Ca) and barium:calcium (Ba:Ca) ratios. Fish were collected from nine sites during summer 2008. Fin ray Sr:Ca differed among some sites, reflecting previously observed differences in water and otolith chemistry for other fish species. Fin ray Ba:Ca did not differ among sites. Classification accuracy for individual fish to location of capture based on fin ray Sr:Ca was relatively poor when data from all nine sites in different watersheds were included. However, individual fish captured from the upper Illinois River watershed were accurately assigned to the river in which they were collected when data were restricted to these sites. Natural chemical signatures in fin rays will likely be effective for reconstructing environmental history of smallmouth bass when spatial differences in water chemistry are present, enabling investigations of stock mixing and recruitment sources for this species.

INTRODUCTION

The ability to determine the frequency and extent of movement among rivers and tributaries is critical for the effective management and conservation of fish populations (Schlosser 1991, Fausch et al. 2002). Understanding movement and dispersal patterns can aid in identifying crucial habitats for spawning, foraging, or refuge as well as defining source and sink populations (Schlosser 1995). For example, poor habitats may remain populated only through supplementation of individuals from higher quality habitats (Figueira and Crowder 2006). Effective management of fish populations requires knowledge of habitat use and movement to determine the most appropriate scale for management. If mixing of fish stocks does not occur, localized fishing pressure may only influence the abundance of local stocks. However, if stock mixing does occur, localized fishing pressure may influence fish stocks at a broader scale.

Smallmouth bass (*Micropterus dolomieu*) is a river- and stream-dwelling species considered to be of high recreational value (Brewer et al. 2007) that likely relies on numerous connected habitats to complete its life history. Historically, smallmouth bass ranged from the Great Lakes south to northern Georgia, east to the Appalachian range, and west to eastern Oklahoma (MacCrimmon and Robbins 1975, Lee et al. 1980). In Illinois, the smallmouth bass is widely distributed throughout the northern two-thirds of the state, but its distribution is rather sporadic in the southern third of the state, with a few isolated populations present (Smith 1979). Reduced habitat heterogeneity, variable flow regimes, changes in temperature, and movement restrictions caused by habitat alterations are negatively associated with smallmouth bass abundance (Reed and Rabeni 1989, Pflieger 1997, Peterson and Kwak 1999, Buynak and Mitchell 2002, Brewer et al. 2007, Kanehl et al. 2007).

Radiotelemetry studies indicate that smallmouth bass exhibit distinct largescale movement to both spawning and overwintering habitats (Todd and Rabeni 1989, Langhurst and Shoenike 1990, Altena 2003, Dauwalter and Fisher 2008). There is also evidence that smallmouth bass exhibit movement among connected streams and rivers (Langhurst and Schoenike 1990, Gunderson-VanArnum et al. 2004) suggesting that stock mixing may occur in lotic networks. However, relatively low sample sizes in telemetry studies or low recapture rates of fish marked with conventional tags can impede characterization of the diversity and distribution of movement patterns among individuals within a population. Also, telemetry studies are typically restricted to large individuals and may not be representative of all life stages of smallmouth bass (see Langhurst and Schoenike 1990). Thus, knowledge of the relative importance of different natal environments and dispersal patterns during early life stages for smallmouth bass populations is very limited (but see Humston et al. 2009). Techniques that could improve understanding of recruitment sources, early life stage dispersal, and environmental history of individual smallmouth bass throughout their lifetimes would be valuable for conservation and management of this species.

Analysis of natural trace element signatures in otoliths and other hard structures has emerged as a powerful technique to infer fish environmental history at all life stages. In the Mississippi River and Illinois River drainages, analysis of otolith chemistry has been successfully used as an indicator of centrarchid source environment (Whitledge 2009, Zeigler 2009, Zeigler and Whitledge 2010). The chemical composition of fish otoliths can be attributed to water chemistry in which fish reside (Kennedy et al. 2002, Wells et al. 2003, Dufour et al. 2005, Whitledge et al. 2006, Zeigler and Whitledge 2010). Otoliths are inert (Campana and Thorrold 2001) enabling retrospective description of fish environmental history when an individual has resided in chemically distinct locations for a period of time sufficient to incorporate the unique signatures of those sites (Kennedy et al. 2002, Dufour et al. 2005, Whitledge et al. 2007). Humston et al. (2009) used otolith microchemstry to determine natal origins and infer dispersal patterns of smallmouth bass in the James River and Maury River in Virginia. Unfortunately, the sacrificial nature of otolith sampling can be problematic, especially when investigating movement and dispersal patterns of a popular sport fish; the potential impacts on small populations (or sub-populations) and removal of trophy-sized fish for otolith sampling is undesirable.

Trace element analyses of fin rays have been demonstrated to be an effective, non-lethal alternative to otolith chemistry for reconstructing individual fish environmental history (Veinott et al. 1999, Arai et al. 2002, Clarke et al. 2007, Allen et al. 2009). However, we are unaware of any studies that have investigated the efficacy of fin rays as a natural recorder of environments occupied by smallmouth bass. Based on otolith and water microchemistry, Whitledge (2009) determined that fish collected in the upper Illinois River and its tributaries could be classified back to their collection location with a relatively high degree of accuracy (64-100%). If smallmouth bass fin ray microchemistry in northern Illinois provides comparable results to Whitledge (2009), this technique may help identify the frequency, timing, and extent of smallmouth bass movement among rivers, and it may reveal the relative importance of different tributaries as source habitats within watersheds in northern Illinois and other areas where geographic differences in water chemistry exist.

The objective of this study was to determine whether natural differences in fin ray chemistry are present in smallmouth bass from different rivers (including larger rivers and their tributaries) in northern Illinois. If so, these differences in fin ray chemical composition could potentially be used as natural tags for investigating smallmouth bass recruitment sources and movement among these rivers and streams. The upper Illinois River, Fox River, and Kankakee River are managed under different regulations for smallmouth bass. Thus, connectivity of these populations in particular would have potential implications for these fisheries and the efficacy of the regulations applied to each of these rivers.

METHODS

Smallmouth bass were obtained from nine sites in northern Illinois. Sampling locations included the Apple River, sites in the upper Rock River and lower Rock River, the Kishwaukee River (a tributary of the Rock River), Pierce Lake (outlet stream drains into the Rock River), the upper Illinois River, the Fox River (an Illinois River tributary), the Kankakee River (also an Illinois River tributary), and Shabbona Lake (an impoundment on Indian Creek, a tributary of the Fox River) (Fig. 1). Sites were chosen because of smallmouth bass presence, the connectivity of many of these sites, and the expectation of a broad range of trace elemental signatures based on previous studies of water and otolith chemistry for other fish species at these sites (Whitledge 2009, Zeigler 2009).

Smallmouth bass (n=6-8 per site) were obtained during summer 2008 by electrofishing. The right leading pectoral fin ray was obtained from each fish and stored frozen until further preparation. Following acquisition of fin ray samples, fish were released at their location of capture.

Pectoral fin ray samples were embedded in epoxy resin and cut into 1.3 mm sections at the widest portion at the base of the fin ray using a Buehler ISOMET low-speed saw. Sections were then ground with silicon carbide paper until the core was exposed and polished. Embedded and polished fin ray sections were mounted on acid-washed glass slides using double sided tape, ultrasonically cleaned for 5 min in ultrapure water to remove surface contamination, and dried in a class 100 laminar flow hood for 24 h. Mounted and cleaned fin ray sections were stored in acid-washed polypropylene Petri dishes in a sealed container until analysis. Fin ray samples were analyzed for Ca, Sr, and Ba concentrations using laser ablation-inductively coupled plasma mass spectrometry. Material from three spots (~20 µm diameter each) was ablated from both the core (to reflect the environment occupied during the fish's early life) and edge, which reflects the fish's most recent growth. Concentrations of Sr, Ba, and Ca for the three ablation spots were then averaged to obtain a single core and edge value for each fish. A standard (NIST 610) was analyzed every 10-15 samples to adjust for possible mass bias and instrument drift. Strontium and barium concentrations were normalized to calcium concentration based on the consideration of calcium as a pseudointernal standard (Ludsin et al. 2006); data are reported as Sr:Ca and Ba:Ca ratios (mmol/mol).

One way analysis of variance (ANOVA) was used to test for and characterize differences in fin ray Sr:Ca and Ba:Ca among sampling locations. Tukey's HSD test was applied to assess differences in fin ray Sr:Ca or Ba:Ca among individual sites when overall ANOVA indicated significance. For fish captured at the three connected sites in the upper portion of the Illinois River drainage (the Kankakee River, upper Illinois River, and Fox River) individual paired sample t-tests were used to determine if there were differences between fin ray core and fin ray edge trace element compositions for fish within each of these three sites. Linear discriminant function analysis (LDFA) with a leave-one-out jackknife procedure was used to determine the accuracy with which individual fish could be classified back to their collection location based on their fin ray elemental signatures. An additional LDFA was performed to determine classification accuracy to the three connected rivers in the upper portion of the Illinois River drainage (the Kankakee River, upper Illinois River, and Fox River). Statistical analyses were conducted using the Statistical Analysis System (SAS version 9.2, SAS Institute Inc. Cary, North Carolina, USA). Statistical significance was set at alpha=0.05.

RESULTS

Mean smallmouth bass pectoral fin ray core Sr:Ca differed among the sampled rivers and lakes ($F_{8,45} = 44.74$, $P < .0001$), with the highest Sr:Ca occurring in the Fox River (Fig. 2). Fish from the Apple River, Kankakee River, Kishwaukee River, upper Rock River, and lower Rock River had the lowest mean pectoral fin ray core Sr:Ca values, while Pierce Lake, Shabbona Lake, and the upper Illinois River had intermediate mean Sr:Ca values. Mean pectoral fin ray core Ba:Ca, however, was not significantly different among sampling locations ($F_{8, 45} = 1.98$, $P = 0.0704$). Therefore, only Sr:Ca data were used in subsequent LDFA analyses, which indicated that classification success of individual fish to their location of capture was variable (0-100% accuracy, Table 1).

Fin rays of smallmouth bass from the Kankakee River, upper Illinois River, and the lower Fox River had significantly different Sr:Ca values at the fin ray core ($P < 0.05$). Paired-sample t-tests indicated that there were no significant differences between fin ray core Sr:Ca and fin ray edge Sr:Ca for individual fish captured in the upper Illinois River ($t_1 = 1.366$, $P = 0.402$), Kankakee River ($t_4 = -0.343$, $P = 0.749$), or Fox River ($t_5 = 2.359$, $P = 0.065$). Results of the second LDFA that included only fin ray data from fish captured in the lower Fox River, upper Illinois River, and Kankakee River indicated that smallmouth bass from these three connected rivers could be assigned back to their environment of capture with 100% accuracy.

DISCUSSION

Differences in Sr:Ca values of smallmouth bass fin ray cores among rivers and lakes sampled in this study can be attributed to geographic differences in water Sr:Ca (Wells et al. 2003, Clarke et al. 2007, Walther and Thorrold 2008, Zeigler and Whitledge 2010). Differences in local bedrock geology in northern Illinois likely contribute to the differences in fin ray and water Sr:Ca observed in this and previous studies (Illinois Department of Natural Resources 1997, Whitledge 2009). Observed differences in fin ray core Sr:Ca values of smallmouth bass in this study were consistent with previous studies that reported high Sr:Ca in fish otoliths from the Fox River and lower values from the upper Illinois River (Whitledge 2009, Zeigler 2009, Zeigler and Whitledge 2010). The lack of significant differences in Ba:Ca of fin ray cores is generally inconsistent with other studies, which have had considerable success with the use of otolith or fin ray Ba:Ca as a marker of freshwater fish environmental history (Wells et al. 2003, Brazner et al. 2004, Ludsin et al. 2006, Clarke et al. 2007). However, otolith Ba:Ca has been demonstrated to be less effective than other naturally occurring trace elemental and stable isotopic markers at discriminating among fishes from the Mississippi River and Illinois River, and their tributaries and floodplain lakes (Zeigler 2009, Zeigler and Whitledge 2010).

Overall classification success rates for individual smallmouth bass to environment of capture in this study were generally lower than published studies using otolith or fin ray microchemistry or stable isotopic composition as indicators of source location for freshwater fishes (Bronte et al. 1996, Wells et al. 2003, Brazner et al. 2004, Clarke et al. 2007, Schaffler and Winkelman 2008, Whitledge 2009, Zeigler and Whitledge 2010).

Misclassifications of individual fish to environment of capture were likely due to sites that possessed water chemistry signatures that were indistinguishable from one another (Whitledge 2009) when data from all nine collection sites were included in LDFA. However, there were no misclassifications of individual fish to environment of capture when the LDFA was restricted to fish from the upper Illinois River and two of its major tributaries, the Fox River and Kankakee River. The distinct Sr:Ca signatures of fish from these three connected rivers suggests that fin ray Sr:Ca could be a useful tool for investigating natal environment, dispersal, and stock mixing of smallmouth bass in these rivers.

The observed differences in fin ray core Sr:Ca in this study suggest that fin rays may provide a non-lethal alternative to otolith Sr:Ca as a natural marker of smallmouth bass natal origins where geographic differences in environmental signatures exist. However, temporal variation in environmental and fin ray trace element signatures could limit the utility of smallmouth bass fin ray chemistry as an environmental tracer. This study evaluated smallmouth bass fin ray microchemistry for only one year. Therefore, it is unknown whether the chemical signatures of smallmouth bass at the study sites will remain consistent across years. However, both this study and Whitledge (2009) found significantly high Sr:Ca for Fox River fishes compared to other sites, suggesting that this distinction is stable across years. To account for potential variation in environmental signatures over time, a record of environmental signatures of water and separate classification models for identifying natal environments of fish from different year classes would be necessary (Ludsin et al. 2006, Schaffler and Winkelman 2008). There is also some potential for resorption of fin ray material during periods of protracted nutritional stress; however, it is likely minimal (see Veinott and Evans 1999). Further study is merited to determine the potential for remobilization of fin ray material.

The use of smallmouth bass pectoral fin ray chemistry as a natural environmental marker in northern Illinois or in other areas where geographic differences in water chemistry exist may provide new insight into the frequency, timing, and extent of smallmouth bass movement among rivers throughout their life history. Application of fin ray chemistry may also provide new information relevant to management of smallmouth bass populations, such as the relative importance of different tributaries as source habitats for smallmouth bass populations in river networks. While telemetry studies have provided useful information about the movement and habitat use of larger individuals (Todd and Rabeni 1989, Langhurst and Shoenike 1990, Altena 2003, Dauwalter and Fisher 2008), little is known about natal environments and dispersal of early life stage smallmouth bass. Fin ray core Sr:Ca and fin ray edge Sr:Ca of individual fish captured from the Fox River, upper Illinois River, and Kankakee River were not significantly different, suggesting that fish collected from these rivers spent their early life history in the rivers in which they were captured. Additional sampling would be required to quantify the relative importance of different rivers in the upper Illinois River watershed as recruitment sources for smallmouth bass and to assess the extent of stock mixing for smallmouth bass in the upper Illinois River drainage.

The ability to determine smallmouth bass environmental history using fin ray microchemistry could also be useful for evaluation of habitat improvement projects. For example, studies have identified that habitat restoration practices have led to increased smallmouth bass abundance (see Kanehl et al. 1997). Fin ray microchemistry could conceivably determine whether increased fish abundance occurred through local reproduction or whether fish moved into restored areas from other locations. In northern Illinois, most streams and rivers are fragmented by dams and have been highly altered through urbanization. The portion of the Fox River flowing through Illinois has 15 low head dams (Santucci et al. 2005). Two larger dams, the Dayton dam on the Fox River (8 km from the confluence with the Illinois River) and the Kankakee Dam on the Kankakee River (47 km from the confluence with the Illinois River) have likely reduced fish movement among these two rivers and the upper Illinois River (Steve Pescitteli, Illinois DNR, pers. comm.). If fish passage was improved at these sites, fin ray chemistry techniques could potentially be used to document mixing of smallmouth bass stocks that were formerly isolated or semi-isolated.

ACKNOWLEDGMENTS

This project was funded by a grant from the Illinois Smallmouth Alliance. Analysis of fin ray samples was performed by the Great Lakes Institute for Environmental Research, University of Windsor. We thank Paul Hitchens and John Zeigler for assistance with fish sampling.

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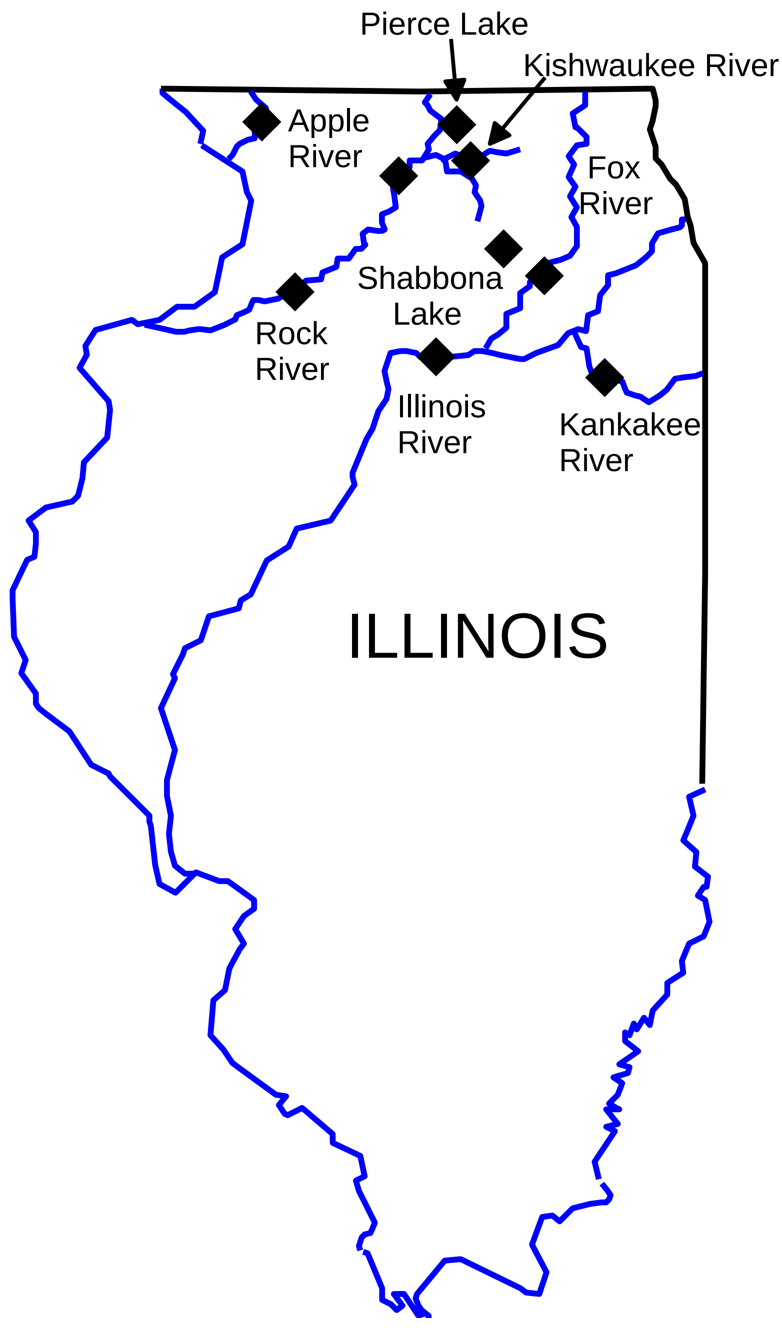
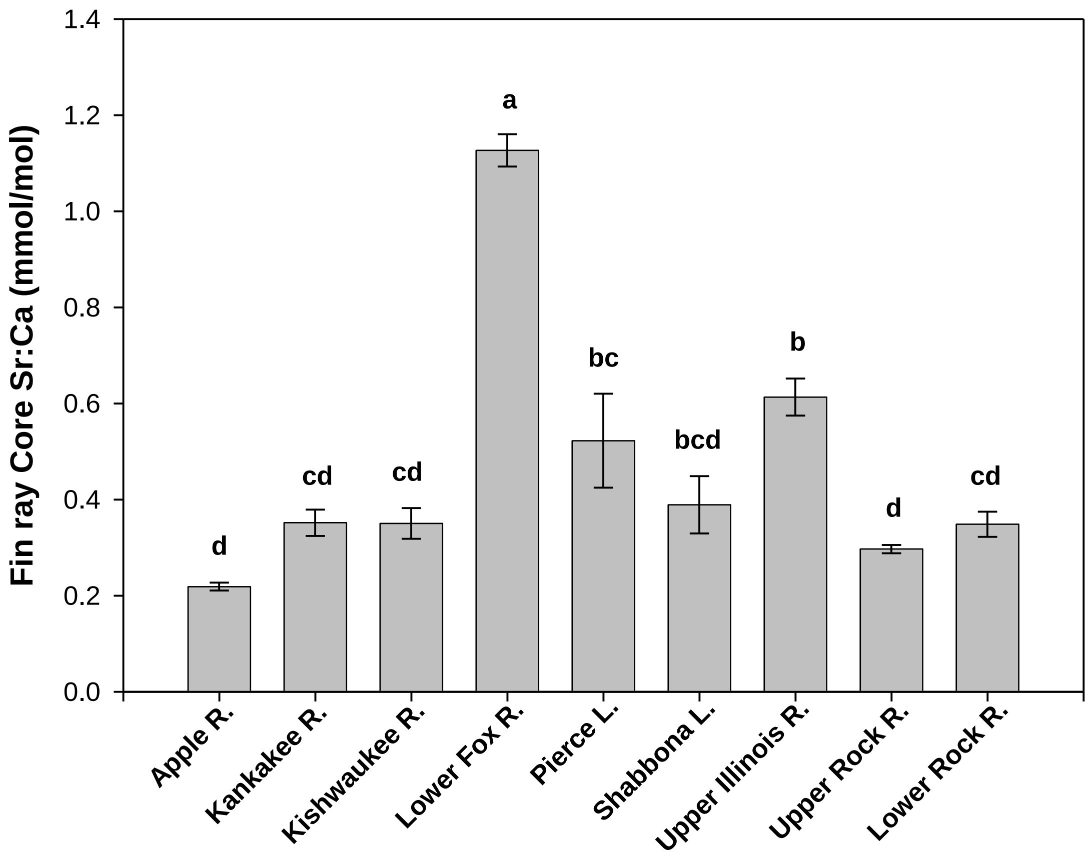
Table 1. Results of linear discriminant function analysis showing classification accuracy (percentage correct [%] determined by jackknife procedure) for individual fish to the environment in which they were captured based on fin ray core Sr:Ca.

Source location	n	%	Source location	n	%
Apple River	6	100	Lower Rock River	6	0
Kankakee River	7	0	Upper Illinois River	7	86
Kishwaukee River	7	0	Pierce Lake	6	33
Lower Fox River	8	100	Shabbona Lake	6	33
Upper Rock River	7	43			

LIST OF FIGURES



Pierce Lake
Kishwaukee River
Apple River
Fox River
Shabbona Lake
Rock River
Illinois River
Kankakee River
ILLINOIS



Fin ray Core Sr:Ca (mmol/mol)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
d
cd
cd
a
bc
bcd
b
d
cd
Apple R.
Kankakee R.
Kishwaukee R.
Lower Fox R.
Pierce L.
Shabbona L.
Upper Illinois R.
Upper Rock R.
Lower Rock R.