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Selected Habitats of Slimy Sculpin in Coldwater Tributaries of the Upper Mississippi River in Minnesota

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ABSTRACT.—Slimy sculpin *Cottus cognatus* are being reintroduced into coldwater streams in the upper Midwestern United States, where they were extirpated by stream degradation during the early- to mid-1900s. Habitat use and selection by slimy sculpin were examined in nine coldwater tributaries of the Upper Mississippi River in southeastern Minnesota to determine which stream habitats are important for successful reintroduction. Most (>70%) individuals (n = 1932) used coarse substrates and vegetation, shallow water (<30 cm), slow current velocities (<20 cm/sec), and moderately embedded (15–60%) substrates. Compared to habitat availability, adults selected boulder substrate and vegetation, whereas young-of-year (YOY) selected gravel, rubble, and vegetation. YOY sculpin selected shallow water (<30 cm), whereas adults exhibited broader selection (1–60 cm). Both age groups selected the slower bottom velocities (especially <20 cm/sec). Habitat use and selection by adult fish were consistent among 3 y of surveys. Habitat suitability index values for sculpin were similar among native sculpin streams and streams where sculpin have been or may be reintroduced within the same geographic region. Slimy sculpin displayed habitat selection similar to that of other sculpin species, except for selecting much slower current velocities. Suitable physical habitats are present in coldwater streams in southeastern Minnesota to support further reintroduction of slimy sculpin. Failed reintroductions of sculpin likely are not related to lack of suitable physical habitats.

INTRODUCTION

Efforts to reintroduce extirpated species of fishes into coldwater rivers and streams in North America (*e.g.*, Lower Columbia Fish Recovery Board, 2004; Katz *et al.*, 2007; Eastern Brook Trout Joint Venture, 2008) have required information on potential limiting factors to make these projects ecologically successful (*e.g.*, Rieman and McIntyre, 1993; U.S. Fish and Wildlife Service, 1998; Palmer *et al.*, 2005; Alexander and Allan, 2007). Decades worth of habitat, behavioral, and population studies have supported the efforts to successfully restore salmonids to their native coldwater systems (Allan and Flecker, 1993; Katz *et al.*, 2007). However, nongame coldwater fishes have not been examined in such detail, and information on their needs often is minimal or entirely lacking (*e.g.*, Recovery Team for Shorthead Sculpin, 2007).

As restorations of aquatic systems expand (Alexander and Allan, 2006), increasing attention is being given to the habitat needs of nongame biota (Lamouroux *et al.*, 1999; Aadland and Kuitunen, 2006; Doledec *et al.*, 2007; Merigoux *et al.*, 2009; Zimmerman and Krueger, 2009), even if these species are not considered rare or endangered (Hannon and Hafernik, 2007; Recovery Team for Shorthead Sculpin, 2007). Many waterway restoration projects have failed to restore essential ecological functions (Palmer *et al.*, 2005; Palmer and Allan, 2006) because they incorporated only the often narrow needs of a few rare or highly

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valued recreational species (Aadland, 1993; Alexander and Allan, 2007), ignoring the broader needs of more numerous nongame species (Aadland, 1993; Lamouroux *et al.*, 1999; Aadland and Kuitunen, 2006; Doledec *et al.*, 2007; Merigoux *et al.*, 2009) and their frequently more important ecological roles in nutrient capture and food web dynamics (Zimmerman and Krueger, 2009).

Coldwater trout streams in North America's Driftless Area Ecoregion (Omernik and Gallant, 1988) of southeastern Minnesota, west-central Wisconsin, and northeastern Iowa were severely degraded by intensive agriculture and logging in the late-1800s and early-1900s (Surber, 1924; Waters, 1977; Trimble and Lund, 1982; Thorn *et al.*, 1997). Deterioration of stream habitat quality (burying of coarse sediments by fines, wider and shallower stream channels, reduced habitat heterogeneity, denuded riparian corridors, warmer waters) ultimately led to the extirpation of some of the native fish fauna, such as brook trout *Salvelinus fontinalis* and slimy sculpin *Cottus cognatus*, from many of the region's drainages (Thorn *et al.*, 1997).

Watershed management and intensive instream habitat restoration since 1930 have resulted in dramatic improvements in conditions for fishes in coldwater streams of the Driftless Area (Hunt, 1988; Thorn, 1988; Thorn *et al.*, 1997). Stream channels have been narrowed and deepened, riparian buffers have been created and protected, instream habitats have been diversified and enhanced, coarse substrates have been cleared of fine sediments and flows of cold groundwater have increased (Thorn, 1988; Thorn *et al.*, 1997). Native brook trout have now recolonized or been reintroduced to a majority of their former streams, although in most systems they now must compete with naturalized brown trout *Salmo trutta* (Thorn *et al.*, 1997; MNDNR, 2003a, b). However, even with self-sustaining and expanding populations of salmonids, many stream restorations are not yet considered ecologically successful (sensu Clewell and Aronson, 2007) because they still lack sculpin, an important component of the native coldwater biotic assemblage (Lyons *et al.*, 1996; Mundahl and Simon, 1998; MNDNR, 2003a, b; Gray and Munkittrick, 2005). Sculpin often dominate coldwater systems both in numbers and biomass (Adams and Schmetterling, 2007), exerting major ecological influence on these systems through their roles as predator and prey (Adams and Schmetterling, 2007; Zimmerman and Krueger, 2009). In their absence, reduced resistance and/or resilience to ecological disturbances may lower system stability (McCann, 2000) and lead to greater difficulty in sustaining harvestable populations of game fishes (Zimmerman and Krueger, 2009).

Sculpin have been reintroduced into only a few streams in Minnesota and Wisconsin (Brynildson and Brynildson, 1978; MNDNR, 2003a), and dispersal barriers (*e.g.*, warm waters) likely have prevented them from recolonizing other streams (MNDNR, 2003a; Schmetterling and Adams, 2004). Slimy sculpin are found in only 22% of coldwater stream reaches within the Driftless Area (MNDNR, 2003a), but recent agency efforts are expanding this percentage. Both public and private natural resource agencies (*e.g.*, MN DNR, WI DNR, U.S. Fish & Wildlife Service, U.S. Department of Agriculture's Natural Resources Conservation Service, Trout Unlimited) that typically focused their activities on protecting and enhancing stream habitats for game fishes are now collaborating efforts to protect and restore non-game biota (*e.g.*, sculpins) associated with coldwater streams in the Driftless Area (MNDNR, 2003b; Hastings and Hewitt, 2005).

Habitat requirements (*e.g.*, water temperatures and depths, current velocities, bottom substrates) have been assessed for several species of sculpin (*e.g.*, Brown, 1991; Petty and Grossman, 1996; White and Harvey, 1999; Davey *et al.*, 2005; Koczaja *et al.*, 2005; Grossman *et al.*, 2006), but only limited habitat use information is available for slimy sculpin in Lake

Ontario (Brandt, 1986) and in two streams in central Pennsylvania (Johnson *et al.*, 1992; van Snik Gray and Stauffer, 1999). Nothing is known about the species' habitat needs in coldwater streams of the upper Midwestern United States, and no study has assessed slimy sculpin in multiple systems or in multiple years to derive general patterns in habitat use and/or suitability (sensu Aadland and Kuitunen, 2006). Stream habitat improvements for trout in Minnesota and Wisconsin (Thorn *et al.*, 1997; Hunt, 1988; Thorn, 1988) are assumed to have positive effects on sculpin populations, but no studies have been conducted. Consequently, to quantify the physical habitat needs of the slimy sculpin in support of future reintroduction efforts, this study was undertaken over 3 y to assess the habitat use and selection of slimy sculpin (both young and adult fish) during summer in several coldwater streams in southeastern Minnesota where sculpin populations are native and sustainable. We also compared availability of selected habitat in streams where sculpin live currently with availability of these habitats in streams that have been chosen for sculpin reintroductions, to ascertain whether successful reintroduction may be limited by lack of needed habitats.

METHODS

STUDY AREA

Southeastern Minnesota includes a mix of coldwater, coolwater, and warmwater streams and rivers, primarily within the Driftless Area Ecoregion (Omernik and Gallant, 1988), and all are tributary to the Mississippi River. This ecoregion of rolling uplands and steeply sloped valleys is dominated by agriculture (mixed row crop, hay, and pasture), although several areas support managed forests or small (<80,000 people) urban areas. Many coldwater streams in this area have had extensive (>2 km) sections of stream habitat improved for trout (mostly introduced brown trout and native brook trout), and this region of Minnesota now has 1145 km of designated trout waters distributed among 139 streams (Thorn *et al.*, 1997).

Sculpin habitat availability and use were assessed at 12 different stream locations in nine streams representing six watersheds in southeastern Minnesota (Fig. 1, Table 1). All streams are coldwater (typical summer water temperatures of 12–18 C) trout streams supporting self-sustaining populations of brown and/or brook trout and are managed for recreational fishing (MNDNR, 2005), and all except Latsch Creek supported native populations of slimy sculpin prior to sculpin reintroduction efforts. Latsch Creek had not supported sculpin for many decades prior to reintroduction in 2004. Three of the study streams (Garvin Brook, Beaver Creek, Cold Spring Brook) have been used as sources of slimy sculpin to reintroduce into other streams in southeastern Minnesota (MNDNR, 2003a).

FIELD ASSESSMENTS

Instream habitat availability and sculpin habitat use surveys were conducted from late-May to late-Jul. in 1997, 2005, and 2006. Similar procedures were followed each year. Two streams were surveyed during all 3 y, one stream was surveyed during 2 y, and the remaining six streams were surveyed only during a single year. Because of personnel and time constraints, sculpin habitat surveys were conducted concurrently with various stream biomonitoring projects (*e.g.*, trout habitat surveys, sculpin population assessments, fish and invertebrate community surveys) during this time period, resulting in the unbalanced sampling design. Data were not adjusted or weighted in any way to account for this design.

Many variables, such as bottom substrate, water depth, current velocity, water temperature regime, and macroinvertebrate abundance, are very important in determining habitat quality for sculpin and regulating population densities (Anderson, 1985; Petty and

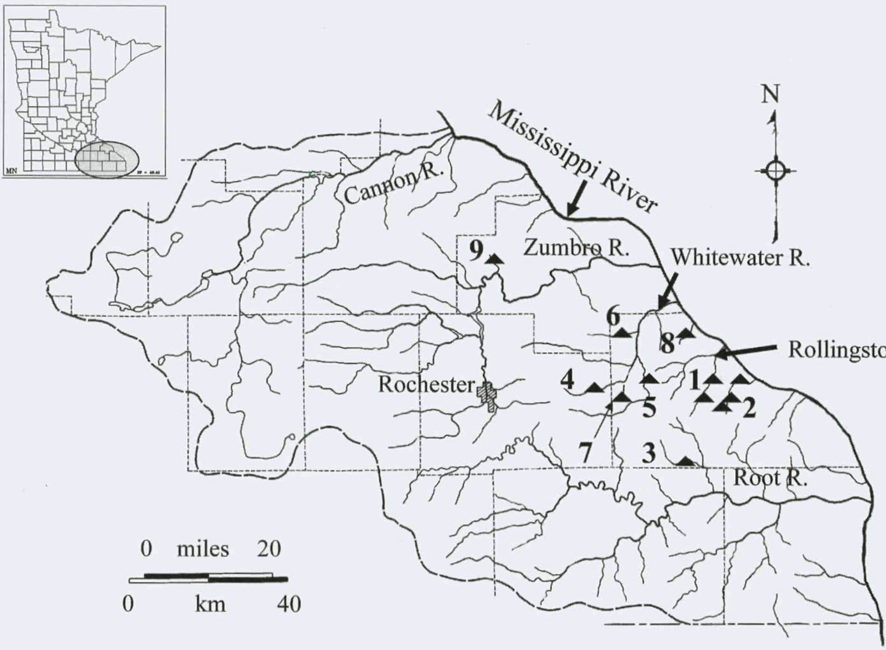

FIG. 1.—Map of streams in southeastern Minnesota, with major drainages and streams where slimy sculpin were studied. Inset highlights location of study area in Minnesota. Triangles indicate sample sites. Study streams were: 1 – Garvin Brook, 2 – Gilmore Creek, 3 – Pine Creek, 4 – Middle Branch Whitewater River, 5 – South Branch Whitewater River, 6 – Beaver Creek, 7 – Trout Run, 8 – Latsch Creek, 9 – Cold Spring Brook. *See* Table 1 for drainage basin information

Grossman, 1996, 2007, 2010). However, we focused on substrates, substrate embeddedness, depth, and current velocity because these form the basis for most stream habitat suitability criteria being developed by natural resource agencies within our region (Aadland and Kuitunen, 2006; MNDNR, 2007). Habitat availability was quantified at each site by assessing these four characteristics within a 50 to 150 m stream section (section length adjusted to include a minimum of three riffle-pool sequences). Ten to 15 transects spaced three stream widths apart were established at each site perpendicular to the thalweg, and habitat characteristics were assessed every 30 cm along each transect. Dominant substrates at each point were assessed visually and categorized as clay (<0.002 mm diameter), silt (0.002–0.06 mm), sand (0.06–2.0 mm), gravel (2–64 mm), rubble (64–250 mm), boulder (>250 mm), bedrock, or vegetation (MNDNR, 2007). Depth (nearest cm) was measured with a meter stick, and bottom current velocity (cm/sec) was measured with a Marsh-McBirney Flo-Mate current velocity meter by placing the sensor directly on the stream bottom (where fish like sculpin without swim bladders are most likely to be located). Embeddedness with fine substrates (degree to which interstitial spaces among coarse substrates were filled with fines) was estimated visually and categorized on a scale of 1 to 5: 5 = 0–5% embedded, 4 = 5–25%, 3 = 25–50%, 2 = 50–75% and 1 = 75–100% (Platts *et al.*, 1983; Bain *et al.*, 1985).

Habitat use by sculpin was determined at each stream site by direct observation during daylight hours. Extremely high water clarity (turbidities <1 NTU), most water depths

TABLE 1.—Mean total lengths (mm) of young-of-year (YOY) and adult slimy sculpin from streams in six watersheds

Watershed/stream		Year	YOY Mean ± SD	YOY n	Adult Mean ± SD	Adult n
Rollingstone Creek Watershed						
Garvin Brook	Site A	1997	24 ± 3	82	73 ± 16	144
	Site B	2005			71 ± 19	100
	Site B	2006			54 ± 13	278
Gilmore Creek Watershed						
Gilmore Creek	Site A	1997	38 ± 5	33	74 ± 14	57
	Site B	2005			67 ± 16	100
	Site B	2006			57 ± 13	82
	Site C	2006			82 ± 12	18
Root River Watershed						
Pine Creek		1997	45 ± 5	128	91 ± 9	32
Whitewater River Watershed						
M.Br. Whitewater River		1997	24 ± 3	62	74 ± 12	38
S.Br. Whitewater River		2006			80 ± 11	30
Beaver Creek		2005			80 ± 15	100
		2006			54 ± 9	105
Trout Run		2006			60 ± 16	109
Latsch Creek Watershed						
Latsch Creek		2006			72 ± 18	42
Zumbro River Watershed						
Cold Spring Brook		2006			74 ± 16	92

<40 cm, and current velocities generally <30 cm/sec facilitated fish observations during sampling. Sculpin of all sizes were easily visible under these conditions. Two or three observers located fish while moving slowly upstream and recorded substrate type, water depth, bottom current velocity, and embedddedness at the point where individual sculpin were first observed. In areas of heavy cover (rubble, boulder, vegetation), bottom habitats were moved slowly and cautiously to reveal any fish hiding within. Fish were netted as they appeared and measured (total length, mm) prior to their release downstream. Both young-of-year (YOY) and adult fish were assessed in 1997, but only adult fish were assessed in 2005 and 2006.

Prior to analysis, habitat availability and use data at each stream site were summarized by placement into appropriate categories: eight substrate categories, five embeddedness categories, seven depth classes (0–10, 11–20, 21–30, 31–40, 41–50, 51–60, >60 cm), and seven bottom current velocity classes (0–10, 11–20, 21–30, 31–40, 41–50, 51–60, >60 cm/sec).

DATA ANALYSES

We chose to analyze our habitat availability and habitat use data by using a univariate approach rather than a multivariate method. Even though multivariate techniques are very powerful methods for visualizing and assessing complicated habitat availability and use data of stream fishes (*e.g.*, Grossman and Freeman, 1987; Petty and Grossman, 2007, 2010), a univariate approach is more compatible with instream flow incremental methodology

(Olson *et al.*, 1988; Reiser *et al.*, 1989; Newcomb *et al.*, 2007) and the development of habitat suitability criteria for stream fishes being conducted by the Minnesota DNR (Aadland and Kuitunen, 2006).

Both habitat availability and habitat use by adult sculpin were compared (each characteristic separately) among streams sampled in a given year, and among years for two streams sampled in each of 3 y, using chi-square contingency table tests. Where needed, the Bonferroni correction was used to maintain the collective significance level of multiple tests at 0.05 (Scheiner and Gurevitch, 1993). These comparisons tested the hypotheses that neither habitat availability nor habitat use differed among streams or among years.

Habitat use by YOY and adult sculpin was compared during 1997 in four streams. Separate chi-square contingency table analyses were used to compare substrate use, water depth use, and bottom current velocity use between the two age groups within each of the four streams separately.

To determine whether sculpin were actively selecting for specific types of habitats, sculpin habitat use was compared to habitat availability using chi-square contingency tables (White and Harvey, 1999). Selection was assessed separately for each habitat parameter, fish age group, stream site, and year of sampling. Selection by sculpin for each of the habitat variables was determined by comparing habitat use with habitat availability at each stream location each year (Maki-Petays *et al.*, 2002; Al-Chokhachy and Budy, 2007). Percentage use (by category) was divided by percentage availability to determine selection (Balz, 1990). Selection for each category of a variable was then normalized to a scale of 0 to 1 by dividing each selection value by the highest selection value observed for each factor. Selection was determined separately for each stream location. However, to summarize selection of all fish collected in the same year, normalized selection values for each category were averaged across all sites sampled for that year, and these averages were then re-normalized if the highest average was <1. A similar process was followed to determine overall selection among years.

The abundance of selected sculpin habitats within streams that contained native populations of sculpin (seven sites on six streams) was compared to streams (seven sites on six streams) where sculpin had recently been reintroduced (Latsch, Big Trout, Little Trout creeks) or where they may be reintroduced (East Burns Valley, West Burns Valley, Pleasant Valley creeks; MN DNR, 2003a). All of these coldwater streams, located in separate drainages immediately east of Gilmore Creek (Fig. 1), also are designated trout streams that contain naturally reproducing populations of brown and/or brook trout and are managed for recreational fishing. Their selection for sculpin reintroduction by the MN DNR was based primarily on walk-through, qualitative assessments of habitat availability during previous trout population surveys (Eric Merten, formerly MN DNR-Fisheries, Lake City, pers. comm.). Habitat availability for the current project was assessed at each stream site as described above for sculpin streams, and a habitat suitability index (HSI) was determined for each habitat variable (depth, current velocity, substrate type, substrate embeddedness) at each site by multiplying percent abundance (by category) by the overall normalized selection value (as determined above) for each category and summing across categories (Newcomb *et al.*, 2007). This produced an HSI that potentially ranged from 0 (totally lacking in any preferred habitat) to 100 (only the most preferred habitat present). A combined HSI for each stream site also was calculated by averaging the four individual habitat HSIs (Newcomb *et al.*, 2007). HSIs for sculpin streams were compared to HSIs for reintroduction streams with *t* tests to assess possible differences among streams. HSIs for streams where sculpin reintroduction has been successful (continued presence of adult fish for two or more years, presence of YOY; Latsch, Little Trout creeks) were compared to those

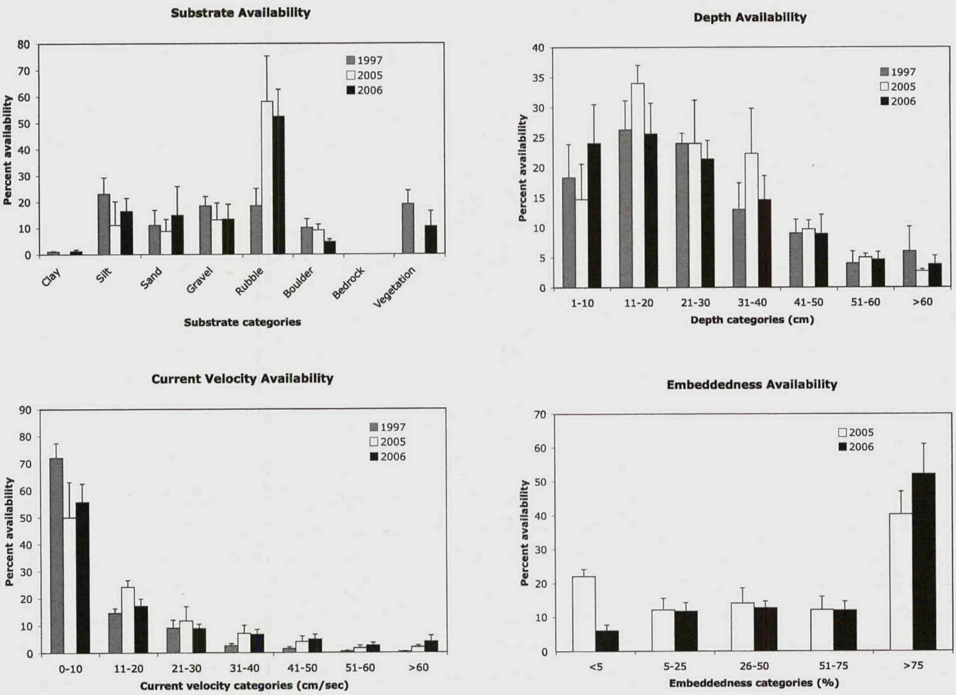

FIG. 2.—Habitat availability in nine streams in southeastern Minnesota during the summers of 1997 (n = 4 streams), 2005 (n = 3) and 2006 (n = 8). Error bars represent ±1 SE of the mean

for stream sites where reintroductions have been unsuccessful (disappearance of adult fish during first 2 y after reintroduction, no evidence of YOY; two sites on Big Trout Creek) with a two-factor analysis of variance test (success/non-success vs. individual habitat HSIs).

RESULTS

Habitat use information was gathered for 305 YOY sculpin from four sites on four streams and 1627 adult sculpin from 12 sites on nine streams (Table 1), and habitat availability data were collected at 3272 points within the same nine streams. Mean size of YOY fish varied from 24 to 45 mm total length among the streams examined, whereas mean size of adult fish varied from 54 to 91 mm total length (Table 1). Among-stream variations in mean size were largely the results of variation in the month of sampling (YOY fish) and the relative abundance of the various year classes present (adult fish). Collections averaged 76 YOY sculpin (range = 33–128) and 88 adult fish (range 18–278) per sampling.

HABITAT AVAILABILITY

The study streams typically were shallow (<40 cm) and slow-moving (<20 cm/sec), with rocky but embedded substrates (Fig. 2). Rubble substrates were usually dominant and bedrock and clay were largely absent. Deep water (>60 cm) and fast currents (>60 cm/sec) typically comprised <5% of available habitats.

The various types of potential sculpin habitat were not always present in similar proportions within the nine streams surveyed. Consequently, all habitat variables assessed

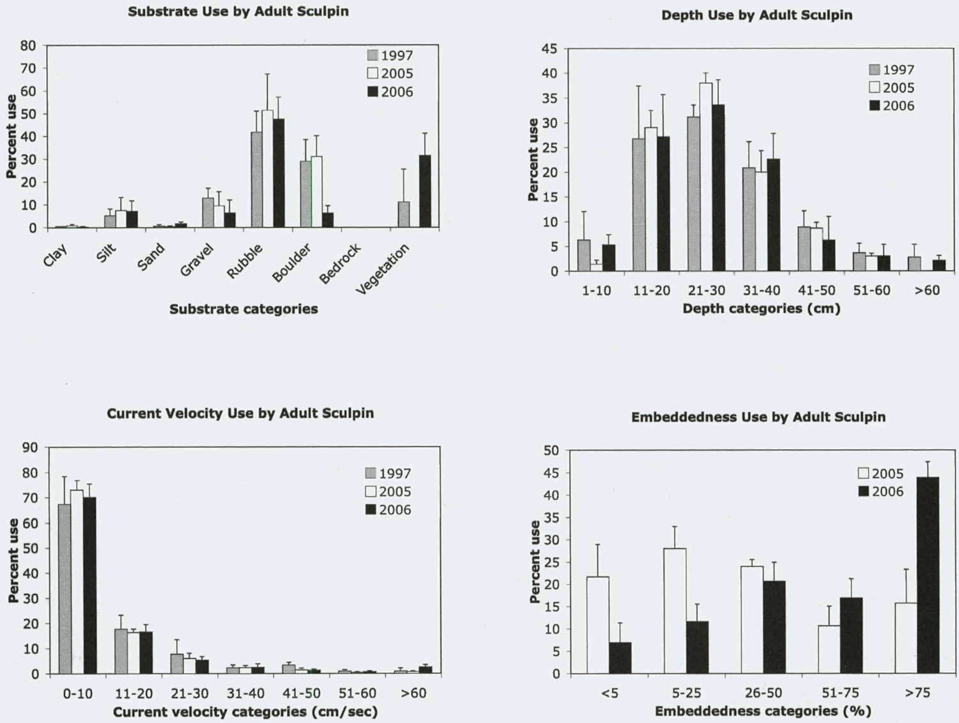

FIG. 3.—Habitat use by adult slimy sculpin in nine streams in southeastern Minnesota during the summers of 1997 (n = 271 sculpin, 4 streams), 2005 (n = 300, 3) and 2006 (n = 1056, 8). Error bars represent ±1 SE of the mean

(substrate, water depth, current velocity, substrate embeddedness) displayed significant (contingency table analyses: all $P < 0.005$) variation in availability among streams for each of the years surveyed. Similarly, habitat availability varied significantly (contingency table analyses: all $P < 0.005$) among years for two streams surveyed in each of 3 y. Even when data were pooled by year across all streams, habitat availability differed significantly (contingency table analyses: all $P < 0.005$) among years for all habitat variables.

HABITAT USE

The majority of adult sculpin were collected in rubble, boulder, or vegetated substrates, in water between 11 and 40 cm deep and in current velocities <20 cm/sec (Fig. 3). Sand substrates, very shallow (<10 cm) and deep (>50 cm) waters, and faster currents (>50 cm/sec) were seldom used by adult fish.

Habitat use by adult sculpin varied significantly (contingency table analyses: $P < 0.001$) among streams for most habitat variables during each of the 3 y. Only depth and current velocity use during 2005 were not significantly (both $P > 0.10$) different among the streams surveyed. Similarly, habitat use varied significantly (contingency table analyses: all $P < 0.005$) among years for two streams surveyed in each of 3 y. However, when data were pooled by year across all streams, habitat use differences became insignificant (contingency table analyses: all $P > 0.05$) among years for substrate, water depth, and current velocity.

TABLE 2.—Comparison of physical habitat use by young-of-year and adult slimy sculpin in four streams, individually and combined, during 1997. Bonferonni correction $\alpha = 0.0033$

Parameter	Stream	Contingency table X^2 value	df	P value
Substrate	Gilmore	33.5	5	<0.001
	M.Br. Whitewater	52.1	5	<0.001
	Pine	40.3	4	<0.001
	Garvin	34.5	5	<0.001
	Combined	205.8	7	<0.001
Water depth	Gilmore	22.0	3	<0.001
	M.Br. Whitewater	37.5	6	<0.001
	Pine	21.9	6	0.004
	Garvin	12.6	5	0.03
	Combined	67.5	6	<0.001
Bottom current velocity	Gilmore	8.0	6	>0.10
	M.Br. Whitewater	53.0	4	<0.001
	Pine	13.5	5	0.020
	Garvin	25.2	4	<0.001
	Combined	8.3	6	>0.10

In the four streams where habitat use of both YOY and adult sculpin were assessed, adult and YOY sculpin exhibited significantly different distributions for substrate, water depth, and current velocity (Table 2). YOY and adult fish used different substrates in all streams, and different depths and bottom current velocities in two streams each. Compared to adult sculpin, YOY fish tended to use finer (and more vegetated) substrates, shallower (<20 cm) water, and more intermediate (11–40 cm/sec) current velocities. When habitat use data were combined across all four streams, differences in substrate and depth use between YOY and adults were still significant, but current velocity use did not differ (Table 2, Fig. 4).

During 1997 surveys, habitat use by both YOY and adult slimy sculpin varied significantly (contingency table analyses: all $P < 0.001$) among the four streams for substrate, water depth, and current velocity. Slimy sculpin used all of the substrate types available in the streams sampled, although YOY sculpin were not found on clay substrates and adult fish were not found on bedrock surfaces (Fig. 4). Substrate use differed significantly (contingency table analysis: $X^2 = 205.8$, df = 7, $P < 0.001$) between YOY and adult fish, with YOY fish using more gravel and vegetation and adult fish using more rubble and boulder substrates.

YOY and adult sculpin both occupied the full range of water depths available in the streams during 1997, with most fish using the shallower (<40 cm) waters (Fig. 4). However, depth distribution of the two groups differed significantly (contingency table analysis: $X^2 = 67.5$, df = 6, $P < 0.001$), with most YOY sculpin found in shallower waters (1–30 cm) than those (11–40 cm) occupied by most adult fish.

Most YOY and adult slimy sculpin were found in water velocities <20 cm/sec during 1997 (Fig. 4), although a few fish were present in areas with high velocities (>50 cm/sec). There was no significant difference (contingency table analysis: $X^2 = 8.3$, df = 6, $P > 0.10$) in the distribution of YOY and adult fish among the various velocity categories.

HABITAT SELECTION

Habitat selection by sculpin was evident (contingency table analyses: $P < 0.001$ for 12 of 14 comparisons) for both YOY and adult fish when habitat use was compared with habitat

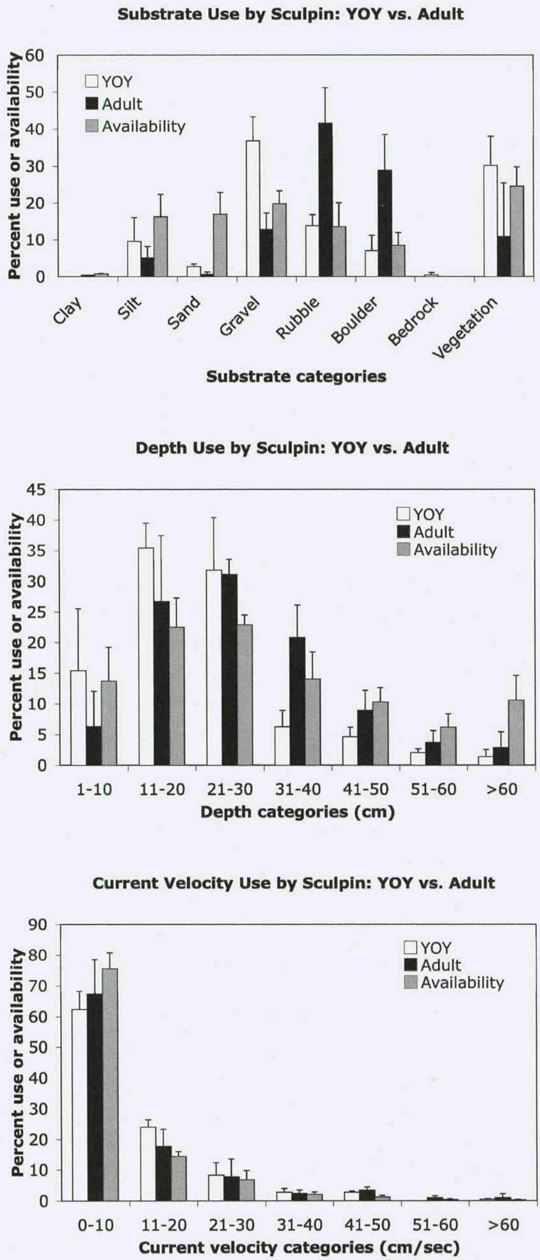

FIG. 4.—Habitat availability and use by young-of-year (YOY) and adult slimy sculpin in four streams in southeastern Minnesota, summer 1997. YOY n = 305; adult n = 271. Error bars represent ±1 SE of the mean

TABLE 3.—Chi-square contingency table analyses of physical habitat selection by young-of-year (YOY) and adult slimy sculpin. Bonferonni correction $\alpha = 0.0036$

Parameter/age group/year		X^2 value	df	P value
Substrate	YOY 1997	80.9	7	<0.001
	Adult 1997	442.9	7	<0.001
	Adult 2005	44.0	6	<0.001
	Adult 2006	38.3	7	<0.001
Water depth	YOY 1997	97.1	6	<0.001
	Adult 1997	78.3	6	<0.001
	Adult 2005	28.3	6	<0.001
	Adult 2006	292.0	6	<0.001
Bottom current velocity	YOY 1997	27.5	6	<0.001
	Adult 1997	27.1	6	<0.001
	Adult 2005	12.4	6	>0.05
	Adult 2006	27.3	6	<0.001
Substrate embeddedness	Adult 2005	19.2	4	<0.001
	Adult 2006	5.5	4	>0.10

availability (Table 3, Fig. 2). In general, both age groups occupied the shallower water, the slower bottom current velocities and the coarser substrates within the ranges of what were available within the various streams surveyed.

Slimy sculpin (both YOY and adults) exhibited distinct selection for certain instream habitats (Fig. 5). YOY fish selected gravel, rubble, and vegetation substrates, whereas adults selected boulders and vegetation. YOY sculpin displayed the greatest selection for water depths <30 cm, whereas adult sculpin exhibited broader selection from 10–60 cm. Both age groups demonstrated fairly broad selection for slower (<40 cm/sec) water, clearly avoiding the faster habitats that were fairly common in these streams. Adult sculpin selected coarse substrates <60% embedded with fine sediments (YOY fish were not assessed for embeddedness).

HABITAT SUITABILITY: NATIVE SCULPIN STREAMS VS. REINTRODUCTION STREAMS

HSI values for individual habitats were generally lowest for substrate (mean = 41.9) and highest for current velocity (mean = 79.2) at the 14 stream sites surveyed (Table 4). Individual habitat HSIs were not significantly different (*t* tests: all $P > 0.05$) between native sculpin streams and reintroduction streams. Combined site HSIs were very similar at most sites, averaging 62.9, and did not differ ($P = 0.63$) between sculpin streams and reintroduction streams. In addition, habitat HSI values were not significantly different (two-factor ANOVA: $P = 0.57$) between stream sites where sculpin reintroduction has been successful (Latsch Creek, Little Trout Creek) and sites where reintroduction has been unsuccessful (two sites on Big Trout Creek; Table 4).

DISCUSSION

This study demonstrated three attributes of slimy sculpin and coldwater stream physical habitats in southeastern Minnesota. First, slimy sculpin exhibited habitat selection for coarse substrates and vegetation, shallow water, and slow bottom current velocities, and this selection was largely consistent across streams and years. Secondly, adult sculpin consistently used coarser substrates and deeper water than did YOY sculpin. Finally, lack of suitable physical habitat likely has not been nor will not be the cause of slimy sculpin reintroduction

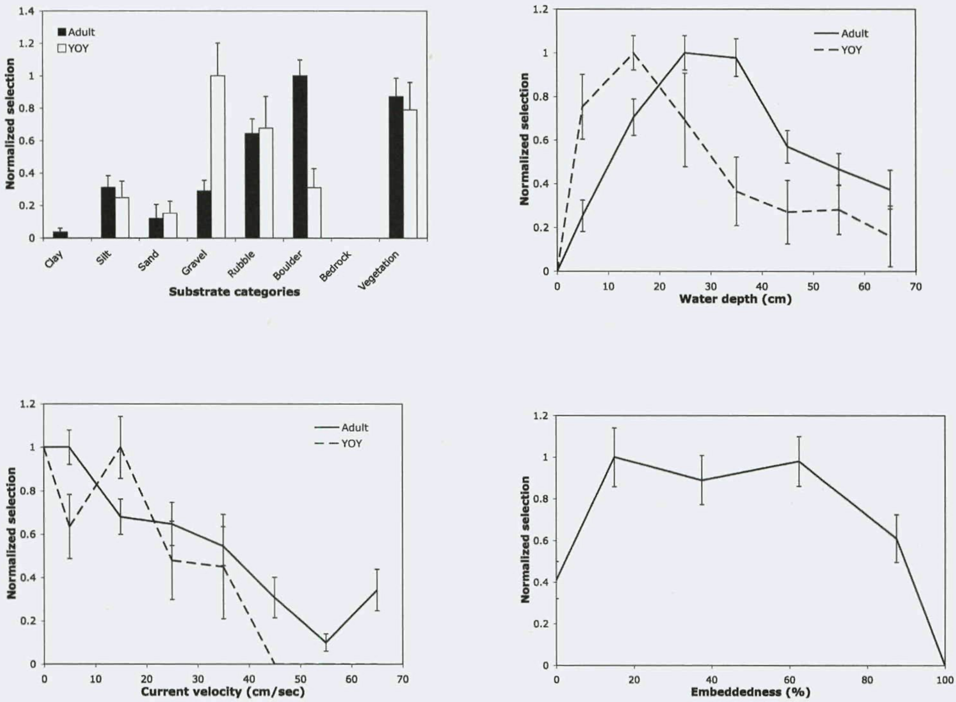

FIG. 5.—Habitat selection by young-of-year (YOY) and adult slimy sculpin in nine streams in southeastern Minnesota, summers of 1997, 2005, and 2006. Embeddedness selection only was assessed in adult fish. Error bars represent ±1 SE of the mean

failures in southeastern Minnesota because streams in this region contain adequate habitats to meet the needs of this species.

Slimy sculpin were found in all habitats available in southeastern Minnesota streams, but consistently displayed positive selection for different stream habitat variables in much the same fashion as reported for several other species of sculpin (Brown, 1991; Petty and Grossman, 1996, 2007, 2010; van Snik Gray and Stauffer, 1999; White and Harvey, 1999; Davey *et al.*, 2005; Koczaja *et al.*, 2005). Sculpin likely do not select habitat variables such as substrate, depth, and current velocity independently of one another, instead simultaneously assessing the quality of several habitat factors (Vadas and Orth, 2001; Grossman *et al.*, 2006; Al-Chokhachy and Budy, 2007; Petty and Grossman, 2007, 2010). Consequently, our use of a combined HSI (average of four individual habitat HSIs) is an attempt to recognize that several physical habitat factors are important to slimy sculpin, with one possibly no more, or less, important than another.

YOY and adult slimy sculpin used stream habitats that differed significantly in substrate and depth, but not in bottom current velocity. Adults and juveniles of many sculpin species frequently occupy slightly different stream habitats, with adults often found in coarser substrates (Johnson *et al.*, 1992; Davey *et al.*, 2005; Grossman *et al.*, 2006; Petty and Grossman, 2007, 2010) in deeper water (Brandt, 1986; Freeman and Stouder, 1989; Johnson *et al.*, 1992; van Snik Gray and Stauffer, 1999; Koczaja *et al.*, 2005; Petty and Grossman, 2007, 2010) with faster current velocities (Johnson *et al.*, 1992; Petty and Grossman, 2007, 2010).

TABLE 4.—Slimy sculpin habitat suitability index (HSI) values for stream physical habitat variables (separate and combined) at sculpin and non-sculpin stream sites, 2006. P values are from *t* tests comparing HSIs between sculpin and non-sculpin streams

	Physical habitat HSI				
Stream	Depth	Current velocity	Substrate	Embed.	Combined HSI
Sculpin streams					
Garvin Brook	67.2	91.8	52.7	53.6	66.3
Gilmore Creek					
Site A	62.7	83.0	31.0	58.0	58.7
Site C	60.8	69.4	10.1	35.0	43.9
S.Br. Whitewater River	82.2	56.2	53.8	70.5	65.7
Beaver Creek	78.0	81.3	36.9	50.2	61.6
Trout Run	71.8	83.0	50.3	62.9	67.0
Cold Spring Brook	82.2	90.5	48.3	38.8	65.0
Average	72.1	79.3	40.4	52.7	61.2
Non-sculpin streams					
Latsch Creek	54.4	84.9	35.2	63.7	59.6
Big Trout Creek					
Site A	61.0	75.7	49.0	62.2	62.0
Site B	64.9	80.7	37.5	55.9	59.8
Little Trout Creek	74.1	78.7	52.6	58.3	65.9
E. Burns Valley Creek	64.4	85.2	44.2	66.5	65.1
W. Burns Valley Creek	57.3	82.5	51.6	82.9	68.6
Pleasant Valley Creek	73.2	66.1	33.3	63.2	59.0
Average	64.2	79.1	43.3	64.7	62.9
P value	0.10	0.97	0.67	0.06	0.63

However, these differing use patterns are not always present between the age groups, especially for current velocity (Daniels, 1987; van Snik Gray and Stauffer, 1999; Koczaja *et al.*, 2005; present study). Differences in habitat use between adult and YOY sculpin generally have been attributed to avoidance of predatory adults by YOY fish (Downhower and Brown, 1979; Brown, 1991), adult sculpin displacing YOY fish from the more predator-resistant (*i.e.*, coarser substrates, deeper water) habitats (Brandt, 1986; Davey *et al.*, 2005; Koczaja *et al.*, 2005), or adult fish outcompeting YOY sculpin for the best foraging locations and displacing them to less favorable habitats (Grossman *et al.*, 2006; Petty and Grossman, 2007, 2010). All of these causes imply that stream habitats occupied by YOY sculpin are not really selected or preferred, but only used until other, more suitable habitats become available (Petty and Grossman, 2007, 2010).

Because YOY and adult sculpin use slightly different habitats, reintroduction efforts for slimy sculpin should consider the need for habitat for both age groups. Even though juvenile sculpin may be relegated to less favorable (for adult fish) habitats because of competition with adults (Petty and Grossman *et al.*, 2007, 2010), these habitats may be important nursery areas that can serve to stabilize recruitment of this vulnerable life history stage (Copp *et al.*, 1994; Laegdsgaard and Johnson, 1995; Jurajda, 1999; Beck *et al.*, 2001; Penczak *et al.*, 2003; Schiemer *et al.*, 2003; King, 2004; Dahlgren *et al.*, 2006). This especially may be important in newly reintroduced populations where recruitment is critical for reintroduction success (Sheller *et al.*, 2006; Seddon *et al.*, 2007; George *et al.*, 2009).

Lack of suitable habitat should not be the cause of any slimy sculpin reintroduction failures in southeastern Minnesota, since this study found that many of the coldwater streams chosen for future sculpin reintroduction have abundances of selected sculpin habitat, similar to those in streams with native, sustaining sculpin populations. However, to reduce the potential for failure in future reintroductions, more thorough feasibility assessments should be undertaken at potential reintroduction sites (Minckley, 1995; Seddon *et al.*, 2007; George *et al.*, 2009; Dunham *et al.*, 2011). Simple stream habitat assessments such as those in this study can be used as a first-step, screening tool to select potential streams for reintroductions of sculpins, but additional surveys of water temperature (Edwards and Cunjak, 2007), invertebrate prey abundance (Dineen, 1951; Petty and Grossman, 1996, 2007, 2010), and competing or predatory fishes (Dineen, 1951; Anderson, 1985; Grossman *et al.*, 1998) should be conducted to improve reintroduction success rates.

The present study examined selected habitats of slimy sculpin in nine coldwater streams, but these comprise only a small proportion of the streams occupied by this species in Minnesota (Eddy and Underhill, 1974; Phillips *et al.*, 1982). On a broader scale, the slimy sculpin has the largest geographical range of any sculpin species in North America, native to 20 U.S. states and 12 Canadian provinces (Page and Burr, 1991). Although the findings of this study agree well with other investigations of habitat use by slimy sculpin in two small streams in Pennsylvania (Johnson *et al.*, 1992; van Snik Gray and Stauffer, 1999), extrapolating the applicability of our findings to include the entire range of slimy sculpin would be presumptuous. However, the general similarities in habitat use by many different species of sculpin in many different regions (Brown, 1991; Petty and Grossman, 1996, 2007, 2010; van Snik Gray and Stauffer, 1999; White and Harvey, 1999; Davey *et al.*, 2005; Koczaja *et al.*, 2005) suggest that our study has applicability well beyond the Driftless Area in Minnesota.

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