Population Dynamics of the Sand Shiner (*Notropis stramineus*) in Non-Wadeable Rivers of Iowa

Christopher D. Smith[a], Travis E. Neebling[a,b], and Michael C. Quist[a,c]

ABSTRACT

The sand shiner (*Notropis stramineus)* is a common cyprinid found throughout the Great Plains region of North America that plays an important ecological role in aquatic systems. This study was conducted to describe population dynamics of sand shiners including age structure, growth, mortality, and recruitment variability in 15 non-wadeable rivers in Iowa. Fish were collected during June–August (2007–2008) using a modified Missouri trawl, a seine, and boat-mounted electrofishing. Scales were removed for age and growth analysis. A total of 3,443 fish was sampled from 15 populations across Iowa, of which 676 were aged. Iowa's sand shiner populations consisted primarily of age-1 fish (53% of all fish sampled), followed by age-2 fish (30%), age-0 fish (15%), and age-3 fish (2%). Sand shiners grew an average of 38.5 mm (SE = 5.7) during their first year, 13.8 mm (4.5) during their second year, and 9.0 mm (6.9) during their third year. Total annual mortality varied from 35.0% to 92.3% among populations with a mean of 77.9% (0.2). Incremental mortality rates were 84.5% (0.2) between age 1 and age 2, and 92.0% (0.1) between age 2 and age 3. Recruitment was highly variable, as indicated by a mean recruitment variation index of -0.12 (0.54). Overall, the sand shiner was characterized by relatively low mean age, fast growth, high mortality, and high recruitment variability. Indices of sand shiner population dynamics were poorly correlated with habitat characteristics.

INTRODUCTION

The sand shiner (*Notropis stramineus)* is an abundant and widely-distributed cyprinid native to the Great Plains of North America. Its distribution extends as far west as the headwaters of the Platte River in Wyoming, as far south as the Rio Grande River drainage, as far east as the Tennessee River drainage, and as far north as the lower Red River of the North drainage in Canada (Lee et al. 1980). In Iowa, the sand shiner is common across the state.

The sand shiner occurs in a variety of habitats including clear lakes with sand or gravel substrates, but is most abundant in moderate velocity lotic systems with a high proportion of sand substrate (Smith 1979). Sand shiner is considered a generalized insectivore and consumes a diverse array of terrestrial and aquatic invertebrates, with a diet that often reflect prey availability (Gillen and Hart 1980). However, the sand shiner has also been reported as a seasonal detritivore (Starrett 1950). Spawning typically occurs from June to mid-August with a peak spawning frequency correlated with maximum summer water temperatures (Summerfelt and Minckley 1969). Like most fishes, spawning can have a substantial influence on population structure resulting in high mortality among adult fish (i.e., age-2 and older fish; Summerfelt and Minckley 1969). While some generalizations have been made with respect to the ecology of sand shiner, there is a paucity of detailed information on the population dynamics (e.g., growth,

[a] Department of Natural Resource Ecology and Management, Iowa State University, Ames, Iowa 50011 USA.

[b] Present address: Wyoming Game and Fish Department, 3030 Energy Lane, Casper, Wyoming 82604 USA.

[c] Corresponding author; present address: USGS – Idaho Cooperative Fish and Wildlife Research Unit, Department of Fish and Wildlife Resources, University of Idaho, Box 441141, Moscow, Idaho 83844 USA. E-mail: mcquist@uidaho.edu

mortality, recruitment variability) of this species. Such information may be particularly useful not only for better understanding the ecology of sand shiner and other small-bodied stream fishes but also for understanding the effects of anthropogenic disturbances on aquatic systems.

Alterations to the landscape are common in all regions of the world. Land use alterations are particularly prevalent in Iowa where approximately 109,000 km² of tallgrass prairie, 99.9% of Iowa's historic prairie ecosystems, have been converted to agriculture (Smith 1998). Agriculture has a number of negative effects on aquatic systems, but the most significant concern is sediment and nutrient loading (Johnes and Heathwaite 1997). High inputs of nutrients and sediment can drastically alter aquatic habitats (Karr et al. 1985), ultimately having a substantial influence on fish assemblage structure and function. For this reason, fish assemblages have long been used to evaluate ecological health of lotic and lentic ecosystems (Karr et al. 1985, Zampella and Bunnell 1998, Wang et al. 2001). More recently, population and individual-level characteristics (e.g., growth rate) have been used to evaluate the quality of aquatic habitats (e.g., Cheruvelil et al. 2005, Wagner et al. 2006). As such, understanding the population dynamics of fishes is critical for their management and conservation as well as management of their habitats.

Most research on fish population dynamics has focused on sport fishes in lakes and large rivers (e.g., Shelton et al. 1979, Putman et al. 1995, Quist and Guy 2001, Tomcko and Pierce 2005). Despite the importance of non-game fishes to the structure and function of aquatic ecosystems, few studies have described the population dynamics of non-game fishes, particularly small-bodied fishes in lotic systems. The objective of this study was to describe sand shiner population dynamics over a large spatial scale. Specifically, this study evaluated age structure, growth, mortality, and recruitment variability of the sand shiner in Iowa's non-wadeable river systems.

METHODS AND MATERIALS

Sampling design and site selection

A non-wadeable river is defined as one that is deemed unsafe or ineffective to electrofish with backpack or barge units most of the year (Flotemersch et al. 2006). In Iowa, non-wadeable systems are typically fifth- to seventh-order rivers. As such, reaches in fifth- to seventh-order rivers were selected to encompass a diversity of instream physical habitat characteristics (e.g., substrate composition), watershed sizes, drainage basins (e.g., Missouri River versus Mississippi River), and stream sizes. Sampling lengths varied with stream order: reaches were 3 km long in fifth-order rivers and 5 km long in sixth- and seventh-order rivers.

Fish sampling

Sampling occurred during the summers of 2007 and 2008. Fish were sampled using a modified Missouri trawl, seine, and boat-mounted electrofishing system. A modified Missouri trawl was used due to its effectiveness at sampling small-bodied fishes in moderate to large riverine systems (Herzog et al. 2005). The opening of the trawl was 2.4 m wide and 0.6 m tall. Mesh size was 34.9-mm bar measure for the inner bag and 6.3-mm bar measure for outer bag. With this design, large mesh on the inside prevented large fish and debris from damaging smaller-bodied fishes retained by the outer bag. Seventy-five trawls were conducted in 5 km reaches and 45 were conducted in 3 km reaches. A successful trawl was defined as one that sampled at least 50 m without becoming snagged.

A bag seine was also used to sample fishes in each reach. The seine was 3.6 m long × 1.2 m deep with a 6.3-mm bar measure mesh. Similar to the trawl, 75 seine hauls were conducted in 5 km reaches and 45 seine hauls were conducted in 3 km reaches.

Electrofishing was conducted using a boat-mounted Smith-Root Inc. (Vancouver, Washington) electrofishing unit. Electrofishing consisted of a single-pass with two netters.

Total length of all sampled sand shiners was measured to the nearest millimeter. Scales were collected from 10 individuals per 5 mm length category for each reach. Scales were removed from the region posterior to the head, dorsal to the lateral line, and ventral to dorsal fin. Approximately ten to fifteen scales were mounted between two glass slides and aged by a single, experienced reader using a microfiche reader. Focus, annuli, and scale edges were marked on paper strips, digitized using a GTCO roll-up II digitizer (GTCO Corp., Columbia, Maryland), and recorded using FishBC 3.0 software (Ball State University, Muncie, Indiana).

Habitat sampling

Detailed habitat sampling methods can be found in Neebling and Quist (in press). However, a brief description of habitat sampling methods is provided here. Habitat assessment procedures were modified from the Iowa Department of Natural Resources wadeable streams physical habitat assessment (Wilton 2004) and the U.S. Environmental Protection Agency non-wadeable river protocol (Flotemersch et al. 2001). Measures of wetted channel width and bank-full width were measured by a laser-range finder to the nearest 0.5 m along transects spaced every 100 m. Secchi disk and water temperature were measured at the transect point closest to the thalweg every three hours during fish sampling. Water depth, current velocity, and substrate composition were measured at seven equidistant points along each transect. Current velocity was measured using a Marsh McBirney Flo-Mate velocity meter (Model 2000; Marsh-McBirney Inc., Frederick, Maryland) following standard methods (Kaufmann et al. 1999, Flotemersch et al. 2001). Substrate composition was estimated by feeling the bottom with a sounding pole or by hand (Platts et al. 1983). A modified Wentworth scale was used to classify substrate types (Orth and Maughan 1982).

Instream habitat, including woody debris, boulders, and anthropogenic structures was measured if located within 1 m upstream or 1 m downstream of the transect (modified from Kaufmann et al. 1999). Surface area and volume of various habitat types in the sampling unit were estimated from length, width, and depth measurements of different cover types.

Bank angle was estimated for both the left and right bank at each transect. Bank angle(s) was measured from a 2-m vertical section extending above the water level; rise and run were measured to provide angle estimates (modified from Kaufmann et al. 1999). Canopy cover was estimated using a convex densiometer (Murphy et al. 1981).

Data analysis

Catch-per-unit-effort (CPUE) was calculated as the number of sand shiners per 100 m of trawling. Trawling was used to describe relative abundance for several reasons. Sand shiners typically inhabit benthic or near-benthic environments with moderate current velocities (Smith 1979). The trawl used in this study is excellent for sampling these habitats that may be too deep for electrofishing and seining. In addition, electrofishing is also most effective for large individuals (Reynolds 1996) and may be ineffective for sampling small-bodied fishes (Larimore 1961). Consequently, trawling sampled over 23 times the number of sand shiners as electrofishing. Although seining is effective for sampling small-bodied fishes (Hayes et al. 1996), standardizing and measuring effort is often difficult due to variance in depth and a propensity of the seine to snag rocks, woody debris, and other items along the river's bottom.

Age-length keys were constructed for each reach to provide estimates of age structure (DeVries and Frie 1996). Mean back-calculated lengths were calculated using the Dahl-Lea method (Summerfelt and Minckley 1969, Quist and Guy 2001, Morey 2004). Total annual mortality was estimated for each reach with a weighted catch curve (Miranda and Bettoli 2007). Age-specific mortality rates were estimated by comparing differences in the relative frequency among successive age-classes in each reach (Ricker 1975). The recruitment variation index (RVI) was calculated to estimate the stability of sand shiner recruitment (RVI values vary from 1 to -1, with higher values indicating more stable recruitment; Guy and Willis 1995). Pearson correlation coefficients were used to evaluate relationships among indices (i.e., mean-back calculated length, total annual mortality, age-specific mortality, RVI). Population indices were also compared to habitat variables to evaluate potential relationships of habitat conditions and population dynamics of sand shiners. All statistical analyses were conducted utilizing a SAS 9.1.3 (SAS Institute 2006) system.

RESULTS

Catch-per-unit-effort of sand shiners varied from 0.03 fish/100 m to 27 fish/100 m with a mean CPUE of 6.48 fish/100 m (SE = 10.6). Lengths varied from 19 to 87 mm, with a mean of 56.2 mm (7.0; Fig. 1). Ages varied from 0 to 3. Age-1 fish composed the majority of the sample across reaches (53%), followed by age-2 (30%), age-0 (15%), and age-3 fish (2%). Mean back-calculated length at age 1 across all reaches was 38.5 mm (5.9), 53.0 mm (4.0) at age 2, and 63.9 mm (9.1) at age 3. Mean annual growth increment between age 1 and age 2 was 13.8 mm (4.5) and 9.0 mm (6.9) between age 2 and age 3. Total annual mortality estimates varied from 35.0% to 92.3% (mean ± SE; 77.9% ± 0.2%). Mortality between age 1 and age 2 varied from 36.2% to 100% across reaches (84.5% ± 0.2%). Mortality between age 2 and age 3 was higher than for younger ages and varied from 71.4% to 100% (92.0% ± 0.1%). Recruitment variation index values varied -0.95 to 0.59 with a mean of -0.12 (0.54).

Mean back-calculated length at age 1 was positively correlated with total annual mortality ($r = 0.71$, $P = 0.01$), and RVI was inversely correlated with age-specific mortality rates ($r = -0.59$, $P = 0.04$; Table 1). Mean back-calculated length at age 1 was positively correlated with bank-full width ($r = 0.45$, $P = 0.10$; Table 2). Mean back-

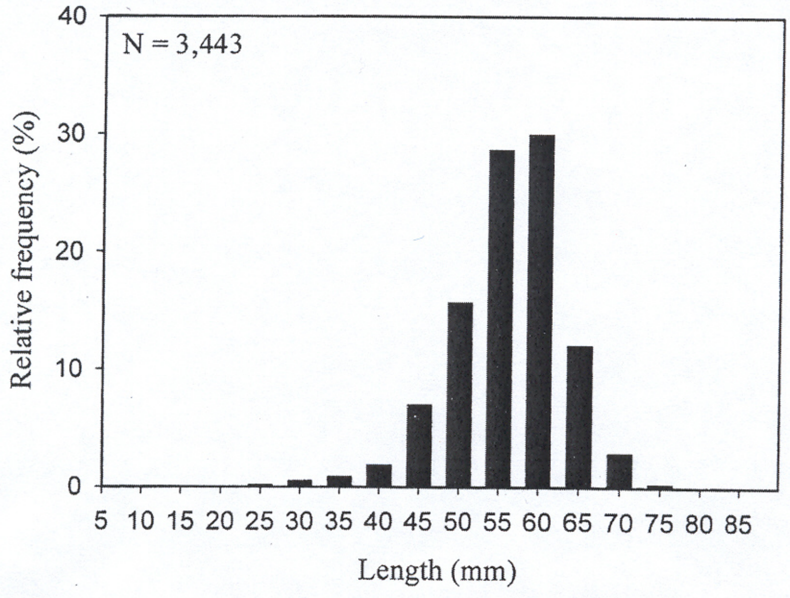

Figure 1. Length-frequency distribution of sand shiners sampled from 15 reaches in non-wadeable rivers in Iowa, 2007-2008.

calculated length at age 3 was positively correlated with percentage of boulder substrate ($r = 0.91$, $P = 0.01$), percentage of bedrock substrate ($r = 0.88$, $P = 0.01$), and amount of boulder cover ($r = 0.88$, $P = 0.01$). Mortality from age 1 to age 2 was inversely correlated with percentage of gravel substrate ($r = -0.75$, $P = 0.01$) and percentage of cobble substrate ($r = -0.62$, $P = 0.04$). Mortality between age 2 and age 3 was inversely correlated with percentage of sand ($r = -0.71$, $P = 0.01$) and percentage of gravel substrate ($r = -0.60$, $P = 0.04$). Total annual mortality was negatively related to the percentage of organic substrate ($r = -0.57$, $P = 0.04$) and percentage of instream cover consisting of logjams ($r = -0.56$, $P = 0.05$), and positively correlated with canopy cover ($r = 0.62$, $P = 0.03$).

DISCUSSION

Studies focused on sand shiner population dynamics are rare, but those that have been conducted have focused primarily on age structure and growth estimates (Summerfelt and Minckley 1969, Morey 2004). Summerfelt and Minckley (1969) reported that sand shiner populations in the Smokey Hill River, Kansas consisted mainly of age-0 and age-1 fishes. Conversely, sand shiner populations in low-order streams in South Dakota were dominated by age-3 sand shiners (Morey 2004). In our study, age-1 fish dominated the sample. Summerfelt and Minckley (1969) also reported back-calculated length at age 1 as 26.8 mm in Kansas, nearly 12 mm less than the current study. Growth rates in the current study were most similar to those reported by Morey (2004). Specifically, the author reported annual growth increments of 13.7 mm for age-1 sand shiners and 10.1 mm for age-2 fish. In our study, the growth increment for age-1 fish was 13.8 mm and 9.0 mm for age-2 fish.

Population dynamics of fishes are commonly related to aquatic habitat characteristics (Putnam et al. 1995, Shea and Peterson 2007). In Iowa rivers, boulder habitat was closely related to the growth of sand shiner. Although the mechanisms are unknown, the sand shiner is reliant on invertebrate populations throughout its life (Gillen and Hart 1980). The positive relationship with boulder habitat may indicate that boulders provide substrate for preferred aquatic invertebrates. Several studies have found increased density and (or) diversity of aquatic invertebrates as substrate coarseness and heterogeneity increased (Way et al. 1995, Schmude et al. 1998, Litvan et al. 2008). In addition to habitat characteristics, density-dependent factors may have influenced growth of sand shiners. Specifically, we found that growth of younger fish was positively

Table 1. Correlation coefficients of various population indices of sand shiner sampled from 15 populations in non-wadeable rivers in Iowa, 2007 – 2008. Indices include catch-per-unit-effort (CPUE = number of fish/100 m trawling), mean back-calculated length at age 1 (BC1), mean back-calculated length at age 2 (BC2), mean back-calculated length at age 3 (BC3), total annual mortality (A), age-specific mortality between age 1 and age 2 (A_{1-2}), age-specific mortality between age 2 and age 3 (A_{2-3}), and recruitment variability index (RVI). Statistically significant values ($P \leq 0.05$) are in bold.

Variable	BC1	BC2	BC3	A	A_{1-2}	A_{2-3}	RVI
CPUE	0.016	0.120	0.395	-0.237	0.161	**-0.519**	0.471
BC1		0.377	**0.744**	**0.713**	0.507	0.083	-0.075
BC2			0.614	0.397	-0.373	-0.067	0.307
BC3				0.444	0.605	0.445	0.413
A					-0.300	0.317	0.184
A_{1-2}						-0.327	-0.223
A_{2-3}							**-0.591**

correlated with total annual mortality. High densities of conspecifics have been shown to have negative effects on growth and survival of fishes (e.g., Byström and García-Berthou 1999, Lorenzen and Enberg 2002), particularly for juvenile fishes (Post et al. 1999). While studies on density-dependent growth in sand shiner populations are unavailable, there is evidence that density-dependent interactions may be important for small-bodied cyprinids in the Great Plains. For example, Matthews et al. (2001) examined the effects of density on survival and growth of red shiner (*Cyprinella lutrensis*). The authors showed that survival and growth were significantly lower in treatments with high densities compared to treatments with low densities. Similarly, Schlosser (1998) showed that growth and survival of creek chub (*Semotilus atromalculatus*) were density-dependent in a Minnesota stream.

A comparison of sand shiner mortality rates was unavailable due to a lack of studies examining mortality of this species. However, a similar study of red shiner provides some basis for comparison. Quist and Guy (2001) found that age-1 red shiners experienced low morality (< 20%), but thereafter mortality rates were in excess of 85% in small Kansas streams. In our study, age-1 sand shiners had much higher mortality (85%) than reported for red shiner but still followed a similar trend of increasing mortality rates among age-2 and older fishes (92%). Mortality of sand shiners in our study was primarily related to substrate composition where mortality of younger fishes decreased with increased large rocky substrate. Similar to growth, rocky substrate may enhance

Table 2. Correlation coefficients of various population indices of sand shiner sampled from 15 populations in non-wadeable rivers in Iowa, 2007 – 2008 and habitat variables. Indices include catch-per-unit-effort (CPUE = number of fish/100 m trawling), mean back-calculated length at age 1 (BC1), mean back-calculated length at age 2 (BC2), mean back-calculated length at age 3 (BC3), total annual mortality (A), age-specific mortality between age 1 and age 2 ($A_{1\text{-}2}$), age-specific mortality between age 2 and age 3 ($A_{2\text{-}3}$), and recruitment variability index (RVI). Statistically significant values ($P \leq 0.05$) are in bold.

Habitat variable	CPUE	BC1	BC2	BC3	A	$A_{1\text{-}2}$	$A_{2\text{-}3}$	RVI
River morphology								
Wetted width (m)	-0.268	0.332	-0.325	0.115	0.163	0.207	0.079	-0.057
Bank-full width (m)	-0.278	**0.446**	-0.413	-0.076	0.014	0.224	-0.013	-0.062
Depth (m)	-0.502	0.097	0.020	-0.212	-0.109	0.020	-0.198	-0.127
Velocity (m/s)	-0.126	0.500	-0.282	0.451	0.391	0.434	0.172	0.006
Substrate composition								
Organic (%)	0.497	-0.386	-0.249	-0.125	**-0.570**	-0.159	-0.008	0.035
Clay (%)	-0.234	0.357	0.272		0.220	-0.436	0.268	-0.326
Silt (%)	-0.044	-0.198	-0.061	-0.509	0.242	0.037	0.216	-0.078
Sand (%)	0.166	0.510	0.068	-0.464	-0.103	0.582	**-0.706**	0.187
Gravel (%)	-0.221	-0.391	-0.113	0.007	-0.031	**-0.755**	**0.599**	-0.025
Cobble (%)	0.190	-0.436	-0.016	0.334	-0.092	**-0.620**	0.433	-0.288
Boulder (%)	0.300	0.185	0.018	**0.908**	0.279	0.219	0.140	0.226
Bedrock (%)	0.435	0.285	0.246	**0.883**	0.257	0.147	-0.023	0.337
Instream cover								
Tree debris (%)	-0.002	0.193	-0.098	0.269	0.492	0.240	-0.181	0.130
Logjam (%)	-0.026	-0.160	-0.164	-0.577	**-0.557**	-0.238	0.233	-0.284
Boulder (%)	0.118	-0.161	0.174	**0.884**	0.052	0.105	0.247	-0.128
Riprap (%)	-0.019	-0.005	0.156	0.126	0.048	-0.064	-0.219	0.364
Bank and riparian characteristics								
Bank angle (°)	-0.275	0.253	-0.315	-0.282	-0.077	0.332	-0.001	-0.414
Canopy cover (%)	0.310	0.041	0.053	**0.733**	**0.617**	-0.224	0.381	0.150

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ıge 2 (A_{1-2}), age-
ɔruitment variability
.re in bold.

A	A_{1-2}	A_{2-3}	RVI
53	0.207	0.079	-0.057
14	0.224	-0.013	-0.062
)9	0.020	-0.198	-0.127
)1	0.434	0.172	0.006
70	-0.159	-0.008	0.035
20	-0.436	0.268	-0.326
42	0.037	0.216	-0.078
)3	0.582	**-0.706**	0.187
31	**-0.755**	**0.599**	-0.025
)2	**-0.620**	0.433	-0.288
79	0.219	0.140	0.226
57	0.147	-0.023	0.337
)2	0.240	-0.181	0.130
57	-0.238	0.233	-0.284
52	0.105	0.247	-0.128
48	-0.064	-0.219	0.364
77	0.332	-0.001	-0.414
17	-0.224	0.381	0.150

prey production; thereby enhancing body condition and survival (Pope and Kruse 2007). High proportions of rocky substrate and increased habitat complexity may also mediate species interactions. Specifically, piscivory is often a cause for high mortality when insufficient habitat is available (e.g., Tonn et al. 1992, Persson and Eklöv 1995). Persson and Eklöv (1995) evaluated predator efficiency of adult European perch (*Perca fluviatilis*) on juvenile perch and roach (*Rutilus rutilus*) and reported that increasing habitat complexity was negatively related to predator efficiency and positively related to prey survival. Lastly, the high mortality rates observed in our study may be attributed to the life history of these small-bodied fishes. Winemiller and Rose (1992) reported that cyprinids are typically small-bodied fishes with a short lifespan and that longevity of fishes in the family is less than all other North American families. Short life spans are particularly common in cyprinids native to the Great Plains (e.g., Quist and Guy 2001, Braaten and Guy 2002).

Like growth and mortality, understanding patterns in recruitment is important for better understanding the life history of fishes and potential effects of disturbance on fish population dynamics. We are unaware of any studies evaluating recruitment variability for any *Notropis* species; however, recruitment variation has been evaluated for a number of sport fishes (Isermann et al. 2002, McKibben 2002). Isermann et al. (2002) used the RVI to compare recruitment of 122 black crappie (*Pomoxis nigromalculatus*) populations across the midwestern and southeastern United States. The authors suggested that RVI values of -0.20 to 0.65 represented extremely high recruitment variability. While these guidelines may or may not be appropriate for sand shiner mean RVI values for sand shiners in the current study indicate that recruitment variability is extremely high in Iowa's non-wadeable rivers. Variable recruitment is likely due to the harsh conditions and high variability of aquatic systems in the Great Plains region (Fausch and Bestgen 1997, Dodds et al. 2004).

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