Am. Midl. Nat. 156:11–22

Densities and Habitat of American Brook Lamprey (Lampetra appendix) Larvae in Minnesota

NEAL D. MUNDAHL,[1] GOLAM SAYEED, STEPHEN TAUBEL, CONRAD ERICKSON, ANDREW ZALATEL AND JULIE COUSINS

Department of Biology and Large River Studies Center, Winona State University, P.O. Box 5838, Winona, Minnesota 55987

Abstract.—At least one formerly large population of American brook lamprey (*Lampetra appendix*) has been extirpated in Minnesota, but little is known about the species in the state. We examined densities and age structures of American brook lamprey larvae in several streams in southeastern Minnesota. Mean densities of lamprey larvae in the best habitats available in 13 streams varied from 0.33–5.78 larvae/m^2. Seven of nine streams examined had missing age classes of larvae, with five streams missing two or more classes. Habitat use and length–weight relationships of larvae were similar to those reported previously for this and other species of lamprey. Many *L. appendix* populations in Minnesota are healthy, but others are susceptible to extirpation because of low densities and multiple missing age classes. The current status of many of these populations, and their susceptibility to further disturbance, need to be more thoroughly examined to better assess the need for legal protection for the species in Minnesota.

Introduction

The American brook lamprey *Lampetra appendix* (DeKay) has the widest geographic distribution of any nonparasitic lamprey in North America (Page and Burr, 1991), but populations have declined or been eliminated from many streams because of human activities that impact the lamprey and its stream habitats (Renaud, 1997; Mundahl, 1998). Residential development within drainage basins (Eddy and Underhill, 1974), dam construction and flood-control projects (Trautman, 1981), pollution from agricultural activities and logging (Eddy and Underhill, 1974; Trautman, 1981), bait collecting (Vladykov, 1949, 1973) and sea lamprey *Petromyzon marinus* control projects (Manion and Purvis, 1971; Cochran *et al.*, 1993) all have been detrimental to populations of *L. appendix*. Populations on the periphery of the species' range are most threatened (NatureServe, 2003), and several states in these regions (*e.g.*, Connecticut, Massachusetts, Vermont, Iowa) have heeded pleas (Vladykov, 1973; Renaud, 1997) to protect North American nonparasitic lampreys in affording *L. appendix* protected status (Johnson, 1987; Hoff, 1988; Schmidt, 1995).

In Minnesota, the American brook lamprey is restricted primarily to the southeastern portion of the state (Phillips *et al.*, 1982), where streams have been impacted by human activities for over a century (Waters, 1977; Thorn *et al.*, 1997) and where several populations of *Lampetra appendix* have been extirpated (Eddy and Underhill, 1974; Phillips *et al.*, 1982). Minnesota lies on the northwestern periphery of the range of *L. appendix*. Although American brook lamprey was listed as a Special Concern species in Minnesota prior to 1996, it was removed from the list after the species was collected in a variety of streams in the southeastern part of the state during the early- and mid-1990s. However, no comprehensive

[1] Corresponding author: Telephone: (507)457-5695; e-mail: nmundahl@winona.edu

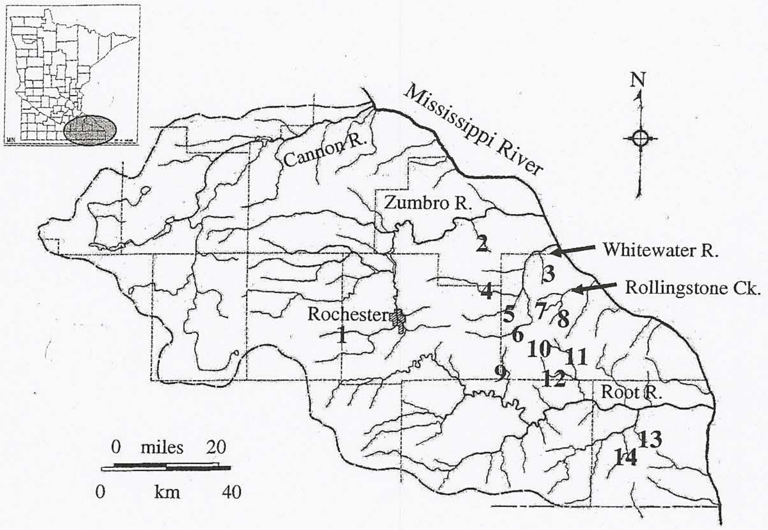


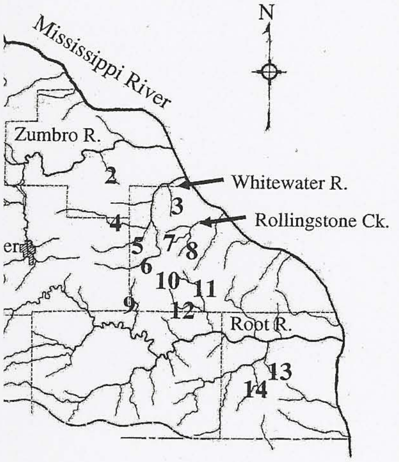
FIG. 1.—Map of streams in southeastern Minnesota, with major drainages and streams where American brook lamprey larvae were collected. Inset highlights location of study area in Minnesota. Study streams were: 1 – Salem Creek, 2 – West Indian Creek, 3 – Trout Valley Creek, 4 – North Branch Whitewater River, 5 – Middle Branch Whitewater River, 6 – South Branch Whitewater River, 7 – Bear Creek, 8 – Rupprecht Creek, 9 – Trout Run Creek, 10 – Ferguson Creek, 11 – Rush Creek, 12 – Pine Creek, 13 – Badger Creek, 14 – Beaver Creek

surveys, or even general population assessments, of *L. appendix* have ever been conducted within this region.

During a series of stream surveys, watershed assessments and student research projects conducted over a period of 5 y, we collected a variety of data on American brook lamprey larvae and their habitats in many streams throughout southeastern Minnesota. Here we summarize these data in an attempt to determine the present status of several populations of American brook lamprey within four drainages in southeastern Minnesota and to evaluate the decision to not provide state-wide protection for the species. We examined densities and age structures of larvae to assess population status and also evaluated their length–weight patterns and habitat use for comparison to previous work on the species in other portions of its range.

STUDY AREA

Streams in southeastern Minnesota extend across two ecoregions (Driftless Area, Western Corn Belt Plains; Omernik and Gallant, 1988) and include a mix of coldwater, coolwater and warmwater systems. Four major drainages (Cannon River – 3785 km^2, Zumbro River – 3656 km^2, Root River – 4275 km^2, Whitewater River – 758 km^2) and many other smaller systems all are tributary to the Mississippi River (Fig. 1). Land use is dominated by agriculture (mixed row crop, hay and pasture), although several areas support managed forests or moderate-sized (30,000–75,000 people) urban areas. This region of rolling uplands and steeply sloped valleys was subjected to intensive agricultural development and logging in the late-1800s, resulting in increased erosion, flooding and stream sedimentation and decreased discharges of coldwater springs (Surber, 1924; Waters, 1977; Trimble and Lund,



ıesota, with major drainages and streams where
set highlights location of study area in Minnesota.
an Creek, 3 – Trout Valley Creek, 4 – North Branch
River, 6 – South Branch Whitewater River, 7 – Bear
, 10 – Ferguson Creek, 11 – Rush Creek, 12 – Pine

nts, of *L. appendix* have ever been conducted

:d assessments and student research projects
a variety of data on American brook lamprey
roughout southeastern Minnesota. Here we
ne the present status of several populations of
:s in southeastern Minnesota and to evaluate
on for the species. We examined densities and
tatus and also evaluated their length–weight
evious work on the species in other portions

AREA

cross two ecoregions (Driftless Area, Western
and include a mix of coldwater, coolwater and
mon River – 3785 km^2, Zumbro River – 3656
– 758 km^2) and many other smaller systems
. 1). Land use is dominated by agriculture
ı several areas support managed forests or
ı areas. This region of rolling uplands and
ve agricultural development and logging in
ı, flooding and stream sedimentation and
ber, 1924; Waters, 1977; Trimble and Lund,

1982; Thorn *et al.*, 1997). Deterioration of stream habitat quality and overexploitation led to extirpation of some of the native fish fauna, most notably brook trout *Salvelinus fontinalis*, in many streams by 1900 (Thorn *et al.*, 1997).

Since 1930, stream habitat degradation in southeastern Minnesota has diminished and some natural stream rehabilitation has occurred as land conservation practices have been implemented (Thorn *et al.*, 1997). Much instream habitat today remains degraded, but extensive sections of stream habitat have been improved for trout (mostly introduced brown trout *Salmo trutta*) over the past several decades (Thorn *et al.*, 1997), with approximately 5 km of new habitat improvements added each year [Minnesota Department of Natural Resources (MDNR), 1998]. Trout management activities in this region today involve 1145 km of 139 streams (Thorn *et al.*, 1997).

This study focused on a five-county area where *Lampetra appendix* was most common in historical collections (MDNR, 1995). Other lampreys (northern brook lamprey *Ichthyomyzon fossor* and silver lamprey *I. unicuspis*) are extremely rare within this region (Phillips *et al.*, 1982).

MATERIALS AND METHODS

During various research and assessment projects conducted in southeastern Minnesota between April and September, 1995–1999, American brook lamprey larvae were collected from their burrows in fine sediments with the aid of backpack electrofishing units (Smith Root Type VII and 12-B POW). Based on prior collecting experience, habitats judged most suitable and likely to contain lamprey larvae were electrofished intensively and all emerging larvae were captured until no additional specimens emerged from the sediments in three successive passes. The total area sampled was measured to determine larval density (Beamish and Lowartz, 1996). This approach was used to determine densities of larvae in the best habitat available, rather than to assess an overall density for an entire stream segment. No attempt was made to determine the total area of habitat suitable for lamprey larvae in each stream.

Larvae collected from several streams were anesthetized (MS-222), weighed (nearest 0.1 g wet weight), measured [mm total length (TL)] and returned to their habitat after recovery. Size measurements were used to assess length-weight patterns of larvae and population age structure (based on smoothed length-frequency distributions; Hardisty and Potter, 1971; Beamish and Medland, 1988) at each of the stream sites. Populations examined during summer were expected to contain a maximum of five size/age groups of larvae, whereas those examined during autumn through spring should contain four size/age groups of larvae plus metamorphosed, prespawning adults (Seagle and Nagel, 1982). Although statoliths can be used to determine American brook lamprey age and verify age classes (*e.g.*, Beamish and Medland, 1988), they were not used because of a no-kill policy in effect during the study period.

During some of the lamprey surveys conducted during late-summer and autumn (baseflow stream conditions present), habitat assessments were made at the point of collection of individual larvae. Water depth and average water column current velocity [cm/s at 0.6-depth (60% of distance from stream surface to bottom); Marsh-McBirney Flowmate current meter] were measured and a sample (>100 ml) of the substrate (top 5 cm) from which the larvae emerged was collected and returned to the laboratory for particle size (serial sieving of dried sediments through 0.2-, 0.4- and 0.8-mm mesh sieves) and volatile organic matter (weight loss on ignition of dried sediments at 550 C for 3 h) analyses.

TABLE 1.—Data collected on American brook lamprey larvae and their habitats in 14 streams within four drainages of the upper Mississippi River in southeastern Minnesota. X indicates data present

Drainage/stream	Density	Age classes	Length–weight	Habitat
Whitewater River drainage				
N. Br. Whitewater	X	X	X	X
M. Br. Whitewater	X	X	X	
S. Br. Whitewater	X	X	X	
Trout Valley Creek	X	X	X	X
Root River drainage				
Rush Creek	X			
Beaver Creek	X	X	X	X
Badger Creek	X	X	X	
Trout Run Creek	X			
Pine Creek	X	X	X	X
Ferguson Creek				X
Rollingstone Creek drainage				
Bear Creek	X		X	X
Rupprecht Creek	X		X	
Zumbro River drainage				
Salem Creek	X	X	X	X
W. Indian Creek	X	X	X	X

Because of the varying goals of the different projects for which data on lamprey larvae were gathered, comparable data were not available for all of the 14 streams examined in this study. Density estimates were conducted in 13 streams, age structures were examined in nine streams, length-weight relationships were assessed in 11 streams and habitat data were gathered from eight streams (Table 1).

RESULTS

DENSITY ESTIMATES, AGE STRUCTURES AND LENGTH–WEIGHT PATTERNS OF LAMPREY LARVAE

Densities of American brook lamprey larvae were determined for small areas (n = 85, mean = 4.22 m^2, range = 0.12–19.60 m^2) of habitat in 13 streams within four drainage basins (Fig. 1). Mean densities ranged from 0.33 larvae/m^2 in Trout Run Creek to 5.78 larvae/m^2 in Pine Creek (Table 2), and differed significantly (Kruskal-Wallis test: $H = 30.89$, $P < 0.001$) among streams. However, since densities were quite variable among streams within the same drainage (Table 2), there was no significant (Kruskal-Wallis test: $H = 5.34$, $P = 0.15$) difference in densities among the four drainages examined. Mean density in a stream was not correlated with either the length range of larvae collected (simple linear regression: $F = 1.10$, $P = 0.32$, $r^2 = 0.08$) or the number of age groups of larvae present (simple linear regression: $F = 0.30$, $P = 0.60$, $r^2 = 0.04$). Overall mean density for all streams was 3.57 larvae/m^2. Maximum densities found in any single location within each stream ranged from 0.33 to 16.67 larvae/m^2, with maximum densities averaging 5.4 larvae/m^2 across all streams.

Lamprey population age structures (*i.e.*, number and size of age classes present) based on length-frequencies varied widely among streams for both April and August samples (Table 2). Small, age-1 larvae comprised the most abundant age class in most (eight of 11) samples during both periods. In April 1997 and 1998, when four age classes of larvae were expected,

TABLE 2.—Mean (±SD) densities (number/m
in 13 streams within four drainages of the up

Drainage/stream	Number
Whitewater River drainage	
N. Br. Whitewater	
M. Br. Whitewater	
S. Br. Whitewater	
Trout Valley Creek	2
Root River drainage	
Rush Creek	
Beaver Creek	
Badger Creek	
Trout Run Creek	
Pine Creek	1
Rollingstone Creek drainage	
Bear Creek	
Rupprecht Creek	
Zumbro River drainage	
Salem Creek	
W. Indian Creek	

only two of five streams contained all fou
missing intermediate-size (ages class 2 or
4 larvae. Dominant year classes had been s
streams). In August 1999, when five age

TABLE 3.—Year classes of American brook la
during April 1997–1998 and August 1999. Va
Year class 0 larvae were not available for captu
sample size

Stream	N	0
April 1997		
N. Br. Whitewater	56	
Pine Creek	48	
April 1998		
Salem Creek	77	
Trout Valley Creek	109	
West Indian Creek	64	
August 1999		
N. Br. Whitewater	124	
M. Br. Whitewater	78	
S. Br. Whitewater	37	
Trout Valley Creek	62	3
Beaver Creek	20	
Badger Creek	22	

rey larvae and their habitats in 14 streams within
ıeastern Minnesota. X indicates data present

classes	Length–weight	Habitat
X	X	X
X	X	
X	X	
X	X	X
X	X	X
X	X	
X	X	X
		X
	X	X
	X	
X	X	X
X	X	X

projects for which data on lamprey larvae
.e for all of the 14 streams examined in this
streams, age structures were examined in
assessed in 11 streams and habitat data

H–WEIGHT PATTERNS OF LAMPREY LARVAE

vere determined for small areas (n = 85,
t in 13 streams within four drainage basins
m^2 in Trout Run Creek to 5.78 larvae/m^2
(Kruskal-Wallis test: H=30.89, $P < 0.001$)
te variable among streams within the same
Kruskal-Wallis test: H = 5.34, P = 0.15)
examined. Mean density in a stream was
ae collected (simple linear regression: F =
groups of larvae present (simple linear
ıll mean density for all streams was 3.57
: location within each stream ranged from
ıveraging 5.4 larvae/m^2 across all streams.
r and size of age classes present) based on
or both April and August samples (Table
ınt age class in most (eight of 11) samples
ı four age classes of larvae were expected,

TABLE 2.—Mean (±SD) densities (number/m^2) and density ranges of American brook lamprey larvae in 13 streams within four drainages of the upper Mississippi River in southeastern Minnesota

Drainage/stream	Number of sites	Density	Range
Whitewater River drainage			
N. Br. Whitewater	9	3.63 (1.35)	1.70–5.13
M. Br. Whitewater	2	4.70 (2.40)	3.00–6.40
S. Br. Whitewater	4	2.52 (1.00)	1.71–3.96
Trout Valley Creek	23	5.74 (3.83)	0.75–16.00
Root River drainage			
Rush Creek	5	2.10 (0.95)	0.57–3.00
Beaver Creek	4	1.17 (0.75)	0.44–2.00
Badger Creek	4	3.69 (2.88)	2.00–8.00
Trout Run Creek	2	0.33 (0.00)	0.33–0.33
Pine Creek	11	5.78 (4.59)	1.16–16.67
Rollingstone Creek drainage			
Bear Creek	4	1.04 (0.45)	0.56–1.50
Rupprecht Creek	3	0.55 (0.39)	0.33–1.00
Zumbro River drainage			
Salem Creek	6	1.93 (1.11)	0.51–3.03
W. Indian Creek	8	1.79 (1.18)	0.34–3.81

only two of five streams contained all four age groups of larvae (Table 3). Two streams were missing intermediate-size (ages class 2 or 3) larvae and one stream contained no large, age-4 larvae. Dominant year classes had been spawned in either 1996 (three streams) or 1997 (two streams). In August 1999, when five age classes of larvae may have been present (although

TABLE 3.—Year classes of American brook lamprey larvae present in southeastern Minnesota streams during April 1997–1998 and August 1999. Values are percentages of all individuals captured at a site. Year class 0 larvae were not available for capture in April, but should have been available in August. N is sample size

Stream	N	Year class 0	1	2	3	4
April 1997						
N. Br. Whitewater	56		80	13		7
Pine Creek	48		46	29	21	4
April 1998						
Salem Creek	77		21	52	22	5
Trout Valley Creek	109		61	36	3	
West Indian Creek	64		88		2	10
August 1999						
N. Br. Whitewater	124		83	14		3
M. Br. Whitewater	78		92	8		
S. Br. Whitewater	37		5	3	14	78
Trout Valley Creek	62	3	58	3		
Beaver Creek	20					100
Badger Creek	22		41	59		

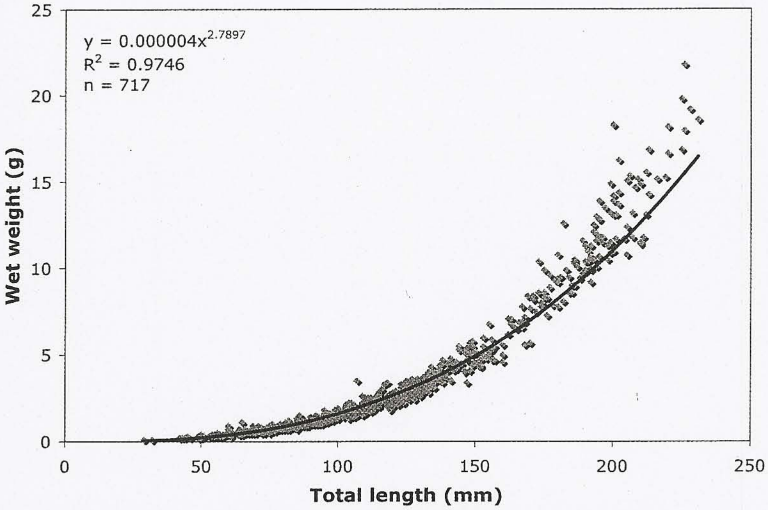


FIG. 2.—Total length–wet weight relationship of American brook lamprey larvae collected from 11 streams in southeastern Minnesota, 1997–1999. See Table 1 for the list of streams included

small, age-O larvae are difficult to collect), only one of six streams contained 4 age classes (Table 3). Three streams were missing both ages 3 and 4 larvae, whereas one stream contained only age 4 larvae. Dominant age classes had been spawned in 1995 (two streams), 1997 (one stream) or 1998 (three streams).

Length–weight relationships of lamprey larvae were determined for specimens from 11 different streams (Table 1). Larvae ranged from 29–231 mm TL and 0.1–21.8 g wet weight. Larvae from most streams exhibited similar length–weight patterns, but significant differences in these relationships (analysis of covariance: $F = 23.79$, $P < 0.01$) were detected among streams. However, these differences were attributed mostly to two streams (Bear and Beaver creeks), where only small numbers of very large larvae were collected. Since these differences were judged to be minor, measurements of larvae from all 11 streams were combined to produce a single length–weight relationship (Fig. 2).

ASSESSMENTS OF LARVAL LAMPREY HABITATS

American brook lamprey larvae typically were collected from soft sediments in shallow (<50 cm), slow-moving (5 cm/s) water (Table 4). However, larvae in some streams occupied habitats different from those in other streams. For example, mean water depths at larvae collection sites differed significantly (Kruskal-Wallis test: $H = 36.76$, $P < 0.001$) among streams, with Trout Valley Creek and North Branch Whitewater River collections generally coming from shallower sites (mean depths < 30 cm). Average water column current velocities also differed significantly (Kruskal-Wallis test: $H = 34.01$, $P < 0.001$) among streams, with Trout Valley Creek collection site velocities averaging 3–4× greater than those found at other streams. Depth and velocity at collection sites were not correlated ($r = -0.13$). Organic contents of surface sediments where larvae were collected averaged <10% (Table 4), but differed significantly (Kruskal-Wallis: $H = 40.82$, $P < 0.001$) among streams. Trout Valley Creek and West Indian Creek sediments had significantly lower organic contents (means < 5%) than did sediments in other streams. However, there was no significant

TABLE 4.—Mean water depth, water colum surface sediments at locations where Americai southeastern Minnesota streams. Ranges are s

Stream	n	Water d (cm
Pine Creek	41	38 (15–
N. Br. Whitewater R.	27	28 (11–
W. Indian Creek	15	46 (20–
Trout Valley Creek	21	21 (3–5
Salem Creek	15	35 (17–
Beaver Creek	4	49 (29–
Ferguson Creek	3	50 (34–
Bear Creek	1	20

relationship (simple linear regression: al and either water depth, current veloci examined.

Sediments where larvae were collected by medium and fine sand and silt (particl gravel (>0.8 mm) were present in sampl abundance in most samples. Particle size- (contingency table: $X^2 = 1727.1$, $P << 0$ Trout Valley and West Indian creeks d

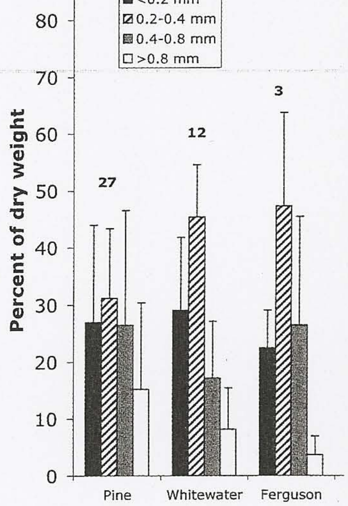
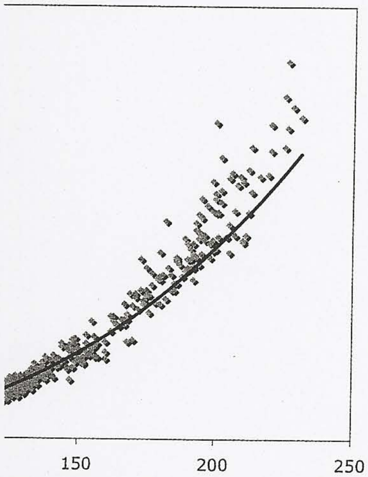


FIG. 3.—Particle size distributions of sedimer eight southeastern Minnesota streams. Bars a and numbers above bars are sample sizes



American brook lamprey larvae collected from
e Table 1 for the list of streams included

one of six streams contained 4 age classes
ages 3 and 4 larvae, whereas one stream
es had been spawned in 1995 (two streams),

e were determined for specimens from 11
29–231 mm TL and 0.1–21.8 g wet weight.
length–weight patterns, but significant
covariance: F = 23.79, P < 0.01) were de-
ces were attributed mostly to two streams
mbers of very large larvae were collected.
measurements of larvae from all 11 streams
ht relationship (Fig. 2).

LAMPREY HABITATS

collected from soft sediments in shallow
. However, larvae in some streams occupied
For example, mean water depths at larvae
Vallis test: $H = 36.76$, $P < 0.001$) among
nch Whitewater River collections generally
30 cm). Average water column current
allis test: $H = 34.01$, $P < 0.001$) among
elocities averaging 3–4× greater than those
ection sites were not correlated (r = –0.13).
vae were collected averaged <10% (Table
= 40.82, P < 0.001) among streams. Trout
had significantly lower organic contents
reams. However, there was no significant

TABLE 4.—Mean water depth, water column current velocity (0.6 depth) and organic content of surface sediments at locations where American brook lamprey larvae emerged from sediments in eight southeastern Minnesota streams. Ranges are shown in parentheses

Stream	n	Water depth (cm)	Current velocity (cm/s)	Sediment organic content (%)
Pine Creek	41	38 (15–100)	5 (0–20)	9.88 (1.73–18.54)
N. Br. Whitewater R.	27	28 (11–45)	5 (0–20)	10.97 (4.80–21.00)
W. Indian Creek	15	46 (20–75)	6 (2–11)	4.22 (2.19–6.60)
Trout Valley Creek	21	21 (3–52)	18 (0–42)	2.82 (0.51–4.80)
Salem Creek	15	35 (17–52)	4 (1–11)	6.50 (3.94–11.20)
Beaver Creek	4	49 (29–67)	4 (4–4)	8.20 (4.18–11.72)
Ferguson Creek	3	50 (34–62)	9 (5–14)	6.84 (4.20–8.52)
Bear Creek	1	20	0	6.01

relationship (simple linear regression: all $P > 0.10$) between the density of lamprey larvae and either water depth, current velocity or sediment organic content in the streams examined.

Sediments where larvae were collected most often were dominated (on a dry weight basis) by medium and fine sand and silt (particles <0.4 mm diameter; Fig. 3). Very coarse sand and gravel (>0.8 mm) were present in samples collected from all streams, but were very low in abundance in most samples. Particle size-class composition of sediments varied significantly (contingency table: $X^2 = 1727.1$, $P \ll 0.001$) among the streams, with sediments in Bear, Trout Valley and West Indian creeks dominated by much finer particles than were the

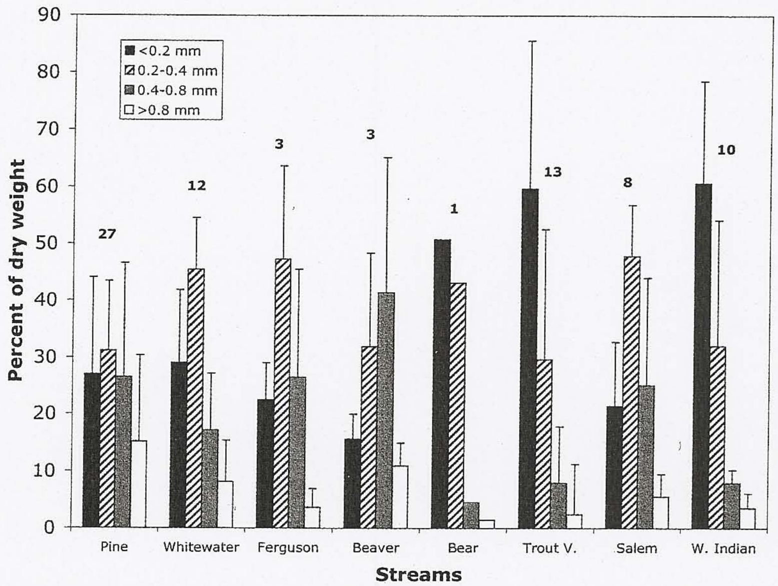


FIG. 3.—Particle size distributions of sediments from American brook lamprey larva collection sites in eight southeastern Minnesota streams. Bars are means, thin lines represent one standard deviation, and numbers above bars are sample sizes

sediments collected from other streams. However, densities of lamprey larvae were no different (*t*-test: $t = 0.16$, $P = 0.88$) in these streams than in those with coarser sediments.

DISCUSSION

Densities of American brook lamprey larvae varied dramatically within and among streams sampled, despite selecting sites with habitats judged most suitable for larvae. Varying densities in southeastern Minnesota streams are not unusual for this (Beamish and Lowartz, 1996) or other lamprey species (Manion and McLain, 1971; Potter *et al.*, 1986; Beamish and Jebbink, 1994; Pajos and Weise, 1994). Much of the variation in densities can be attributed to slight variations in habitat, especially with respect to sediment particle size composition (*see* review by Beamish and Lowartz, 1996). The abundance of American brook lamprey larvae increases exponentially with increases in medium-fine sand (0.15–0.25 mm diam; Beamish and Lowartz, 1996), with larvae avoiding finer and coarser sediments (Anderson and White, 1988; Lee, 1989). However, in the present study, densities of larvae displayed no pattern related to sediment size composition. Densities of some species of lamprey larvae also may be affected by sediment organic content, current velocity and water depth, but none of these have been found to have a significant effect on densities of *Lampetra appendix* larvae (Anderson and White, 1988; Beamish and Lowartz, 1996; present study).

Very few studies have assessed population sizes or densities of American brook lamprey larvae (Smith and McLain, 1962; Waters *et al.*, 1993; Simonson and Lyons, 1995; Beamish and Lowartz, 1996). Population estimates of *Lampetra appendix* larvae that included all stream habitats (Smith and McLain, 1962; Waters *et al.*, 1993; Simonson and Lyons, 1995) are not comparable to densities measured only in suitable habitats as in the present study. Similarly, mean lamprey densities from the present study are not comparable to those reported by Beamish and Lowartz (1996), since the latter study included habitats where larvae were least likely to exist. However, maximum densities from the 13 streams in the present study (median = 3.81 larvae/m^2, mean = 5.40 larvae/m^2, range = 0.33–16.67 larvae/m^2) are comparable, but considerably lower, than maximum densities (median = 11.8 larvae/m^2, mean = 14.7 larvae/m^2, range = 3.7–26.7 larvae/m^2) observed in 10 streams by Beamish and Lowartz (1996). In fact, nearly half (46%; 6 of 13 streams) of the Minnesota streams had maximum densities lower than the lowest stream maximum of Beamish and Lowartz (1996). Lower maximum densities can be indicative of reduced population sizes, poorer quality habitat or both. However, without information on the total amount of habitat available for lamprey larvae in each stream, it is not possible to estimate the impact of these lower maximum densities on the overall populations of *L. appendix* within these streams. Lower densities of larvae scattered throughout a more extensive habitat can compensate for the lack of a few, isolated groups of larvae at high densities.

Despite good densities of American brook lamprey larvae in many southeastern Minnesota streams, and the lack of a relationship between larval density and the number of age classes present in a stream, the reduced age structures observed at six of the nine stream sites examined is of concern. Missing age classes have been observed previously in populations of *Lampetra appendix* and other species of lamprey (Schaffner, 1902; Okkelberg, 1922; Hubbs, 1925; Thomas, 1962; Morman, 1979; Trautman, 1981; Seagle and Nagel, 1982). There is no evidence that American brook lamprey larvae segregate by size among different sites (Beamish and Lowartz, 1996), so missing age classes are not an artifact of sampling location. Missing or weak year classes in fish populations are common and can result from a wide array of environmental and biological causes (Scalet *et al.*, 1996; Ross, 1997). It is possible that missing year classes are characteristic of, and possibly normal for, populations of American brook lamprey on the periphery of their geographic range.

The reduction or loss of a single age
should not be a major problem and, in
Lampetra appendix is semelparous with
individuals requiring >5 y to reach mat
Seagle and Nagel, 1982), and these may
older year classes of lamprey larvae may
metamorphosis (Morkert *et al.*, 1998). Ho
are present (*e.g.*, Beaver Creek and Mi
lamprey populations likely are at risk o
flooding, interfere with spring spawning
larvae. The flood-prone nature of streams
brief (<1 wk) spawning period of Ame
scenario. For example, lamprey larvae we
1999, but following several years with sev
in 2004 despite intensive sampling at sev

Degraded habitat also can be a cause o
brook lamprey. Adult American brook la
spawning (Cochran *et al.*, 1993). Lack of su
example, spawning substrates in Ruppre
Only during years when sufficient numb
displace these sediments will spawning b
lamprey spawners and successful spawning
only once in 5 y, with generally only tw
observed in most years.

American brook lamprey larvae in Min
identical to those reported for two other *L*
et al., 1976) and Ontario (Lanteigne *et al.*
those exhibited by larvae of other lampr
aepyptera; Manion and McLain, 1971; Ro
lifestyle of these organisms limits the degr
and populations.

The status of the American brook lamp
though declines and losses have occurre
center of its range, it is the most abunda
Morman, 1979). Recent surveys in Wisconsi
widespread and abundant than previously
populations avoiding detection until recent
Cochran, pers. comm.). Records indicate t
nine drainages in Minnesota (MDNR, 199
American brook lamprey populations are
present lack of public awareness (Mundahl,
a wide geographic area tend to support th
from protected status in Minnesota in 1996.
of *L. appendix* has disappeared from a Minne
potentially at risk because of low densities
habitat threats and spawning and/or early d
problems, and the species' limited capacity
of reduced or extirpated populations. Ba
available (*e.g.*, Beamish and Lowartz, 1996

Iowever, densities of lamprey larvae were no
streams than in those with coarser sediments.

USSION

arvae varied dramatically within and among
habitats judged most suitable for larvae. Varying
are not unusual for this (Beamish and Lowartz,
McLain, 1971; Potter *et al.*, 1986; Beamish and
of the variation in densities can be attributed
respect to sediment particle size composition
The abundance of American brook lamprey
s in medium-fine sand (0.15–0.25 mm diam;
oiding finer and coarser sediments (Anderson
present study, densities of larvae displayed no
1. Densities of some species of lamprey larvae
ontent, current velocity and water depth, but
ificant effect on densities of *Lampetra appendix*
and Lowartz, 1996; present study).
sizes or densities of American brook lamprey
l., 1993; Simonson and Lyons, 1995; Beamish
of *Lampetra appendix* larvae that included all
aters *et al.*, 1993; Simonson and Lyons, 1995)
ly in suitable habitats as in the present study.
present study are not comparable to those
nce the latter study included habitats where
ximum densities from the 13 streams in the
$= 5.40$ larvae/m^2, range $= 0.33$–16.67 larvae/
r, than maximum densities (median = 11.8
.7–26.7 larvae/m^2) observed in 10 streams by
half (46%; 6 of 13 streams) of the Minnesota
the lowest stream maximum of Beamish and
an be indicative of reduced population sizes,
ut information on the total amount of habitat
is not possible to estimate the impact of these
ulations of *L. appendix* within these streams.
a more extensive habitat can compensate for
high densities.
ook lamprey larvae in many southeastern
ship between larval density and the number
d age structures observed at six of the nine
age classes have been observed previously in
ecies of lamprey (Schaffner, 1902; Okkelberg,
, 1979; Trautman, 1981; Seagle and Nagel,
rook lamprey larvae segregate by size among
so missing age classes are not an artifact of
es in fish populations are common and can
d biological causes (Scalet *et al.*, 1996; Ross,
re characteristic of, and possibly normal for,
e periphery of their geographic range.

The reduction or loss of a single age class in a population of American brook lamprey should not be a major problem and, in most cases, should be only temporary. Although *Lampetra appendix* is semelparous with a 5-y life cycle (Okkelberg, 1922; Hubbs, 1925), individuals requiring >5 y to reach maturity are present in many systems (Thomas, 1962; Seagle and Nagel, 1982), and these may spawn in place of a missing year class. In addition, older year classes of lamprey larvae may be missing in streams with rapid growth and early metamorphosis (Morkert *et al.*, 1998). However, in streams where only one or two age classes are present (*e.g.*, Beaver Creek and Middle Branch Whitewater River), American brook lamprey populations likely are at risk of being lost if environmental conditions, such as flooding, interfere with spring spawning and/or development of eggs and newly hatched larvae. The flood-prone nature of streams in southeastern Minnesota (Waters, 1977) and the brief (<1 wk) spawning period of American brook lamprey makes this a very possible scenario. For example, lamprey larvae were common in South Branch Whitewater River in 1999, but following several years with severe prolonged floods, no lamprey were collected in 2004 despite intensive sampling at several sites.

Degraded habitat also can be a cause of missing age classes in populations of American brook lamprey. Adult American brook lamprey require riffle areas with clean substrate for spawning (Cochran *et al.*, 1993). Lack of such areas will severely impair spawning efforts. For example, spawning substrates in Rupprecht Creek are buried beneath >5 cm of fine silt. Only during years when sufficient numbers of spawners are present to dig through and displace these sediments will spawning be successful. Large numbers of American brook lamprey spawners and successful spawning have been observed in this stream by the authors only once in 5 y, with generally only two or three adults and no active spawning nests observed in most years.

American brook lamprey larvae in Minnesota exhibited length–weight patterns virtually identical to those reported for two other *Lampetra appendix* populations in Delaware (Rohde *et al.*, 1976) and Ontario (Lanteigne *et al.*, 1981). These patterns also were very similar to those exhibited by larvae of other lamprey species (sea lamprey, least brook lamprey *L. aepyptera*; Manion and McLain, 1971; Rohde *et al.*, 1976), indicating that the burrowing lifestyle of these organisms limits the degree of allometric variation possible among species and populations.

The status of the American brook lamprey in North America is apparently secure, even though declines and losses have occurred in some regions (NatureServe, 2003). In the center of its range, it is the most abundant and widely distributed lamprey species (*e.g.*, Morman, 1979). Recent surveys in Wisconsin suggest that *Lampetra appendix* may be far more widespread and abundant than previously believed (Lyons *et al.*, 2000), with many small populations avoiding detection until recent advances in stream electrofishing equipment (P. Cochran, pers. comm.). Records indicate that the species has been found in 46 streams in nine drainages in Minnesota (MDNR, 1995; Hatch *et al.*, 2003), and many of the state's American brook lamprey populations are healthy, despite past habitat threats and the present lack of public awareness (Mundahl, 1998). Good populations in many streams over a wide geographic area tend to support the decision to remove American brook lamprey from protected status in Minnesota in 1996. However, at least one formerly large population of *L. appendix* has disappeared from a Minnesota stream (Phillips *et al.*, 1982), and others are potentially at risk because of low densities of larvae and missing age classes. Continuing habitat threats and spawning and/or early development failures are the likely causes of these problems, and the species' limited capacity for dispersal (Morman, 1979) inhibits recovery of reduced or extirpated populations. Based on what little comparative information is available (*e.g.*, Beamish and Lowartz, 1996), more information is needed on *L. appendix*, especially on the periphery of its range in Minnesota, to adequately document current populations and assess their susceptibility to human activities. Additionally, with our knowledge of the habitat needs of American brook lamprey larvae, the amount of suitable habitat in area streams should be quantified to determine their ability to support viable populations of lamprey. Only after such information is in hand can it be decided whether or not the American brook lamprey should receive protected status in Minnesota.

Acknowledgments.—We thank the more than 20 Winona State University biology students who assisted in the field and laboratory. Konrad Schmidt, Terry Lee and members of the WinCres Chapter of Trout Unlimited furnished information on collecting sites for lampreys. Funding was provided by the Minnesota Department of Natural Resources Natural Heritage and Nongame Grant Program, the Minnesota Pollution Control Agency Whitewater Watershed Project and the Winona State University Professional Improvement Fund. The Minnesota Department of Natural Resources Natural Heritage Database, Jay Hatch of the University of Minnesota James Ford Bell Museum of Natural History and Konrad Schmidt kindly provided records of American brook lamprey collections. Collecting permits were provided by the Minnesota Department of Natural Resources. Phil Cochran and several anonymous reviewers provided helpful comments that greatly improved this paper.

LITERATURE CITED

ANDERSON, A. A. AND A. M. WHITE. 1988. Habitat selection of *Ichthyomyzon fossor* and *Lampetra appendix* in a northeastern Ohio stream. *Ohio J. Sci.*, **88**:7.

BEAMISH, F. W. H. AND J. JEBBINK. 1994. Abundance of lamprey larvae and physical habitat. *Env. Biol. Fishes*, **39**:209–214.

——— AND S. LOWARTZ. 1996. Larval habitat of American brook lamprey. *Can. J. Fish. Aqua. Sci.*, **53**: 693–700.

——— AND T. E. MEDLAND. 1988. Age determination for lampreys. *Trans. Amer. Fish. Soc.*, **117**:63–71.

COCHRAN, P. A., M. E. SNEEN AND A. P. GRIPENTROG. 1993. Notes on the biology of the American brook lamprey (*Lampetra appendix*) in Wisconsin. *Trans. Wisc. Acad. Sci., Arts and Lett.*, **81**:39–46.

EDDY, S. AND J. C. UNDERHILL. 1974. Northern fishes, with special reference to the Upper Mississippi Valley, 3rd ed. University of Minnesota Press, Minneapolis. 414 p.

HARDISTY, M. W. AND I. C. POTTER. 1971. The behaviour, ecology, and growth of larval lampreys, p. 85–125. *In:* M. W. Hardisty and I. C. Potter (eds.). The biology of lampreys, Vol. 1. Academic Press, London.

HATCH, J. T., K. P. SCHMIDT, D. P. SIEMS, J. C. UNDERHILL, R. A. BELLIG AND R. A. BAKER. 2003. A new distributional checklist of Minnesota fishes, with comments on historical significance. *J. Minn. Acad. Sci.*, **67**:1–17.

HOFF, J. G. 1988. Some aspects of the ecology of the American brook lamprey, *Lampetra appendix*, in the Mashpee River, Cape Cod, Massachusetts. *Can. Field-Nat.*, **102**:735–737.

HUBBS, C. L. 1925. The life cycle and growth of lampreys. *Mich. Acad. Sci., Arts and Lett.*, **4**:587–603.

JOHNSON, J. E. 1987. Protected fishes of the United States and Canada. American Fisheries Society, Bethesda, Maryland. 42 p.

LANTEIGNE, J., J. M. HANSON AND S. U. QADRI. 1981. Occurrence and growth patterns of the American brook lamprey, *Lathenteron lamottenii*, in the Ottawa River. *Can. Field-Nat.*, **95**:261–265.

LEE, D. S. 1989. Proximate determinants of larval lamprey habitat selection. Ph.D. Dissertation, Michigan State University, East Lansing. 155 p.

LYONS, J., P. A. COCHRAN AND D. FAGO. 2000. Wisconsin fishes 2000: status and distribution. The University of Wisconsin Sea Grant Institute, Madison. 87 p.

MANION, P. J. AND A. L. MCLAIN. 1971. Biology of larval sea lampreys (*Petromyzon marinus*) of the 1960 year-class, isolated in the Big Garlic River, Michigan, 1960–1965. Great Lakes Fishery Commission Technical Report Number 16. 35 p.

——— AND H. A. PURVIS. 1971. Giant American brook lampreys, *Lampetra lamottei*, in the Upper Great Lakes. *J. Fish. Res. Bd. Can.*, **28**:616–620.

MINNESOTA DEPARTMENT OF NATURAL RESOURCES. 1995. Known locations for American brook lamprey

(*Lampetra appendix*) in Minnesota, Ja
Minnesota Department of Natural R
Program, St. Paul. 26 p.

———. 1998. Trout fishing access in southea
Resources, St. Paul. 101 p.

MORKERT, S. B., W. D. SWINK AND J. G. SEELYE. 19
in the Chippewa River, Michigan. *N. A*

MORMAN, R. H. 1979. Distribution and ecology of
Great Lakes Fishery Commission Techn

MUNDAHL, N. D. 1998. Good lampreys are hard

NATURESERVE. 2003. NatureServe Explorer: an on
NatureServe, Arlington, Virginia. Avail
December 27, 2004).

OKKELBERG, P. 1922. Notes on the life history of t
Zool., Univ. Michigan 125. 14 p.

OMERNIK, J. M. AND A. L. GALLANT. 1988. Ecoreg
Protection Agency, Corvallis, Oregon. F

PAGE, L. M. AND B. M. BURR. 1991. A field guide
Houghton Mifflin Company, Boston. 4

PAJOS, T. A. AND J. G. WEISE. 1994. Estimating
sampling methods. *N. Am. J. Fish. Mgm*

PHILLIPS, G. L., W. D. SCHMID AND J. C. UNDERHII
Minnesota Press, Minneapolis. 248 p.

POTTER, I. C., R. W. HILLIARD, J. S. BRADLEY
mental variables on the density of
433–440.

RENAUD, C. B. 1997. Conservation status of Nort
Ichthyol., **13**:143–148.

ROHDE, F. C., R. G. ARNDT AND J. C. S. WANG. 19
aepyptera and *Lampetra lamottenii* (Pisces
Coast, United States). *Bull. S. Calif. Aca*

ROSS, M. R. 1997. Fisheries conservation and n
New Jersey. 374 p.

SCALET, C. G., L. D. FLAKE AND D. W. WILLIS. 199
approach. W.H. Freeman and Company

SCHAFFNER, S. C. 1902. Notes on the occurrence
Ann Arbor. *Report Mich. Acad. Sci.*, **3**:71-

SCHMIDT, K. 1996. Endangered, threatened, an
Currents (Spec Iss.), 4th ed. 77 p.

SEAGLE, H. H., JR. AND J. W. NAGEL. 1982. Life
Lampetra appendix, in Tennessee. *Copeia,*

SIMONSON, T. D. AND J. LYONS. 1995. Comparison o
stream fish assemblages. *N. Amer. J. Fish*

SMITH, B. R. AND A. L. MCLAIN. 1962. Estimation
of three streams. Great Lakes Fishery C

SURBER, T. 1924. A biological reconnaissance of t
Minnesota Department of Natural Reso

THOMAS, M. L. A. 1962. Observations on the
Entosphenus lamottei (Le Sueur) in the
Toronto, Toronto. 214 p.

THORN, W. C., C. S. ANDERSON, W. E. LORENZEN, I
trout management in southeast Minnes

TRAUTMAN, M. B. 1981. The fishes of Ohio, 2nd

ı Minnesota, to adequately document current
ı to human activities. Additionally, with our
ı brook lamprey larvae, the amount of suitable
ɛd to determine their ability to support viable
ɔrmation is in hand can it be decided whether
receive protected status in Minnesota.

Vinona State University biology students who assisted
y Lee and members of the WinCres Chapter of Trout
sites for lampreys. Funding was provided by the
ıtural Heritage and Nongame Grant Program, the
Watershed Project and the Winona State University
Department of Natural Resources Natural Heritage
ɔta James Ford Bell Museum of Natural History and
ɛrican brook lamprey collections. Collecting permits
of Natural Resources. Phil Cochran and several
that greatly improved this paper.

URE CITED

election of *Ichthyomyzon fossor* and *Lampetra appendix*
i., **88**:7.
f lamprey larvae and physical habitat. *Env. Biol. Fishes*,

merican brook lamprey. *Can. J. Fish. Aqua. Sci.*, **53**:

ɔn for lampreys. *Trans. Amer. Fish. Soc.*, **117**:63–71.
1993. Notes on the biology of the American brook
. *Trans. Wisc. Acad. Sci., Arts and Lett.*, **81**:39–46.
.es, with special reference to the Upper Mississippi
ess, Minneapolis. 414 p.
iour, ecology, and growth of larval lampreys, p. 85–
(eds.). The biology of lampreys, Vol. 1. Academic

HILL, R. A. BELLIG AND R. A. BAKER. 2003. A new dis-
with comments on historical significance. *J. Minn.*

ɛ American brook lamprey, *Lampetra appendix*, in the
Can. Field-Nat., **102**:735–737.
npreys. *Mich. Acad. Sci., Arts and Lett.*, **4**:587–603.
ed States and Canada. American Fisheries Society,

Occurrence and growth patterns of the American
e Ottawa River. *Can. Field-Nat.*, **95**:261–265.
val lamprey habitat selection. Ph.D. Dissertation,
55 p.
sin fishes 2000: status and distribution. The Univer-
ison. 87 p.
al sea lampreys (*Petromyzon marinus*) of the 1960 year
ıigan, 1960–1965. Great Lakes Fishery Commission

ɔok lampreys, *Lampetra lamottei*, in the Upper Great

)5. Known locations for American brook lamprey

(*Lampetra appendix*) in Minnesota, January 1995. Minnesota Natural Heritage Database, Minnesota Department of Natural Resources, Natural Heritage and Nongame Research Program, St. Paul. 26 p.

———. 1998. Trout fishing access in southeastern Minnesota. Minnesota Department of Natural Resources, St. Paul. 101 p.

MORKERT, S. B., W. D. SWINK AND J. G. SEELYE. 1998. Evidence for early metamorphosis of sea lampreys in the Chippewa River, Michigan. *N. Amer. J. Fish. Mgmt.*, **18**:966–971.

MORMAN, R. H. 1979. Distribution and ecology of lampreys in the lower peninsula of Michigan, 1957–75. Great Lakes Fishery Commission Technical Report No. 33. 59 p.

MUNDAHL, N. D. 1998. Good lampreys are hard to find. *Minn. Volunteer*, **61**(256):19–25.

NATURESERVE. 2003. NatureServe Explorer: an online encyclopedia of life [web application]. Version 1.8. NatureServe, Arlington, Virginia. Available http://www.natureserve.org/explorer. (Accessed: December 27, 2004).

OKKELBERG, P. 1922. Notes on the life history of the brook lamprey, *Ichthyomyzon unicolor*. Occ. Pap. Mus. Zool., Univ. Michigan 125. 14 p.

OMERNIK, J. M. AND A. L. GALLANT. 1988. Ecoregions of the upper midwest states. U.S. Environmental Protection Agency, Corvallis, Oregon. EPA/600/3-88/037. 56 p.

PAGE, L. M. AND B. M. BURR. 1991. A field guide to freshwater fishes: North America north of Mexico. Houghton Mifflin Company, Boston. 432 p.

PAJOS, T. A. AND J. G. WEISE. 1994. Estimating populations of larval sea lamprey with electrofishing sampling methods. *N. Am. J. Fish. Mgmt.*, **14**:580–587.

PHILLIPS, G. L., W. D. SCHMID AND J. C. UNDERHILL. 1982. Fishes of the Minnesota region. University of Minnesota Press, Minneapolis. 248 p.

POTTER, I. C., R. W. HILLIARD, J. S. BRADLEY AND R. J. MCKAY. 1986. The influence of environmental variables on the density of larval lampreys in different seasons. *Oecologia*, **70**: 433–440.

RENAUD, C. B. 1997. Conservation status of Northern Hemisphere lampreys (Petromyzontidae). *J. Appl. Ichthyol.*, **13**:143–148.

ROHDE, F. C., R. G. ARNDT AND J. C. S. WANG. 1976. Life history of the freshwater lampreys, *Okkelbergia aepyptera* and *Lampetra lamottenii* (Pisces: Petromyzontidae), on the Delmarva Peninsula (East Coast, United States). *Bull. S. Calif. Acad. Sci.*, **75**:99–111.

ROSS, M. R. 1997. Fisheries conservation and management. Prentice Hall, Inc., Upper Saddle River, New Jersey. 374 p.

SCALET, C. G., L. D. FLAKE AND D. W. WILLIS. 1996. Introduction to wildlife and fisheries: an integrated approach. W.H. Freeman and Company, New York. 512 p.

SCHAFFNER, S. C. 1902. Notes on the occurrence of ammocetes, the larval form of *Lampetra wilderi*, near Ann Arbor. *Report Mich. Acad. Sci.*, **3**:71–72.

SCHMIDT, K. 1996. Endangered, threatened, and special status fishes of North America. American Currents (Spec Iss.), 4th ed. 77 p.

SEAGLE, H. H., JR. AND J. W. NAGEL. 1982. Life cycle and fecundity of the American brook lamprey, *Lampetra appendix*, in Tennessee. *Copeia*, **1982**:362–366.

SIMONSON, T. D. AND J. LYONS. 1995. Comparison of catch per effort and removal procedures for sampling stream fish assemblages. *N. Amer. J. Fish. Mgmt.*, **15**:419–427.

SMITH, B. R. AND A. L. MCLAIN. 1962. Estimation of the brook and sea lamprey ammocoete populations of three streams. Great Lakes Fishery Commission Technical Report No. 4. 26 p.

SURBER, T. 1924. A biological reconnaissance of the Root River drainage basin, southeastern Minnesota. Minnesota Department of Natural Resources, St. Paul.

THOMAS, M. L. A. 1962. Observations on the ecology of ammocetes of *Petromyzon marinus* L. and *Entosphenus lamottei* (Le Sueur) in the Great Lakes watershed. Master's Thesis, University of Toronto, Toronto. 214 p.

THORN, W. C., C. S. ANDERSON, W. E. LORENZEN, D. L. HENDRICKSON AND J. W. WAGNER. 1997. A review of trout management in southeast Minnesota streams. *N. Amer. J. Fish. Mgmt.*, **17**:860–872.

TRAUTMAN, M. B. 1981. The fishes of Ohio, 2nd ed. The Ohio State University Press, Columbus. 782 p.

TRIMBLE, S. W. AND S. W. LUND. 1982. Soil conservation and the reduction of erosion and sediment in the Coon Creek basin, Wisconsin. U.S. Geological Survey Professional Paper 1234.

VLADYKOV, V. D. 1949. Quebec lampreys. I. List of species and their economic importance. Department of Fisheries, Quebec, Contribution 26. 67 p.

———. 1973. North American nonparasitic lampreys of the family Petromyzontidae must be protected. *Can. Field-Nat.*, **87**:235–239.

WATERS, T. F. 1977. The streams and rivers of Minnesota. University of Minnesota Press, Minneapolis. 372 p.

———, J. P. KAEHLER, T. J. POLOMIS AND T. J. KWAK. 1993. Production dynamics of smallmouth bass in a small Minnesota stream. *Trans. Amer. Fish. Soc.*, **122**:588–598.

SUBMITTED 5 JANUARY 2005 ACCEPTED 12 JANUARY 2006

Am. Midl. Nat. 156:23–36

Spatial and Tempo
Darter Abundance
North-ce

PETER C. SMILEY, JR.,[1] ERIC D. I

Forest and Wildlife Research Center, Mississipp

ABSTRACT.—Little is known about the
habitat use of the goldstripe darter (*Ethe*
species associates and habitat use of this
pine plantations in north-central Missis
among sampling periods differed among
of goldstripe darters exhibited significan
while the remaining 10 streams did n
Goldstripe darters exhibited the great
culatus), brown madtom (*Noturus phae*
Goldstripe darter abundance was positiv
and sand. Our results suggest that mar
forested riparian zones adjacent to first-
goldstripe darters.

IN

The goldstripe darter (*Etheostoma paru*
subgenus *Fuscatelum* (Bart and Taylor, 19
by the lack of bright breeding colors, th
line (Bart and Taylor, 1999). Goldstripe
from eastern Texas to central Georgia
extent in southeastern Missouri and s
Goldstripe darter populations are consid
within its distribution across the southea
this species is considered rare or endan
Arkansas, Missouri) and the eastern-mos
Pigg, 1999; Arkansas Natural Heritage C
Heritage Program, 2003; Herbert and G

Understanding the ecology and habi
developing recovery plans designed t
Unfortunately, information on the eco
Mississippi and other portions of its rang
concerning the habitat use of the goldst
contained in regional ichthyological su
captured from small springs and spring

[1] Corresponding author present address:
Hayes Drive, Columbus, Ohio 43210. Teleph
50@osu.edu

[2] Present address: Department of Forest
Corvallis Oregon 97331