Conservation Biology Research Grants Program
Division of Ecological Services
Minnesota Department of Natural Resources

STUDIES OF TOPEKA SHINER (*NOTROPIS TOPEKA*) LIFE HISTORY AND DISTRIBUTION IN MINNESOTA

A Thesis Submitted to the Faculty of the Graduate School
of the University of Minnesota
by

Shawn Patrick Dahle

In Partial Fulfillment of the Requirements
for the Degree of Master of Science

September 2001

ACKNOWLEDGMENTS

This thesis is the culmination of four years of planning, research, analysis, writing, and synthesis. Its completion would not have been possible without the cooperation and assistance of many people whom I would like to sincerely thank.

First and foremost, I thank my major advisor, Jay Hatch, for giving me the opportunity to attend graduate school and pursue my Master's degree. The whole experience has so enriched my life that I will forever be indebted for this opportunity. Jay's steadfast willingness and ample ability to teach, guide, and assist me throughout the past three years was invaluable. He gave me the freedom that every graduate student dreams of, but whenever I needed to be put back on track, Jay was always there to help.

I also thank my examining committee members, Bruce Vondracek and Sandy Weisberg, for their helpful suggestions and timely assistance with the preparation of this thesis. Andrew Simons generously provided space and shared equipment in the Bell Museum's ichthyology lab, and the faculty and staff of the Fisheries and Wildlife Department guided me to the successful completion of my degree program.

I thank my numerous undergraduate assistants (Eric Bohme, Eric Frankson, Ben Lamb, Rob Maresh, Anna Lee Marlowe, Kurt Nieman, Tim Ostergren, Mike Wyatt, and Krishna Yuvaraj) for their countless hours of work in the field and lab. Konrad Schmidt, Kristin Blann, Joanne Iskierka, Cindy Lee, John Martineau, Susan Milnor, Brian Nerbonne, and Mark Otnes collected and provided me with data from the 1998 field season, prior to my joining the project. This project was made possible by generous funding and support from Rich Baker from the Minnesota DNR's Natural Heritage and Nongame Research Program and the U.S. Fish and Wildlife Service.

Finally, I thank all of my family and friends for their unconditional support and encouragement throughout this challenging, yet rewarding pursuit. This work is dedicated to you all.

TABLE OF CONTENTS

CHAPTER 1

CHAPTER 2

CHAPTER 3

LIST OF TABLES

LIST OF FIGURES

FOREWORD

The Topeka shiner (*Notropis topeka*) was reportedly common in headwater prairie streams throughout the central United States (Tabor 1998). Its historic range extended from central Missouri and Kansas to southeastern South Dakota and southern Minnesota (Bailey and Allum 1962). Stream surveys conducted in Kansas and Missouri during the early 1990's indicated that the Topeka shiner's distribution and abundance in these states had vastly declined during the previous 25 years (Tabor 1998). Although it was already known that this species' distribution had declined in parts of its range (Minckley and Cross 1959; Bailey and Allum 1962; Pflieger 1971; Eddy and Underhill 1974), the magnitude of the more recent declines was unexpected. Since this discovery, interest in and concern for this native prairie minnow has intensified. During the 1990's, surveys were conducted across the Topeka shiner's range to determine its status. Surveys of the Topeka shiner in Minnesota suggested that this species was "far more common in [this state] than was once thought" (Hatch 2001). This was not the case in other parts of this species' range however, so on January 14, 1999, the Topeka shiner was listed as federally endangered.

Studies of Topeka shiner life history and distribution were initiated in Minnesota during May 1997 and concluded during August 2000. Much of the 1997 and some of the 1998 data were published by Hatch (2001) and Hatch and Besaw (2001). The remaining data were included in this thesis. This thesis was written in manuscript format to simplify the transition to publishing. Each chapter contains its own introduction, methods, results, discussion, and literature cited sections. Chapter 1 discusses the Topeka shiner's distribution, habitat-use, and seasonal abundance in Minnesota. Chapter 2 analyzes their demography, growth, and reproductive effort, and Chapter 3 provides a volumetric analysis of this species' diet. The goal of these studies was to provide detailed life history and distribution information to evaluate this species' status in

Minnesota and facilitate rangewide research and recovery efforts.

CHAPTER 1

Distribution, Habitat-use, and Seasonal Abundance of the Topeka Shiner (*Notropis topeka*) in Minnesota

Introduction

Historically, the Topeka shiner (*Notropis topeka*) was considered a characteristic species of headwater streams located throughout the central prairie regions of the United States (Tabor 1998). Its range included tributaries of the Arkansas, Mississippi, and Missouri River drainages in parts of Kansas, Missouri, Nebraska, Iowa, South Dakota, and Minnesota (Bailey and Allum 1962). This distribution was considered small when compared with the distributions of other prairie fishes (Minckley and Cross 1959). During the past century, the Topeka shiner has experienced a rangewide decline in distribution and abundance (Minckley and Cross 1959; Bailey and Allum 1962; Pflieger 1971; Eddy and Underhill 1974; Gelwicks and Bruenderman 1996). Currently this species exists in highly fragmented populations which comprise less than 10% of their original geographic range (Tabor 1998). This discovery led to the Topeka shiner's listing as federally endangered on January 14, 1999.

Many factors have been associated with the Topeka shiner's decline; however, none has been clearly demonstrated thus far. Increased sedimentation and eutrophication of prairie streams resulting from intensive agricultural development throughout the Topeka shiner's range are thought to have had the greatest impact on this species in the past (Tabor 1998). Agricultural landuse practices such as intensive cultivation, tiling, grazing, and irrigation also have been implicated in their decline by creating unstable water levels, a loss of aquatic vegetation, elevated temperatures, and increased turbidity of streams (Minckley and Cross 1959; Menzel et al. 1984; Cross and Moss 1987). Stream channelization is thought to impact many aquatic species by eliminating or degrading natural habitats, altering the natural hydrologic regimes of streams, and increasing temperature, sedimentation, and turbidity (Simpson et al. 1982). Tributary impoundments may also impair this species by altering the natural hydrologic regimes of streams, reducing longitudinal movement of fishes, and providing sanctuaries for introduced piscivorous fish species, such as the largemouth bass (*Micropterus salmoides*), which would otherwise be unable to colonize these small streams (Mammoliti 1995). These factors continue to present a serious threat to this species' existence.

Prior to its proposed listing, little was known about this native minnow in Minnesota. A single record from 1890 indicated its presence in the Cedar River drainage near Austin, MN; however, it has not been collected from this drainage since (Eddy and Underhill 1974). All other historic records indicate that this species has been restricted to the Missouri River drainage in the southwest corner of the state. Between 1939 and 1989, Topeka shiners were identified at 32 sites in 10 streams of the Missouri River drainage (Underhill 1957; Anderson et. al. 1977; Schmidt 1993). There is one other possible record from this drainage. In 1947, an unspecified number of Topeka shiners were reportedly captured in Okabena Lake, Nobles County; however, no specimens were kept for verification and subsequent sampling of this region has produced no Topeka shiners (Hatch 2001). This record represents the only occurrence from a lake and the only occurrence within the Little Sioux watershed; therefore, its validity remains questionable. The habitat and abundance of this species have not been previously examined in Minnesota.

From preliminary studies of the Topeka shiner in Minnesota, Hatch (2001) concluded that the species was "far more common in [this state] than was once thought." He also provided a detailed review of habitat descriptions from across the Topeka shiner's range. Most early habitat descriptions came from Kansas and Missouri where this species inhabited quiet, open pools of clear, upland streams with mostly clean gravel, sand, and rubble bottoms (Minckley and Cross 1959; Pflieger 1971 and 1975). Hatch's

(2001) examination revealed that habitats found in northern states differed substantially from these descriptions. In South Dakota (Elsen 1977), Nebraska (Michl and Peters 1993), and Minnesota (Hatch 2001), Topeka shiners occurred in "low gradient, periodically turbid streams" with "silt and detritus" substrates. Hatch (2001) also recognized that Topeka shiners utilized off-channel habitats (e.g., oxbows and excavated ponds) and hypothesized that these habitats are perhaps "crucial to the long-term survival of this species."

The objectives of the current study were to further document the occurrence of Topeka shiners throughout the Missouri River drainage, establish Topeka shiner presence or absence in the Des Moines River drainage, quantify and compare seasonal habitat-use between instream and off-channel habitats, measure and compare characteristics of both habitat-types, estimate seasonal population size of an instream and off-channel population, and present research and management recommendations to facilitate efforts in the recovery and conservation of this endangered minnow.

Methods

Study area.—The majority of the following studies were conducted in the Missouri River drainage of southwestern Minnesota. This drainage is comprised of three major watersheds: the Big Sioux (1,437 km^2), the Rock (2,365 km^2), and the Little Sioux (808 km^2). The Missouri River drainage exhibits gently sloping to undulating landscapes with silty to loamy soils; large outcroppings of Sioux quartzite bedrock are common in the southwestern regions. Mean annual precipitation ranges from 56 cm in the northwest to 76 cm in the southeast. This drainage contains an extensive network of low to medium gradient, intermittent streams that largely retain their natural meander. Natural lakes are only present in the Little Sioux watershed and stream impoundments are rare. This former prairie land is now highly agriculturalized, primarily for row-crop and livestock production. Approximately 73% of the land is cultivated for corn and soy beans. Grassy riparian corridors are often grazed by small herds of cattle and hog feedlots are becoming increasingly prevalent. Fertilizer and manure application rates are medium to very high in this region. Wind erosion potential is moderate but water erosion potential is high to extreme for most of the Missouri River drainage (University of Minnesota 2000).

Surveys were also conducted in the Des Moines River drainage. This drainage is comprised of the West Fork (3473 km^2) and East Fork (528 km^2) watersheds. Its geomorphology ranges from clayey till plain to undulating loamy soils. Mean annual precipitation ranges between 61 and 76 cm. Slope steepness is low (0-6%) and drainage ditches and natural lakes are common in this drainage. Agricultural landuse and erosion potentials are similar to the Missouri River drainage (University of Minnesota 2000).

Distribution surveys.—Between May 1997 and August 2000 (including the preliminary study), distribution surveys were conducted at 203 locations within 24 streams and three closed-basin ponds of the Missouri River drainage. These included 31 historic locations, which were defined as "sites having Topeka shiner collected prior to 1990." One historic location of the Rock River was not sampled. Additionally, 85 locations were surveyed in 10 streams of the Des Moines River drainage during the summer of 2000. Sampling was conducted using three types of seine: a 6.1 x 1.2 m bag seine (3.2 mm mesh) was used during 1997-1999; a 3.7 x 1.8 m straight seine (4.8 mm mesh) was used during 2000; and one-person 1.2 x 1.2 m "scoop" seines (6.4 mm mesh) were used throughout the study. Topeka shiner voucher specimens, collected prior to listing, were deposited in the James Ford Bell Museum of Natural History, University of Minnesota.

Habitat comparison study.—During 1999 and 2000, habitat-use studies were conducted to quantitatively compare the relative abundance of Topeka shiners in off-channel habitats (e.g., oxbows, cutoff tributary channels, and excavated ponds in the floodplain) with those in adjacent instream segments. The preliminary study provided qualitative results that indicated far greater abundance in off-channel habitats (Hatch 2001). For this comparison, eight sites were selected (Sites 1-4 during 1999, Sites 5-8 during 2000) that exhibited adjacent off-channel and instream habitats where Topeka shiners were known to exist (Figure 1.1). The first four sites that met this criteria were used during 1999; however, during 2000, eight sites were sampled concurrently and four were discontinued due to repeal of landowner permission or thickening aquatic vegetation. Each of the final eight study sites was seined on four occasions (approximately once per month) between May and September. Seine hauls were standardized (i.e., individual 12 x 2 m hauls) to provide a comparable measurement of relative abundance (i.e., catch-per-unit-effort, CPUE). The number of hauls per habitat varied depending on off-channel habitat size, number of instream habitats per segment, and seasonal changes in water level and aquatic vegetation. Usually, the entire perimeter of the off-channel habitat and every instream pool, backwater, or slow run were sampled. The number of each species sampled was recorded per haul.

The relationship between Topeka shiner relative abundance and habitat-type was quantitatively analyzed using contingency tables. CPUE was categorized by order of magnitude (i.e., 0, 1's, 10's, 100's) and the frequency of catches within each category was tallied for each habitat-type. The resulting contingency tables were tested for overall independence using chi-square tests (significance level = 0.05) after applying Yates's continuity correction (Everitt 1977). Where association was significant, the skew of CPUE was used to determine which habitat contained higher relative abundance.

Habitat measurements were recorded at all eight sites during June 2000. Five equidistant transects were made across the off-channel habitat and three instream habitats at each site. Depth and mean flow were measured at four equidistant points across each transect. Depth was measured (± 0.01 m) using a 3 m pole and mean flow was measured (± 0.01 m/s) using a Marsh-McBirney Flomate portable flowmeter with top-setting wading rod set at 0.6 x depth (Orth 1983). Habitat length was measured (± 0.1 m) once and wetted width was measured (± 0.1 m) at each transect using a 100 m tape. For the whole habitat area, substrate composition, bank erosion, and cover were estimated by inspection to the nearest five percent. The measurements of the three instream habitats were averaged and compared with the measurements of the off-channel habitat to identify differences between habitat-types that may influence Topeka shiner abundance.

Seasonal population size.—Mark-recapture population estimates were conducted seasonally on two populations. The first population estimate was conducted on an off-channel population at Site 2 on July 13, 1999. This site was chosen because it was known to contain a dense population of Topeka shiners. The entire off-channel pond was intensively seined until the catch rate neared zero. Adult Topeka shiners with standard length greater than 30 mm were retained while young-of-the-year, which were too small to mark, were released. Adults were anesthetized (using a 0.2 g/l solution of MS222 neutralized with baking soda) and marked with a small injection of acrylic dye in their ventral caudal peduncle according to the procedures of Lotrich and Meredith (1974). Lotrich and Meredith (1974) reported a marking mortality rate of 4% using a variety of small fishes (not including *N. topeka*). In an independent experiment, the marking mortality rate for 15 Topeka shiners held one week was 6.7%. Marked Topeka shiners were revived and released alive. A single recapture census was conducted one week later.

Population estimates were repeated at Site 2 on May 11 and July 26, 2000, using a different colored dye each time. The same procedures were followed during three population estimates conducted on an instream population at Site 9 (Figure 1.1). This site was chosen because it was known to have a relatively large instream population located in a state park. In each case, population estimates at Site 9 were conducted the day after they were conducted at Site 2. Population sizes were estimated using

Chapman's adjusted Petersen estimate, $N = (M + 1) \times (C + 1) / (R + 1)$, where N = population size at time of marking, M = number of fish marked, C = sample taken for census, and R = number of recaptured marks in the census, and 95% confidence intervals for N were calculated using Pearson's formulae, $R + 1.92 \pm 1.960 \times \sqrt{}(R + 1.0)$ (Ricker 1975).

Results

Distribution surveys.—Topeka shiners were identified at 98 of 203 (48%) locations sampled within the Missouri River drainage, including 22 of 31 (71%) historic locations and 76 of 172 (42%) new locations (Table 1.1). They remained extant in all 10 historic streams and were discovered in seven new streams in this drainage. This species was most commonly located in low-order tributaries or headwater reaches of larger streams. Topeka shiners were widely distributed throughout the Big Sioux and Rock watersheds; however, they were not found within the Little Sioux watershed or the Des Moines River drainage.

Habitat comparison study.—Topeka shiner relative abundance was consistently higher in off-channel habitats at six of eight sites during the habitat comparison study (Figure 1.2). With the exception of Site 5, instream CPUE remained relatively low (i.e., less than six Topeka shiners per haul) through the duration of the study. Although CPUE varied seasonally and among sites, it was usually an order of magnitude or more higher in the off-channel habitats. Contingency table analyses indicated that Topeka shiner relative abundance was associated with habitat-type at seven of eight sites (Table 1.2). At six of these (Sites 2-4 and 6-8), CPUE was significantly higher in the off-channel habitat. While CPUE was associated with habitat-type at Site 1 (Table 1.2), it was not clear which habitat-type exhibited a higher relative abundance. This may have been a result of reduced catchability in the off-channel habitat. CPUE was higher in the off-channel habitat during the first two samples; however, rooted aquatic vegetation became very dense during July and August which greatly reduced the effectiveness of seining. During the same period, no Topeka shiners were caught in this habitat. Relative abundance was independent of habitat-type at Site 5 (Table 1.2). Of the instream segments in this study, this segment contained the only large pool habitat, a 660 m^2 scour pool. This was the only instream habitat in which Topeka shiner relative abundance was equivalent with the off-channel habitat.

In addition to differences between Topeka shiner CPUE, instream and off-channel habitats differed in their species richness and community composition. All eight off-channel habitats contained fewer species than their instream counterparts. Off-channel habitats contained an average of nine species (typically species that preferred slow-flow) while the instream segments averaged 14 species. Topeka shiner percent community composition was consistently greater in the off-channel habitats as well. Topeka shiners averaged 16% of the community composition in the off-channel habitats versus only 3% in instream habitats. Site 5 was again the exception where Topeka shiner community composition was equal between the habitats.

Comparisons of habitat measurements revealed four consistent differences between the two habitat-types: mean flow, mean depth, size, and substrate composition (Table 1.3). Mean flow ranged between 0.07 and 0.44 m/s in instream habitats; however, each habitat contained an area with zero flow. The off-channel habitats exhibited no flow because they were isolated from the streams during this study. Mean depth was greater in the off-channel habitat at five of eight sites, averaging 0.78 m in the off-channel habitats versus 0.50 m in instream habitats. The off-channel habitat at six sites had a greater surface area and total volume than the average of the instream habitats. Although bank erosion was more prevalent in the instream segments, seven of eight off-channel habitats exhibited a greater percent of silt substrates. The substrate composition of the off-channel habitats averaged 75% silt while variable flow dynamics produced a greater diversity of larger substrate types in instream habitats. Boulders and concrete rip-rap blocks were the most prevalent types of cover in both habitat-types. Rooted aquatic vegetation was dominant in two off-channel habitats and filamentous algae was common in all. Vegetation was not abundant in instream habitats.

Not surprisingly, the characteristics exhibited by most off-channel habitats were typical of large pools. These included no flow, greater mean depth, larger surface area and volume, and a greater composition of thick silt substrates. The instream habitats, with the exception of the scour pool at Site 5, were faster-flowing, shallower, smaller, and contained a greater diversity of larger substrates. The instream habitats consisted mainly of bend pools, backwaters, and the margins of slow runs. The scour pool at Site 5 was unique in that it more closely resembled the off-channel habitats in many characteristics, including slow flow, large surface area, thick silt substrates, and high relative abundance and community composition of Topeka shiners.

Seasonal population size.—Adult population size at both sites was much higher in early May than in late July during 2000 (Table 1.4). Although population estimates were not conducted during the spring of 1999, sampling at Site 2 indicated that adult abundance was far greater in the spring than during the summer population estimate. A total of 657 adult Topeka shiner were caught here on May 23, 1999, including 416 adults in one seine haul. Sampling was not conducted at Site 9 during the spring of 1999; therefore, no comparison could be made for this site during this year. Despite its much smaller volume, the off-channel habitat maintained higher abundances of Topeka shiners than the instream segment until July 2000. Population size was much lower during July 2000 than during July 1999 at both sites, but especially at Site 2. The adult population at Site 2 plummeted to only 17 adults during the summer of 2000.

Discussion

Distribution surveys.—The Topeka shiner seems to be maintaining viable populations in Minnesota. Excluding the two historic records from the Cedar River drainage and Okabena Lake, the historic range of the Topeka shiner remains fully intact in this state. Topeka shiners were located at 98 of 203 (48%) locations sampled within the Missouri River drainage during 1997-2000. Compared with previous surveys' catch rates of 17 of 29 (59%) locations during 1973-1974 and 10 of 23 (43%) locations during 1984-1985, it seems reasonable to suggest that their distribution in Minnesota has remained fairly stable during at least the past 28 years. This observation is in sharp contrast with the declines occurring in southern states. For example, Topeka shiners were located at only 22 of 128 (17%) historic locations in Kansas during 1991-1992 (Tabor 1998) and 20 of 136 (15%) historic locations in Missouri during 1992-1995 (Gelwicks and Bruenderman 1996). Minnesota populations may represent the largest and most stable population complex remaining in this species' range.

It is unclear why Topeka shiners were not found in the Des Moines River drainage. This species was historically and is currently located in the upper portion of this drainage in Iowa (Harlan et al. 1987; Bruce Menzel, pers. comm.). Since Topeka shiners are commonly found in headwaters, one would expect to find them in Minnesota in this drainage. There are a few possible reasons why this did not occur. Compared with the Big Sioux and Rock watersheds, the Des Moines River drainage has fewer small, meandering streams and more channelized ditches (University of Minnesota 2000), which may reduce the presence of both off-channel habitats and instream pools. This drainage also has a greater percentage of poorly drained soils (University of Minnesota 2000), which may reduce surface to groundwater contact. Finally, the Des Moines River drainage has many large, natural lakes which contain several piscivorous fish species. Combined, these factors may have precluded the Topeka shiner from colonizing this drainage. None of these hypotheses has been formally analyzed or tested however. It should be noted that the Little Sioux watershed closely resembles the Des Moines River drainage in these characteristics; however, Topeka shiners have not been reported from this drainage in Iowa (Harlan et al. 1987).

Habitat comparison study.—Although this study did not show that Topeka shiners preferred off-channel habitats over instream ones (because they could seldom move freely between the two), it did demonstrate that Topeka shiners utilized off-habitats quite effectively. Although the results were equivocal at one site (Site 1) and equivalent at another (Site 5), the relative abundance of Topeka shiners was clearly higher in the off-channel habitats at six of eight sites. Not only were Topeka shiners capable of carrying out their life history in these isolated habitats, they were often quite successful at it. Their populations attained high densities which dominated the community in several off-channel habitats, especially by juveniles in the fall.

But what is the importance of off-channel habitats to the Topeka shiner? One hypothesis is that off-channel habitats provide low-flow refuges for Topeka shiners during floods. Kuitunen et al. (2000) showed that non-breeding adult Topeka shiners preferred instream habitats with no flow. Due to their pool-like qualities and peripheral location, these habitats may provide the lowest flow conditions in the floodplain during floods. Also, Adams et al. (2000) observed frequent “oral grasping” of wire mesh by Topeka shiners in swimming performance tests, and suggested that this behavior may limit downstream displacement during freshets. Perhaps Topeka shiners colonize off-channel habitats during floods to avoid being displaced downstream.

Another hypothesis is that off-channel habitats provide this species with isolated refuges during droughts, similar to intermittent pools. Fish that remain in off-channel habitats after floodwaters recede are trapped until the next high water connection occurs. During this period, conditions in these habitats can become quite inhospitable, especially during droughts (Tramer 1977). However, some researchers have suggested that Topeka shiners thrive under these conditions. Minckley and Cross (1959) reported that Topeka shiners reproduced more successfully than other species during periods of drought, and Kerns (1983) observed that Topeka shiner juveniles exhibited drought-resistance, as evidenced by their dominance in shrinking intermittent pools where other species had succumbed. During this study, Topeka shiner young-of-the-year were often dominant in off-channel habitats late in the summer. Topeka shiners also survived harsh conditions in an oxbow that experienced winterkill during January 2000, where only highly-tolerant species (i.e., black bullhead (*Ameiurus melas*) and fathead minnows (*Pimephales promelas*) survived. Furthermore, most off-channel habitats contained fewer predator and competitor species than instream habitats. These accounts suggest that off-channel habitats provide Topeka shiners with low-flow nurseries during droughts, and that the inhospitable conditions in these habitats may not be tolerable for many predator and competitor species.

A third hypothesis is that off-channel habitats represent “source” habitats for Topeka shiners. In this view, Topeka shiner populations achieve varying degrees of positive growth in off-channel habitats and, during floods, some portion of the population disperses, either colonizing new source habitats or maintaining populations in marginal, sink habitats. This system is termed a metapopulation. Over a large spatial and temporal scale, extinction and colonization dynamics become the dominant processes regulating many partially-isolated subpopulations (Cox 1997). During this study, Topeka shiners benefited from the (hypothesized) preferable conditions of off-channel habitats year-round, not just during droughts. In many cases, Topeka shiner populations successfully reproduced in off-channel habitats for several consecutive years and often attained very high densities. Undoubtedly, Topeka shiners dispersed from these habitats during high water, but occasionally, they may have become extirpated due to these habitats drying up. Although there are no supporting habitat-specific migration, reproduction, or mortality rates, the low numbers of instream Topeka shiners at most sites suggested that they may not be self-sustaining. In any case, the possibility of metapopulation dynamics occurring in Minnesota Topeka shiner populations warrants further investigation.

Conversely, a fourth hypothesis is that off-channel habitats, in and of themselves, are not an important part of this species' niche. Instead, their presence in a watershed is an indication of a more natural prairie stream system, in which Topeka shiners are successful. Many streams in regions where the Topeka shiner has declined precipitously, such as Kansas and Missouri, have been highly altered by stream channelization and impoundments (Tabor 1998). Furthermore, many of these impoundments have been stocked with largemouth bass, which may extirpate local Topeka shiner populations (Schrank et al. 2001). Perhaps, Topeka shiners are faring much better in Minnesota due to the comparatively low levels of stream channelization, impoundment, and largemouth bass abundance. In this case, the use of off-channel habitats could be merely coincidental.

It is too soon to conclude which combination, if any of these hypotheses is correct. What is known, however, is that southwestern Minnesota and northwestern Iowa are the only regions in this species' range where off-channel habitats currently exist, and in these regions, Topeka shiners are not experiencing the same declines as they are in areas without these habitats.

Seasonal relative abundance and population size.—Repeated sampling of individual populations revealed a seasonal trend in the relative abundance of Topeka shiners. Adult Topeka shiners were caught far more abundantly during the spring and early summer and became scarce as the spawning season ended around late July. The seasonal decline of adults is likely due to the short life span of the Topeka shiner. The majority of Age-2 adults and all Age-3 adults expire shortly after spawning (Chapter 2); therefore, adult numbers are expected to be highest in the spring (pre-spawn) and lowest in late summer (post-spawn) each year. Meanwhile, relative abundance increased during late July and August as young-of-the-year became recruited to the sampling gear.

The low adult population sizes of July 2000 may be a result of the exceptionally dry spring. While the water level at Site 9 remained fairly stable (due to flow regulation by an upstream impoundment dam), the volume of Site 2's pool was reduced by about half of its normal summer size, which was already small. The dense Topeka shiner population inhabiting this pool may have crashed as a result of this major reduction in habitat size. This is a potential strategic risk associated with remaining in intermittent pools or off-channel habitats during droughts, but it is one that has apparently been successful for the Topeka shiner. If there are many of these habitats in a drainage (as there are in the Big Sioux and Rock watersheds), then the odds of all populations going simultaneously extinct become increasingly small. According to the hypothesized drought-resistance of this species, one would also expect Topeka shiner young-of-the-year to dominate these habitats during low-flow years. Unfortunately, this hypothesis could not be tested at Site 2 during 2000 because young-of-the-year were not sampled effectively during the July population estimate and sampling was not conducted at this site during 2001.

Conclusion

Recent genetic studies by Michels (2000) revealed that most Topeka shiner populations are genetically distinct, even at a fine geographic scale; therefore, this species may be adapted to local habitat conditions that vary across its range. Habitat characteristics from Minnesota and other northern states indicated that Topeka shiners may be more tolerant of sedimentation and turbidity than was previously supposed (Hatch 2001). Also, anecdotal evidence has suggested that Topeka shiner juveniles be adapted to surviving in oxygen-depleted conditions, which occur in intermittent pools and off-channel habitats during summer droughts or ice-covered off-channel habitats during winter. Research into the age-specific physiological tolerances of this species is needed.

Although Topeka shiners in northern states seemed to be somewhat tolerant of sedimentation and eutrophication, evidence suggests that these factors have had a serious impact on southern populations in the past. These declines have likely been compounded by stream channelization and impoundment, predatory fish introduction, lowering of the water table, and perhaps off-channel habitat destruction. Research into the various effects of these actions is also warranted.

In the meantime, potentially harmful practices (e.g., intensive cultivation, tiling, and grazing of riparian zones, excessive irrigation and groundwater appropriation, stream channelization and impoundment, and exotic predator and competitor introduction) should be restricted or banned in watersheds containing Topeka shiners. Although their importance is not yet understood, off-channel habitats are clearly critical habitats in Minnesota that deserve special protection. Like most conservation efforts, this will require cooperation with and assistance for private landowners, who own the vast majority of the lands on which these habitats exist. Implementing these research and management actions will hopefully facilitate the recovery of this endangered minnow and help to conserve another bit of our prairie's native biodiversity.

Literature Cited

Adams, S. R., J. J. Hoover, and K. J. Killgore. 2000. Swimming performance of the Topeka shiner (Notropis topeka) an endangered Midwestern minnow. American Midland Naturalist. 144: 178-186.

Anderson, C. P., J. E. Erickson, J. Ross, and J. C. Underhill. 1977. Revised distribution records of some Minnesota fishes. Journal of the Minnesota Academy of Science. 43: 3-6.

Bailey, R. M. and M. O. Allum. 1962. Fishes of South Dakota. Miscellaneous Publications of the Museum of Zoology, University of Michigan. 119: 68-70.

Cox, G. W. 1997. Conservation biology: concepts and applications. 2nd edition. Wm. C. Brown Publishers, Dubuque. 362 pp.

Cross, F. B. and R. E. Moss. 1987. Historic changes in fish communities and aquatic habitats in plains streams of Kansas. pp. 155-165, in: W. J. Matthews and D. C. Heins, eds. Community and evolutionary ecology of North American stream fishes. University of Oklahoma Press, Norman. 310 pp.

Eddy, S. and J. C. Underhill. 1974. Northern fishes with special reference to the Upper Mississippi Valley. 2nd edition. University of Minnesota Press, Minneapolis. 404 pp.

Elsen, D. S. 1977. Distribution of fishes in the James River in North Dakota and South Dakota prior to Garrision and Oahe diversion projects. Unpublished thesis. University of North Dakota, Grand Forks. 86 pp.

Everitt, B. S. 1997. The analysis of contingency tables. Chapman and Hall, New York. 128 pp.

Gelwicks, G. and S. A. Bruenderman. 1996. Status survey for the Topeka shiner in Missouri. Unpublished report. Missouri Department of Conservation. 25 pp.

Harlan, J. R., E. B. Speaker, and J. Mayhew. 1987. Iowa fish and fishing. Iowa Department of Natural Resources, Des Moines. 323 pp.

Hatch, J. T. 2001. What we know about Minnesota's first endangered fish species: the Topeka shiner. Journal of the Minnesota Academy of Science. 65: 39-46.

Kerns, H. A. 1983. Aspects of the life history of the Topeka shiner, *Notropis topeka* (Gilbert), in Kansas. Unpublished thesis. Museum of Natural History, University of Kansas, Lawrence. 32 pp.

Kuitunen, A., L. P. Aadland, S. L. Johnson, J. Harvey, and K. L. Terry. 2000.

Microhabitat relationships of the Topeka shiner. Unpublished preliminary report. Minnesota Department of Natural Resources. 10 pp.

Lotrich, V. A. and W. H. Meredith. 1974. A technique and the effectiveness of various acrylic colors for subcutaneous marking of fish. Transactions of the American Fisheries Society. 103: 140-142.

Mammoliti, C. S. 1995. The effects of watershed impoundments on the Topeka shiner (*Notropis topeka*). Unpublished report. Kansas Department of Wildlife and Parks. 14 pp.

Matthews, W. J. and E. G. Zimmerman. 1990. Potential effects of global warming on native fishes of the southern Great Plains and southwest. Fisheries. 15: 26-31.

Menzel, B. W., J. B. Barnum, and L. M. Antosch. 1984. Ecological alterations of Iowa prairie-agricultural streams. Iowa State Journal of Research. 59: 5-30.

Michels, A. M. 2000. Population genetic structure and phylogeography of the endangered Topeka shiner (*Notropis topeka*) and the abundant sand shiner (*Notropis ludibundus*) using mitochondrial DNA sequence. Unpublished dissertation. University of Kansas, Lawrence. 68 pp.

Michl, G. T. and E. J. Peters. 1993. New distribution record of the Topeka shiner in the Loup Drainage Basin in Nebraska. Prairie Naturalist. 25(1): 51-54.

Minckley, W. L. and F. B. Cross. 1959. Distribution, habitat, and abundance of the Topeka shiner Notropis topeka (Gilbert) in Kansas. American Midland Naturalist. 61: 210-217.

Orth, D. J. 1983. Aquatic habitat measurements. pp. 61-84, in: L. A. Nielsen and D. L. Johnson (editors), Fisheries Techniques. American Fisheries Society, Bethesda. 468 pp.

Pflieger, W. L. 1971. A distributional study of Missouri fishes. University of Kansas Publications, Museum of Natural History. 20: 225-570.

Pflieger, W. L. 1975. The fishes of Missouri. Missouri Department of Conservation. 343 pp.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Bulletin of the Fisheries Research Board of Canada, Ottawa. No. 191. 382 pp.

Schmidt, K. P. 1993. Minnesota state parks fish species lists. Unpublished report. Minnesota Department of Natural Resources, Division of Parks and Recreation. 136 pp.

Schrank, S. J., C. S. Guy, M. R. Whiles, and B. L. Brock. 2001. Influence of instream landscape-level factors on the distribution of Topeka shiners *Notropis topeka* in Kansas streams. Copeia 2001(2): 413-421.

Simpson, P. W., J. R. Newman, M. A. Keirn, R. M. Matter, and P. A. Guthrie. 1982. Manual of stream channelization impacts on fish and wildlife. Fish and Wildlife Service, Washington, D. C. 155 pp.

Tabor, V. M. 1998. Final rule to list the Topeka shiner as endangered. Federal Register. 63: 69008-69021.

Tramer, E. J. 1977. Catastrophic mortality of stream fishes trapped in shrinking pools. American Midland Naturalist. 97(2): 469-478.

Underhill, J. C. 1957. The distribution of Minnesota minnows and darters in relation to Pleistocene glaciation. Minnesota Museum of Natural History, University of Minnesota. Occasional Papers: No. 7. 45 pp.

University of Minnesota. January 1, 2000. Southwestern Minnesota river basin information page. <http://www.soils.agri.umn.edu/research/swminn/> (Accessed: July 2001).

Table 1.1: Summary of distribution surveys for Topeka shiners in the Missouri River drainage of southwestern Minnesota, May 1997 - August 2000.

	New Sites		**Historic Sites**	
Rock Watershed	No. Sampled	Topeka Present	No. Sampled	Topeka Extant
Ash Creek	2	1	-	-
Champepadan Creek	12	5	-	-
Chanarambie Creek	5	2	2	1
Elk Creek	10	8	-	-
Kanaranzi Creek	11	6	6	3
Ladd's Pond	1	1	-	-
Little Rock River	10	2	1	1
Mound Creek	2	0	2	1
Mud Creek	4	0	-	-
Norwegian Creek	3	0	-	-
Poplar Creek	6	6	-	-
Rock Co. Park Pond	1	0	-	-
Rock River	31	19	12	11
subtotal	98	50	23	17
Big Sioux Watershed	No. Sampled	Topeka Present	No. Sampled	Topeka Extant
Beaver Creek	11	3	3	1
Blood Run	1	0	-	-
Flandreau Creek	7	1	1	0
Fourmile Creek	1	0	-	-
Little Beaver Creek	3	2	-	-
Medary Creek	5	4	1	1
Pipestone Creek	10	7	2	2
Split Rock Creek	14	7	1	1
Spring Creek	3	0	-	-
Springwater Creek	3	1	-	-
Willow Creek	4	1	-	-
subtotal	62	26	8	5
Little Sioux Watershed	No. Sampled	Topeka Present	No. Sampled	Topeka Extant
Judicial ditches	2	0	-	-
Lake/lake outlets	3	0	-	-
Little Sioux River	7	0	-	-
subtotal	12	0	-	-
Missouri drainage total	172	76	31	22

Table 1.2: Contingency table analyses of Topeka shiner catch-per-unit-effort (CPUE) and habitat-type (off-channel vs. instream) from eight sites in southwestern Minnesota during 1999 and 2000. Standardized seining was conducted at each site four times (monthly) between May and September (Sites 1-4 during 1999; Sites 5-8 during 2000). Frequencies of catches within ordered CPUE categories are reported for each habitat-type. Significant results of chi-square tests (P<0.05) indicate a non-independent association between the two variables.

1999

	Site 1		**Site 2**		**Site 3**		**Site 4**	
CPUE category	Off-channel	In-stream	Off-channel	In-stream	Off-channel	In-stream	Off-channel	In-stream
0	8	5	0	9	5	16	0	12
1's	1	13	3	9	7	1	7	10
10's	2	1	3	0	4	0	15	1
100's	0	0	5	0	2	0	1	0
P-value	P<0.05		P<0.01		P<0.025		P<0.001	

2000

	Site 5		**Site 6**		**Site 7**		**Site 8**	
CPUE category	Off-channel	In-stream	Off-channel	In-stream	Off-channel	In-stream	Off-channel	In-stream
0	3	7	2	30	19	37	1	18
1's	15	14	13	5	17	3	7	7
10's	8	9	5	0	10	0	7	3
100's	0	1	0	0	1	0	0	0
P-value	P>0.05		P<0.001		P<0.001		P<0.01	

Table 1.3: Habitat measurements from two habitat-types (off-channel vs. instream) at eight sites in southwestern Minnesota during June 2000. Instream values equal the mean of three instream habitats. Mean flow was not measured in the off-channel habitats but was effectively zero. Substrate composition and cover were visually estimated to the nearest five percent. Cover types: SV = submerged vegetation; BO = boulders; RR = concrete rip-rap blocks; OH = overhanging bank/grass; WD = woody debris.

	Site 1		**Site 2**		**Site 3**		**Site 4**	
Habitat measurements	Off-channel	In-stream	Off-channel	In-stream	Off-channel	In-stream	Off-channel	In-stream
mean flow (m/s)	-	0.23	-	0.21	-	0.44	-	0.10
mean depth (m)	0.51	0.54	0.87	0.40	0.38	0.37	0.62	0.36
surface area(m^2)	204	175	402	150	1496	271	2504	293
volume (m^3)	104	95	350	60	568	100	1552	105
% silt	75	25	50	67	95	8	90	25
% sand	15	48	5	33	5	75	10	47
% gravel	10	25	30	0	0	17	0	28
% rubble	0	0	0	0	0	0	0	0
% boulder	0	2	15	0	0	0	0	0
% cover	40	2	15	10	0	0	25	2
cover type	SV	BO	RR	OH	na	na	SV	OH

	Site 5		**Site 6**		**Site 7**		**Site 8**	
Habitat measurements	Off-channel	In-stream	Off-channel	In-stream	Off-channel	In-stream	Off-channel	In-stream
mean flow (m/s)	-	0.09	-	0.07	-	0.18	-	0.42
mean depth (m)	1.23	0.48	0.83	0.4	0.62	0.74	1.22	0.68
surface area(m^2)	843	358	374	469	1850	709	285	920
volume (m^3)	1037	172	310	188	1147	525	348	626
% silt	75	52	80	27	75	32	60	18
% sand	5	14	0	24	5	43	15	78
% gravel	0	30	5	48	20	20	0	2
% rubble	0	0	10	2	0	2	0	2
% boulder	20	5	5	0	0	3	25	0
% cover	10	5	5	2	1	5	25	5
cover type	BO	RR	BO	BO	WD	RR	RR	WD

Table 1.4: Petersen single-census population estimates of adult Topeka shiners located at two sites in southwestern Minnesota. M = number marked on date, C = number captured during census one week later, R = number of marked recaptured during census, N = estimated population size

		Number		Est.	95%
Site/Date	M	C	R	N	Conf. Int.
<u>Site 2, off-channel</u>					
July 13, 1999	164	114	61	306	239 - 391
May 11, 2000	323	287	249	373	330 - 422
July 26, 2000	12	7	5	17	8 - 33
<u>Site 9, instream</u>					
July 14, 1999	76	40	15	197	123 - 313
May 12, 2000	33	48	10	151	86 - 260
July 27, 2000	55	42	30	78	55 - 109

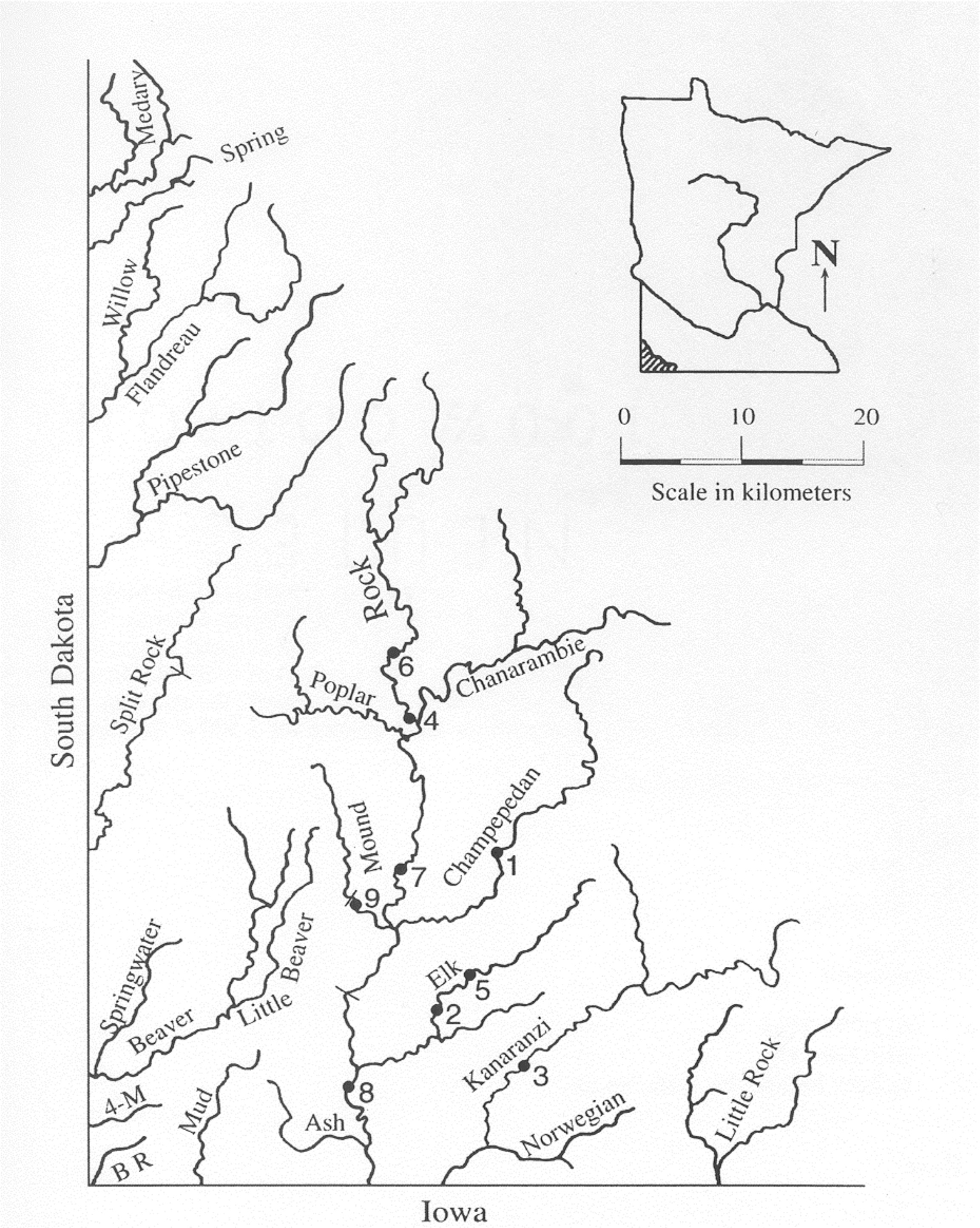

Figure 1.1: Location of the Missouri River drainage in southwestern Minnesota (inset) and streams of the Big Sioux and Rock watersheds where Topeka shiners were found. Numbered dots indicate the locations of nine study sites. Perpendicular lines on streams represent dams. BR = Blood Run; 4-M = Fourmile Creek. Epithets of "river" or "creek" are given in Table 1.1.

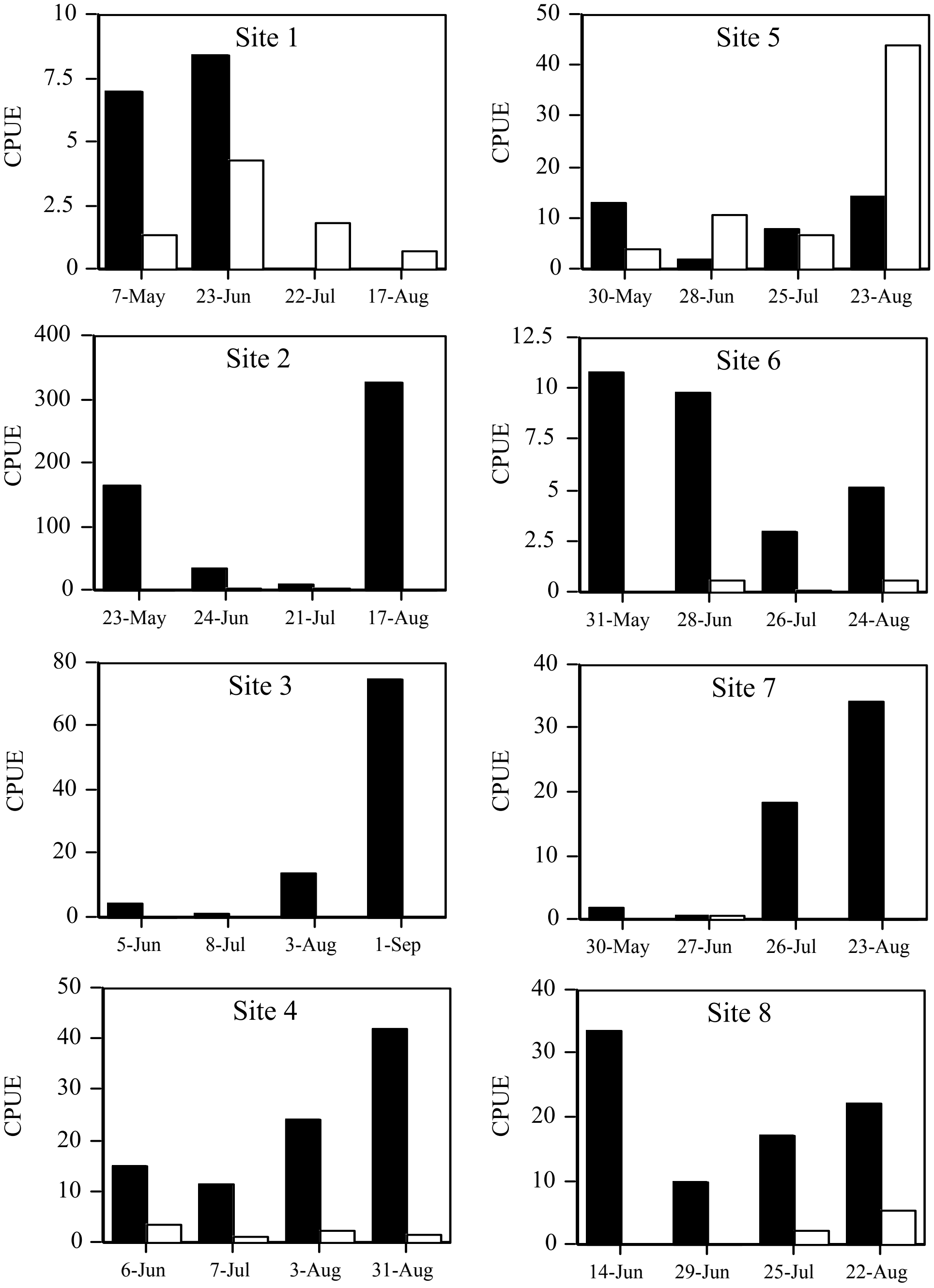

Figure 1.2: Catch-per-unit-effort (CPUE) of Topeka shiners sampled from two habitat-types (off-channel vs. instream) at eight locations in southwestern Minnesota. Sites 1-4 were sampled in 1999 and Sites 5-8 were sampled in 2000. Black rectangles show off-channel CPUE and white rectangles show instream CPUE.

CHAPTER 2

Demography, Growth, and Reproductive Effort of the Topeka Shiner (*Notropis topeka*) Near the Northern Limit of Its Range

Introduction

The Topeka shiner (*Notropis topeka*) is a small, stout minnow that inhabits slow-flowing pools of headwater streams in the central prairie regions of the United States. Formerly common from central Missouri and Kansas to southern Minnesota and southeastern South Dakota, this species now exists in highly disjunct populations comprising less than 10% of its historic range (Tabor 1998). Factors causing this species' decline are not known but may include agrarian development of prairie watersheds (Cross and Moss 1987), stream channelization (Simpson et al. 1982), tributary impoundment (Mammoliti 1995), predation by introduced piscivorous fishes (Schrank et al. 2001), and climate change (Minckley and Cross 1959). The Topeka shiner was listed as federally endangered on January 14, 1999 (Tabor 1998).

Although research involving the Topeka shiner has increased during recent years, information regarding its life history still lacks great depth. Minckley and Cross (1959), Cross (1967), and Cross and Collins (1995) provided information on this species' longevity, growth, maturity, and spawning season in Kansas. Pflieger (1975 and 1997) provided similar information from Missouri as well as descriptions of reproductive behavior. Katula (1998) observed the spawning behavior of 13 captive individuals from Minnesota, and Stark et al. (1999) did the same for an isolated, wild population in western Kansas. Until this study, the only intensive life history study of the Topeka shiner was conducted by Kerns (1983) on a population in the South Fork of the Cottonwood River in central Kansas, near the southern limit of this species' range.

This study was conducted on 21 Topeka shiner populations in southwestern

Minnesota, near the northern limit of this species' range. Preliminary results were reported by Hatch (2001). The objectives of this study were to provide detailed information on the demography, growth, and reproductive effort of Topeka shiners in Minnesota. The age composition, longevity, body-size relationships, length-at-age, growth rate, reproductive schedule, maturity, and clutch size of this species were analyzed using age, sex, and site-specific tests to determine possible sources of variation in life history traits. The results were compared with findings from the southern portion of the Topeka shiner's range to provide a rangewide perspective of this species' life history.

Methods

Study areas.—The primary life history data for this study were collected from three sites in the Big Sioux and Rock watersheds of southwestern Minnesota (Figure 2.1). Site MC was a 400 m stream reach located in Mound Creek, just below an impoundment dam in Blue Mounds State Park. This site contained a series of pools and slow runs separated by small riffles. Sampling was conducted regularly (i.e., at two to three week intervals) at this site from April-October 1998. Site BC was a 250 m stream reach located in Beaver Creek, Rock County. This site contained a large scour pool downstream of a long run. Sampling was conducted regularly at this site from April-August 1999. Site LP was a small, land-locked farm pond near the city limits of Luverne, Minnesota. Topeka shiners were accidentally introduced here sometime after the pond was excavated in 1992. Sampling was conducted regularly at this site from April-August 1998. The locations of the instream sites were chosen because they were known to contain relatively large populations of Topeka shiners, and the farm pond site was chosen because it represented the only known occurrence of Topeka shiners in a closed-basin system. Supplemental data were also obtained from single collections made at 18 other sites in these watersheds during 1998.

Fieldwork .—Topeka shiners were sampled using a 6.1 x 1.2 m bag seine (3.2 mm mesh) or 1.2 x 1.2 m one-person seines (6.4 mm mesh). For most samples in 1998, a randomly selected subsample was euthanized using MS222, fixed in 10% formalin, and transported to the Bell Museum of Natural History for laboratory analyses. To prevent harming regularly sampled populations, some samples were measured in the field and released alive. Total length (TL) and standard length (SL) were measured (± 0.1 mm) using a dial calipers, and scales (located just above the lateral line near the anterior base of the dorsal fin) were collected for aging. Mature individuals were sexed in the field by visual examination of sexually-dimorphic reproductive characteristics. Data from unsexed individuals were not used in these analyses. Due to permit restrictions after listing, no Topeka shiners were sacrificed during 1999; instead, measurements were taken in the field as described above. Field measurements were only used to supplement demographic and growth analyses. In total, information was obtained from 736 Topeka shiners during 1998 and 146 Topeka shiners during 1999.

Laboratory analyses.—Fixed specimens were rinsed for 24 hr prior to all analyses. Total length (TL) and standard length (SL) were measured (± 0.1 mm) using a dial calipers. Total body mass (TBM), eviscerated body mass (EBM), and gonadal mass (GM) were weighed (± 0.001 g) on a Sartorius analytical balance, after blotting away excess water. Gonadosomatic indices (GSI, equals GM / EBM x 100) were calculated to analyze reproductive development. When immature gonads weighed < 0.001 g, a value of 0.0005 was used to calculate GSI. In the lab, sex was determined by gross examination of gonads under microscope magnification (6-25 x). Scale samples were collected from preserved specimens (as in the field) and all samples were mounted on microscope slides in Sayer's medium (Uphoff 1948). Body-size relationships between TL and SL, TBM and SL, EBM and SL, and EBM and TBM were analyzed using linear regression techniques. Sex-specific regression lines were tested for coincidence, parallelism, and equal intercepts using a multiple regression model with sex as a "dummy" variable (Kleinbaum et al. 1988).

Age was determined by counting annuli on scales magnified by an overhead microprojector (65 x). The distance from the scale focus to each annulus and the scale margin was measured (± 1 mm) using a metric ruler. Annuli determination was validated by sequential examination of scale margins from fish collected throughout the year (Casselman 1987). Each fish was assigned an age equal to the number of months from June (i.e., the first full month of spawning) of its hatching year to the time of its capture; therefore, fish captured during June were either 12, 24, or 36 months old. Scale measurements were used to "back-calculate" growth histories according to the Lee method: $L_i = a + [(L_c - a) / S_c] \times S_i$, where L_i is the SL of the fish at formation of the i^{th} annulus, L_c is the SL of the fish at capture, S_i is the scale measurement to the i^{th} annulus, S_c is the scale measurement to the edge of the scale, and "a" is the intercept of the body-scale regression (Carlander 1981). Site and sex-specific correction factors (i.e., "a") were used when calculating mean SL-at-age and annual growth increments (i.e., $L_{i+1} - L_i$) at Sites MC, LP, BC, and all 21 sites combined. Site and sex-specific differences were tested using either a Z-test or a Student's t-test (Devore and Peck 1997). The significance level was 0.05 for all statistical tests. Growth curves of SL-at-capture were used to compare growth rates between sites and sexes as well.

Reproductive schedule was determined using three successive methods. First, the ovaries of all females were classified according to the five developmental stages described by Heins and Rabito (1986): latent (LA), early maturing (EM), late maturing (LM), mature (MA), or ripe (RE). These stages corresponded with increasing levels of yolk loading in separate groups of ova. Females with LM, MA, or RE ovaries were considered reproductively mature. The percent of females in each stage was calculated during the study period to determine the onset, peak, and end of the spawning season. This information was also used to calculate percent maturity by age-class. Since testes were not initially classified according to their development, a quick,*a posterori* examination was conducted to make GSI a surrogate measure of maturity. The testes of 30 males (with GSI ranging between 0.2 and 1.0) were classified as either latent or mature. Mature testes were generally larger, denser, and more opaque than immature testes. From this examination, a "critical" GSI value was determined, above which most males exhibited mature testes. Percent maturity was then calculated by age-class. Next, mean GSI was analyzed during the field season for both males and females to determine whether this method corroborated the gonadal classification method. Finally, field observations of reproductive characteristics (i.e., breeding coloration and abdominal distention) were checked against both spawning season determination methods.

To estimate clutch size, the group of larger, mature ova were counted from ovaries classified as MA. Mature ova from RE ovaries were not counted because a portion of the clutch may have been oviposited prior to capture. Three mature ova from each pair of MA ovaries were chosen at random and two diameters (the longest and shortest dimensions) were measured (± 0.036 mm) using an optical micrometer at 25 x magnification (Heins et al. 1992). These values were averaged to determine mean mature ova size. Clutch size was analyzed by age-class, SL, EBM, and habitat-type using standard correlation and linear regression techniques (Devore and Peck 1997). Preserved specimens were deposited in the Bell Museum of Natural History, University of Minnesota.

Results

Demography.—Age was determined for 544 females and 383 males from combined 1998 and 1999 samples. Of these, 17% were three to four months old (Age-0), 55% were 10 to

16 months old (Age-1), 26% were 22 to 27 months old (Age-2), and 2% were 34 to 37 months old (Age-3). The sex ratio did not differ significantly from 1:1 for Age-0 (one-tailed Z tests, $P = 0.32$) or Age-3 ($P = 0.09$) individuals; however, females comprised a significantly greater percentage of Age-1 (59%; $P < 0.0001$) and Age-2 (62%; $P = 0.0001$) individuals. Age-0 specimens were underrepresented in these samples because they were not sampled effectively until September, upon reaching a SL of about 22 mm. For September-October samples ($N = 189$), 83% were Age-0, 14% were Age-1, and 3% were Age-2. Seasonal changes in percent age composition during 1998 indicated that Ages 1-3 experienced high mortality rates near the end of summer, just prior to young-of-the-year recruitment (Figure 2.2). Nineteen Age-3 individuals were found during 1998 and only one during 1999. The three oldest females were 36 months old and the two oldest males were 37 months old.

Body-size relationships.—Body-size relationships were determined for 373 females and 293 males from all 1998 samples. All sex-specific regression lines proved to be non-coincident (all $F_{2,\,662} > 3.00$, all $P < 0.05$); therefore, separate female and male regression equations were necessary (Table 2.1). Sex-specific regression lines were also tested for parallelism and equal intercepts using a F-test (d.f. = 1, 662; $F_{crit.} = 3.84$). The lines for TL by SL and SL by TL had equal intercepts ($P > 0.05$ and $P > 0.10$, respectively) but were not parallel (both $P < 0.05$). The lines for TBM by SL were parallel ($P > 0.10$) but did not have equal intercepts ($P < 0.05$), and the lines for EBM by SL and EBM by TBM were not parallel and did not have equal intercepts (all $P < 0.001$). This means that males and females had about the same length relationships, but for any given length, males had more somatic mass than females. This relationship was masked when GM was included (i.e., using TBM) because females devoted more energy to the production of gametes than did males. All body-size relationships were highly linear with coefficients of determination (r^2) ranging between 0.973 and 0.999.

Growth.—Sequential examination of the scale margins of fish collected during April-October indicated that most Age-1 or older Topeka shiners achieved the majority of their annual growth during May-July. The scales of fish caught during this period exhibited widely spaced circuli that are indicative of rapid somatic growth (Casselman 1987). During August-October, the circuli became increasingly compressed indicating slow somatic growth. During April, 27% of all specimens exhibited a newly formed annulus. This figure was 100% by June, suggesting that peak annulus formation occurred during May. Therefore, back-calculated growth histories were associated with SLs attained at 11, 23, or 35 months of age.

Back-calculated growth histories showed wide variation among sites and between sexes (Table 2.2). Mean SL-at-annulus formation for females of Ages 1-3 ranged from 27.4 to 32.0 mm, 39.5 to 42.2 mm, and 46.1 to 47.3 mm, respectively, and for males of Ages 1-2 ranged from 26.8 to 33.9 mm and 45.2 to 48.5 mm, respectively. Weighted mean SLs differed between the sexes in each age-class at each site (independent T-tests, all $P < 0.05$), except for Age-1 males and females at Site MC ($P = 0.91$). On average, Age-1 males were longer than Age-1 females at Site LP, but Age-1 females were longer than Age-1 males at Site BC. After Age-1, males attained longer lengths-at-age than females at each site. Mean growth increments showed evidence of compensatory and depensatory growth during the second year (Table 2.2). On average, males at Site MC grew more slowly but lived longer and attained longer maximum lengths than males at Sites LP or BC. The opposite was true for females at these sites. After the first year's growth, females at Sites LP and BC grew more slowly but lived longer and attained longer maximum lengths than females at Site MC. This suggested that shorter Age-1 individuals grew more during the second year than did longer Age-1 individuals. These results may be biased, however, due to low sample sizes of Age-3 fish. For combined 1998 and 1999 samples, back-calculated weighted mean SLs for females of Ages 1-3 (N

= 392) were 29.3 mm, 41.1 mm, and 46.5 mm, respectively, and for males of Ages 1-3 (N = 254) were 29.6 mm, 46.3 mm, and 55.6 mm, respectively. The longest individuals were a 51.7 mm SL, 25 month old female collected from Site MC on July 23, 1998 and a 64.4 mm SL, 36 month old male collected from Site MC on June 24, 1998.

Growth curves of SL-at-capture from all sites showed that males grew faster than females throughout their life cycle (Figure 2.3). This was true for each of the three primary sites as well (Figure 2.4). Males at Site BC showed the steepest growth rates, followed by Site LP and Site MC males. For the females, Site LP showed the steepest growth rates, followed by Site MC and Site BC females. Age-0 individuals were not included at Sites LP and BC because they were not recruited by August when sampling was ended at these sites. The earliest collection date for Age-0 individuals was August 12, 1998 and August 3, 1999. Individuals from the 1998 sample (N = 41), averaged 19.7 mm SL (SD = 3.9) and ranged between 11.4 and 26.5 mm SL. By October 23, Age-0 fish at this site averaged 28.1 mm SL (N = 63, SD = 3.9). The mean daily growth rate for this sample (calculated by dividing the difference between the means by the number of days between sampling) was 0.1167 mm/day between August 12 and October 23 (N = 72 days). The water temperature at this site was 24 ˚C on August 12 and September 11, but dropped to about 10 ˚C by October 23; therefore, it was likely that the majority of Age-0 growth occurred before October.

Reproductive schedule.—The reproductive schedule determined by ovarian classification indicated that spawning occurred from mid-May until early August during 1998 (Table 2.3). No MA or RE ovaries were observed outside of this range. Based on the frequency of MA or RE ovaries, the peak of spawning occurred during June.

The spawning season determined by mean GSI corresponded well with the ovarian classification method. Mean GSI curves were very similar between the sexes (Figure 2.5). Mean GSI rapidly increased during mid-May, peaked during early July, and sharply declined during late July/early August. GSI averaged 2.2 (SD = 1.0) for LA females, 5.1 (SD = 3.0) for EM females, 14.9 (SD = 6.6) for LM females, 23.3 (SD = 6.3) for MA females, and 27.1 (SD = 10.8) for RE females. The highest GSI (40.2) was calculated from a 31.6 mm SL, 12 month old, RE female collected on June 8. Males exhibited GSIs ranging from < 0.1 to 1.7, with the highest from a 59.3 mm SL, 24 month old individual collected on June 24.

Field observations of reproductive characteristics mirrored the spawning seasons determined in the lab. During each year, mature Topeka shiners began showing sexually-dimorphic reproductive characteristics by mid-May. Mature males exhibited brilliant red-orange coloration in their fins, abdomen, and cheeks as well as small, nuptial tubercles on their head and snout. A few of the largest females also exhibited slight fin and body coloration, but this was not typical of females. Instead, mature females exhibited varying degrees of abdominal distention and elevated urogenital papillae. Slight pressure on the abdomen of ripe individuals of either sex expelled gametes. Reproductive characteristics were exhibited throughout July but diminished during August, and by early fall, the sexes were nearly indistinguishable. On a few occasions during June and July, mature males were observed defending small areas near the edges of orangespotted sunfish (*Lepomis humilis*) and green sunfish (*Lepomis cyanellus*) nests. These males were busy chasing conspecifics away from their territory, but also appeared to raid the eggs of the sunfish on occasion. The spawning act itself was not observed.

Maturity.—Visual examination indicated that testes transitioned from immature to mature in the GSI range of 0.5-0.6; therefore, males with GSI > 0.6 were considered reproductively mature. Between May 16 and August 6, 20% (N = 23) of Age-1 males, 86% (N = 38) of Age-2 males, and 100% (N = 3) of Age-3 males exhibited GSIs > 0.6. During the same period, 52% (N = 186) of Age-1 females, 93% (N = 67) of Age-2 females, and 100% (N = 9) of Age-3 females exhibited LM, MA, or RE ovaries. These figures approximate the percent of reproductively mature individuals for each age-class during the spawning season. The smallest mature individuals were a 29.0 mm SL, 12 month old, LM female and a 41.2 mm SL, 13 month old male with GSI of 0.6.

Clutch size.—Clutch sizes determined from 66 MA ovaries averaged 453 mature ova (SD = 187) and ranged between 157 and 839 mature ova (Table 2.3). The mean diameter of mature ova averaged 0.835 mm (SD = 0.046) and ranged between 0.726 and 0.972 mm. Mean clutch sizes were 351 mature ova for Age-1 females (N = 32, SD = 125), 559 mature ova for Age-2 females (N = 30, SD = 194), and 478 mature ova for Age-3 females (N = 4, SD = 93). Clutch size was more strongly correlated with fish size than age however (r = 0.68 for EBM, 0.59 for SL, and 0.44 for age-class). Linear regressions of clutch size by SL and EBM produced the best fits (r^2 = 0.35 and 0.46, respectively), but were not particularly useful for predicting clutch size (Figure 2.6).

The analysis by habitat-type produced unexpected results. Mean clutch size of 27 mature females collected from seven instream sites was 570 mature ova (SD = 210). Twenty-seven mature females collected from the farm pond (Site LP) with statistically equal mean SL (one-tailed T-tests, P = 0.43), mean age (P = 0.44), mean EBM (P = 0.38), and mean ova diameter (P = 0.13) as the instream sample had a mean clutch size of 423 mature ova (SD = 88). Even with substantial variability, the instream sample's mean clutch size was significantly greater than the off-channel's sample (P = 0.001). The only other significant difference between the two samples was mean collection date (June 17 instream vs. June 6 off-channel; P = 0.02), which by itself was not correlated with clutch size.

Discussion

Demography.—Topeka shiners are a short-lived species with a maximum life expectancy of three years. This life span was also reported for southern populations in Kansas (Cross 1967; Kerns 1983; Cross and Collins 1995) and Missouri (Pflieger 1975 and 1997). The highly skewed age composition of Minnesota populations during the fall mirrored those reported from Kansas populations (Minckley and Cross 1959; Kerns 1983). Kerns (1983), however, suggested that males had a greater longevity than females. This was not the case in Minnesota. Of the 20 Age-3 individuals found here, 13 were female. Due to the small sample size, the sex ratio of this age group did not differ significantly from 1:1; thus, it is likely that females and males exhibit equal longevity in Minnesota. Some evidence suggested that Minnesota fish have longer average life spans than Kansas populations. Kerns (1983) reported catching only 26 individuals equivalent in age to the 24-35 month-olds in this study, which comprised only 3% of his total sample (N = 1002). During this study, 122 individuals were caught from this age-range, comprising 13% of the total aged sample (N = 927). Furthermore, an additional nine individuals were older than this age-range (i.e., 36-37 months old). This finding suggests either a sampling bias between the studies or a longer average life span of Minnesota populations.

Growth.—Despite their more northerly location, Topeka shiners from Minnesota may have attained longer lengths-at-age than southern populations. Cross (1967) reported mean TLs for Ages 0-2 of 30 mm, 43 mm, and 55 mm, respectively, for 772 fish caught in Kansas on October 13, 1956. Pflieger (1975) reported the same mean TL ranges as Cross (1967) for Age-0 (20 to 40 mm) and Age-1 (35 to 55 mm) individuals from Missouri. Kerns (1983) reported mean TLs for Ages 0-1 of 35.5 mm and 51.2 mm, respectively, for fish caught in Kansas on October 3, 1980. For fish collected on October 23, 1998 during this study, mean TLs were 35.7 mm and 53.7 mm for Age-0 (N = 67) and Age-1 (N = 5) fish, respectively. The Minnesota figures are comparable with Kerns's (1983) figures but are substantially greater than both Cross's (1967) and Pflieger's (1975) figures.

Kerns (1983) reported back-calculated mean SLs of 23.9 mm for Age-1 males and 24.9 mm for Age-1 females. These were considerably less than back-calculated weighted mean SLs of Age-1 fish during this study (Table 2.1). Kerns (1983) also derived mean SLs for fish caught on May 23, 1981. These were 34.6 mm for Age-1 fish, 42.5 mm for Age-2 fish, and 53.2 mm for Age-3 fish. Ages 1-3 collected during May 30-31, 1998 during this study had mean SLs of 36.1 mm, 48.5 mm, and 49.4 mm, respectively. Excluding the Age-3 fish (of which N = 3 for this sample), Ages 1-2 were again considerably longer than Kerns's figures. Also, at least 29 males from Minnesota collections were longer than the longest of Kerns's (1983) samples (55 mm). The mean daily growth rate calculated by Kerns (1983) for Age-0 Topeka shiners (between July 16 and October 3) was 0.1308 mm/day. This growth rate was slightly greater than the same statistic calculated during this study (0.1167 mm/day), perhaps because his range of dates were slightly earlier (i.e., during a warmer, faster growth period) than this study's range of dates (August 12 - October 23). All of these comparisons are qualitative because the calculation methods, sample sizes, and variances from other studies were not detailed enough to permit statistical comparisons. If Topeka shiner populations in Minnesota actually do live longer and attain larger sizes-at-age than southern populations, then this may be a hedge against less predictable conditions in the northern range (Stearns 1976).

Like most diminutive, short-lived fishes with prolonged spawning seasons, Topeka shiners exhibited a wide range of sizes for given ages. Growth histories also varied by sex, which is often indistinguishable in the field during the non-spawning season. These characteristics render age composition determination by length frequency inaccurate and undesirable. Although it does not avoid errors that may result from inaccurate sexing and requires considerably more time and energy, the analysis of scales is still the most accurate, non-lethal method for this purpose. In future studies, researchers will need to obtain large seasonal sample sizes if growth histories are to be compared among populations; otherwise, other non-lethal indices of growth (e.g., the rate of glycine uptake by scales, RNA/DNA ratios, or condition factors) should be considered (Busacker et al. 1990).

Reproductive effort.—Sequential examination of gonadal development, seasonal mean GSI, and field observations of reproductive characteristics all indicated a spawning season from mid-May to early August in Minnesota during 1998. Because field observations provided exactly the same spawning season as the laboratory analyses, required little effort, and were non-lethal, they are recommended for future spawning season determinations. This spawning season was also concluded by Hatch (2001) in Minnesota during a 1997 preliminary study. Similar spawning seasons were reported by Pflieger (1975 and 1997) in Missouri and Kerns (1983) in Kansas; however, a spawning season from late June through August was reported by Cross (1967) and Cross and Collins (1995) in Kansas and Harlan et al. (1987) in Iowa. During this study, the first appearance of breeding coloration in males coincided with water temperatures of 17-18 ˚C. Katula (1998) reported that captive Topeka shiners did not commence spawning until water temperature was raised from 21.1 to 24.4 ˚C. Kerns (1983) was able to maintain breeding coloration in males that were kept near 21 ˚C throughout the year. Several studies have reported that Topeka shiners utilize either sunfish or fathead minnow (*Pimephales promelas*) nests for spawning (Pflieger 1975, Kerns 1983; Stark et. al. 1999); however, to date, only Katula (1998) has witnessed the spawning act.

Percent maturity by age-class was similar between Kerns's (1983) study and the present one. The gonadal classification method seemed quite accurate at estimating reproductive maturity in females; however, the use of a critical GSI level for estimating maturity in males seemed less accurate, even though it closely matched Kerns's (1983) estimates. If this method is to be used, GM should be measured ± 0.0001 g, especially for small males. Assigning the arbitrary value of 0.0005 g to testes weighing < 0.001 g caused an overestimate of the GSI of small males which could have affected the percent maturity estimate. The critical GSI level of 0.6 was probably conservative enough to exclude these measurement errors; however, it may have also excluded medium-sized males from the maturity estimate that were actually reproductively mature.

The presence of multiple stages of ovarian development throughout the spawning season indicated that this species is a multiple-clutch spawner (Heins and Rabito 1986) (i.e., a species that produces successive groups of mature ova that are spawned at different times during the spawning season). Heins and Rabito (1986) suggested that some members of the genus *Notropis* cycle through the ovarian classes LM, MA, and RE as they produce and spawn successive clutches of mature ova. Hatch (2001) provided ova size frequency distributions for two mature Topeka shiner females that showed two distinct clutches of maturing and mature ova. Heins and Rabito (1986) have shown experimentally that this is indicative of multiple-clutch spawners. Distinct groups of developing, maturing, and mature ova were present in ovaries examined during this study as well. Although Kerns (1983) also observed three size categories of ova and counted the group of larger, mature ova, he did not directly associate this with multiple clutches. The mean "clutch size" reported by Kerns (1983) for Age-1 females (356 mature ova) was equivalent with Age-1 females in Minnesota; however, his Age-2 females (819 mature ova) had a greater mean clutch size than noted during this study. Kerns (1983) was also able to produce better fits for the regressions of clutch size by SL and EBM (r^2 = 0.88 and 0.92, respectively).

Although the total reproductive potential per individual may be higher for southern populations (due to their larger clutch size at Age-2), the actual number of offspring may be equal between northern and southern populations (due to the larger size and longevity of Minnesota populations). Minnesota populations may be additionally benefited by the presence and utilization of off-channel habitats, in which Topeka shiners achieved very high densities (Chapter 1). The finding that mean clutch size was lower in the off-channel habitat compared with the instream sites was therefore unexpected. If

Topeka shiners periodically migrate between these two habitat-types (as was hypothesized), then there does not seem to be a biological basis for this difference. Perhaps this difference was nutritional and not biological (Chapter 3). In any case, the need for long-term comparative studies of the differences between these habitat-types has been clearly demonstrated in Minnesota.

Literature Cited

Busacker, G. P., I. R. Adelman, and E. M. Goolish. 1990. Physiological and biochemical indices of growth. pp. 370-372 in: C. B. Schreck and P. B. Moyle, eds. Methods for fish biology. American Fisheries Society, Bethesda. 684 pp.

Carlander, K. D. 1981. Caution on the use of regression method of back-calculating lengths from scale measurements. Fisheries 6(1): 2-4.

Casselman, J. M. 1987. Determination of age and growth. pp. 209-242, in: A. H. Weatherly and H. S. Gill (co-authors), The biology of fish growth. Academic Press Inc., London. 443 pp.

Cross, F. B. 1967. Handbook of fishes of Kansas. Miscellaneous Publications of the Museum of Natural History, University of Kansas. 45: 129-130.

Cross, F. B. and J. T. Collins. 1995. Fishes in Kansas. University of Kansas Natural History Museum, University Press of Kansas, Lawrence. 315 pp.

Cross, F. B. and R. E. Moss. 1987. Historic changes in fish communities and aquatic habitats in plains streams of Kansas. pp. 155-165, in: W. J. Matthews and D. C. Heins, eds. Community and evolutionary ecology of North American stream fishes. University of Oklahoma Press, Norman. 310 pp.

Devore, J. and R. Peck. 1997. Statistics: the exploration and analysis of data. 3rd edition. Duxbury Press, Belmont. 641 pp.

Harlan, J. R., E. B. Speaker, and J. Mayhew. 1987. Iowa fish and fishing. Iowa Department of Natural Resources, Des Moines. 323 pp.

Hatch, J. T. 2001. What we know about Minnesota's first endangered fish species: the Topeka shiner. Journal of the Minnesota Academy of Science. 65: 39-46.

Heins, D. C. and F. G. Rabito, Jr. 1986. Spawning performance in North American minnows: direct evidence of the occurrence of multiple clutches in the genus *Notropis*. Journal of Fish Biology. 28: 343-357.

Heins, D. C., J. A. Baker, and W. P. Dunlap. 1992. Yolk loading in oocytes of darters and its consequences for life-history study. Copeia 1992(2): 404-412.

Katula, R. 1998. Eureka Topeka! Tropical Fish Hobbyist. 47(4): 54-60.

Kerns, H. A. 1983. Aspects of the life history of the Topeka shiner, *Notropis topeka* (Gilbert), in Kansas. Unpublished thesis. Museum of Natural History, University of Kansas, Lawrence. 32 pp.

Kleinbaum, D. G., L. L. Kupper, and K. E. Muller. 1988. Applied regression analysis and other multivariable methods. PWS-Kent Publishing Company, Boston. 718 pp.

Mammoliti, C. S. 1995. The effects of watershed impoundments on the Topeka shiner (*Notropis topeka*). Unpublished report. Kansas Department of Wildlife and Parks. 14 pp.

Minckley, W. L. and F. B. Cross. 1959. Distribution, habitat, and abundance of the Topeka shiner Notropis topeka (Gilbert) in Kansas. American Midland Naturalist. 61: 210-217.

Pflieger, W. L. 1975. The fishes of Missouri. Missouri Department of Conservation. 343 pp.

Pflieger, W. L. 1997. The fishes of Missouri. Missouri Department of Conservation. 382 pp.

Schrank, S. J., C. S. Guy, M. R. Whiles, and B. L. Brock. 2001. Influence of instream landscape-level factors on the distribution of Topeka shiners *Notropis topeka* in Kansas streams. Copeia 2001(2): 413-421.

Simpson, P. W., J. R. Newman, M. A. Keirn, R. M. Matter, and P. A. Guthrie. 1982. Manual of stream channelization impacts on fish and wildlife. Fish and Wildlife Service, Washington, D. C. 155 pp.

Stark, W., J. Luginbill and M. E. Eberle. 1999. The status of the Topeka shiner (Notropis topeka) in Willow Creek, Wallace County, Kansas. Unpublished report. Kansas Department of Wildlife and Parks. 12 pp.

Stearns, S. C. 1976. Life history tactics: a review of ideas. Quarterly Review of Biology. 51: 3-47.

Tabor, V. M. 1998. Final rule to list the Topeka shiner as endangered. Federal Register. 63: 69008-69021.

Uphoff, D. E. 1948. A new mounting medium for fish scales. Copeia 1948(1): 62.

Table 2.1: Summary of least-squares regressions of body-size relationships for female (N = 373) and male (N = 293) Topeka shiners collected from 21 sites in southwestern Minnesota during April - October, 1998. TL = total length (mm), SL = standard length (mm), TBM = total body mass (g), EBM = eviscerated body mass (g)

Regression (Y by X)	Sex	Range (X)	Slope	Intercept	R^2
TL by SL	F	21.6 - 51.5	1.238	0.545	0.994
	M	24.0 - 59.8	1.225	1.144	0.996
SL by TL	F	26.7 - 64.2	0.803	-0.229	0.994
	M	30.3 - 74.3	0.813	-0.765	0.996
log EBM by log SL	F	1.3 - 1.7	3.288	-5.309	0.983
	M	1.4 - 1.8	3.529	-5.657	0.989
log TBM by log SL	F	1.3 - 1.7	3.430	-5.387	0.973
	M	1.4 - 1.8	3.476	-5.468	0.988
EBM by TBM	F	0.140 - 3.150	0.664	0.045	0.979
	M	0.218 - 5.260	0.805	-0.018	0.999

Table 2.2: Back-calculated mean standard lengths (SL, mm) at-age and mean annual growth increments for Topeka shiners collected from three sites in southwestern Minnesota during the summers of 1998 and 1999. Half-lengths of 95% confidence intervals (CI) are provided in parentheses.

Site MC (1998)

Age class	No. fish	Mean SL at capt.	Mean SL (CI) at annulus I	II	III	Mean Growth Incr.(CI) I - II	II - III
	Females						
1	43	38.8	27.4 (0.7)				
2	49	46.8	27.9 (0.6)	42.0 (0.8)		14.1 (0.6)	
	Weighted Mean		*27.7*	*42.0*		*14.1*	
	Males						
1	15	48.6	29.9 (1.3)				
2	42	51.9	26.8 (0.6)	45.2 (1.5)		18.4 (1.1)	
3	6	61.4	28.8 (1.2)	46.4 (2.6)	55.6 (1.9)	17.6 (1.8)	9.2 (1.0)
	Weighted Mean		*27.7*	*45.3*	*55.6*	*18.3*	*9.2*

Site LP (1998)

Age class	No. fish	Mean SL at capt.	Mean SL (CI) at annulus I	II	III	Mean Growth Incr.(CI) I - II	II - III
	Females						
1	90	38.1	31.0 (0.7)				
2	29	46.0	31.6 (1.4)	42.2 (0.8)		10.7 (0.9)	
3	7	48.8	27.7 (1.1)	39.5 (1.3)	46.1 (1.1)	11.9 (0.9)	6.6 (1.0)
	Weighted Mean		*31.0*	*41.7*	*46.1*	*10.9*	*6.6*
	Males						
1	65	41.8	32.8 (1.4)				
2	7	51.9	33.9 (2.7)	48.5 (1.9)		14.6 (2.4)	
	Weighted Mean		*32.9*	*48.5*		*14.6*	

Site BC (1999)

Age class	No. fish	Mean SL at capt.	Mean SL (CI) at annulus I	II	III	Mean Growth Incr.(CI) I - II	II - III
	Females						
1	65	39.8	32.0 (0.9)				
2	23	45.0	30.6 (1.0)	41.3 (1.1)		10.7 (0.6)	
3	1	49.1	27.7	39.7	47.3	12.0	7.6
	Weighted Mean		*31.6*	*41.3*	*47.3*	*10.6*	*7.6*
	Males						
1	41	41.3	28.3 (1.2)				
2	15	53.2	28.1 (1.6)	47.6 (2.2)		19.5 (1.8)	
	Weighted Mean		*28.3*	*47.6*		*19.5*	

Table 2.3: Summaries of percent ovarian condition and clutch size of mature female Topeka shiners collected from 21 sites in southwestern Minnesota during 1998. The ovarian condition classifications are described by Heins and Rabito (1986).

	Ovarian condition (%)						Clutch size		
Date	n	LA	EM	LM	MA	RE	n	Mean	Range
25-26 Apr	44	57	41	2	-	-	0	-	-
16-17 May	62	5	35	48	10	2	6	386	285 - 457
30-31 May	52	6	15	38	40	-	21	560	216 - 821
8-9 Jun	106	27	20	32	18	3	19	394	172 - 839
24 Jun	17	-	-	18	65	18	11	427	178 - 815
7 Jul	10	-	-	40	60	-	6	461	304 - 693
16 Jul	1	-	-	-	100	-	1	256	-
22-23 Jul	6	33	50	17	-	-	0	-	-
30 Jul	4	-	25	50	25	-	1	484	-
6 Aug	4	50	25	-	25	-	1	157	-
12 Aug	18	100	-	-	-	-	0	-	-
10 Sep	52	98	2	-	-	-	0	-	-
23 Oct	25	100	-	-	-	-	0	-	-
Total/Mean	401						66	453	157 - 839

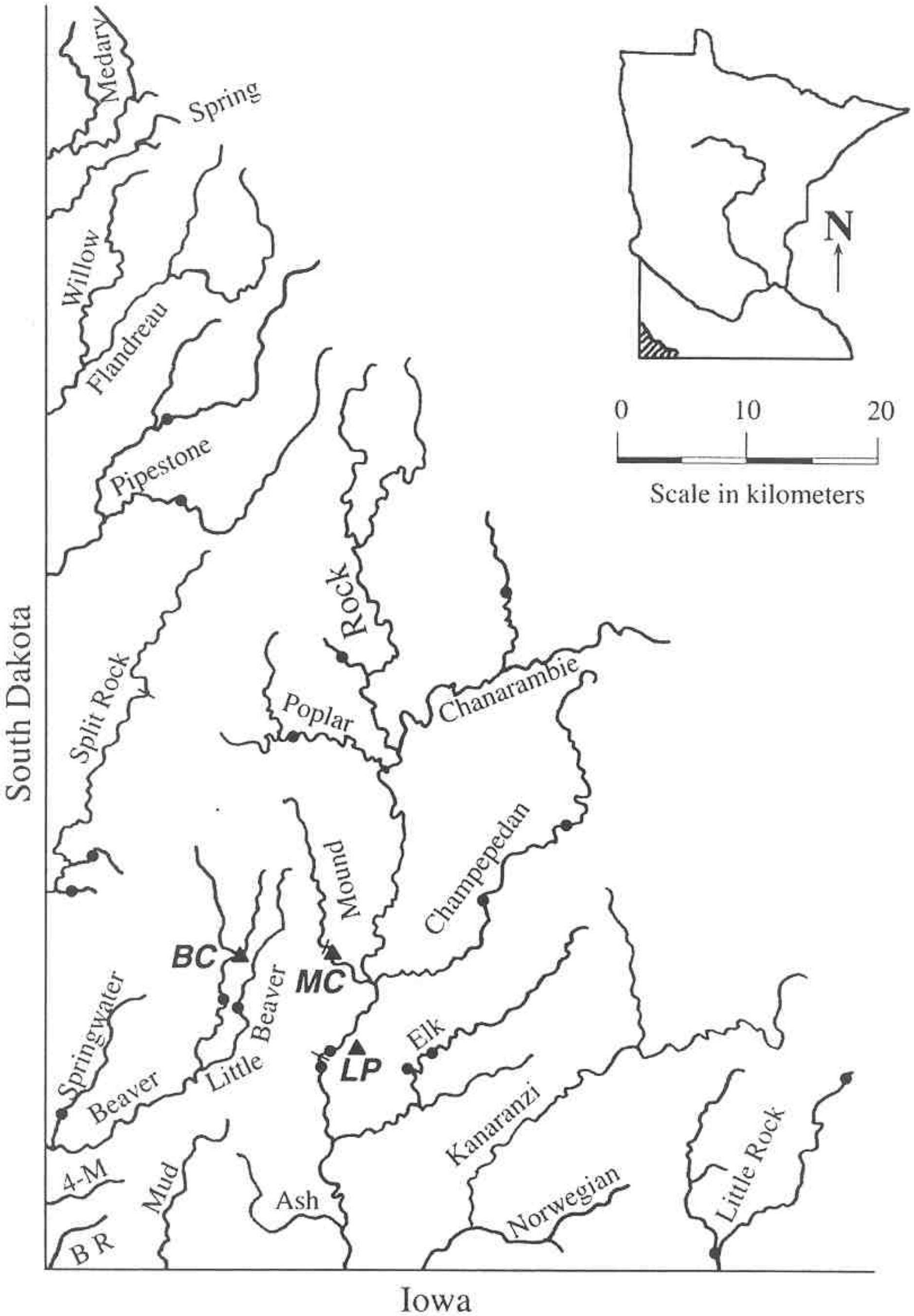

Figure 2.1: Location of 21 Topeka shiner collection sites within the Big Sioux and Rock watersheds of southwestern Minnesota. The labeled triangles represent the three primary study sites and the unlabeled dots represent the 18 supplementary study sites.

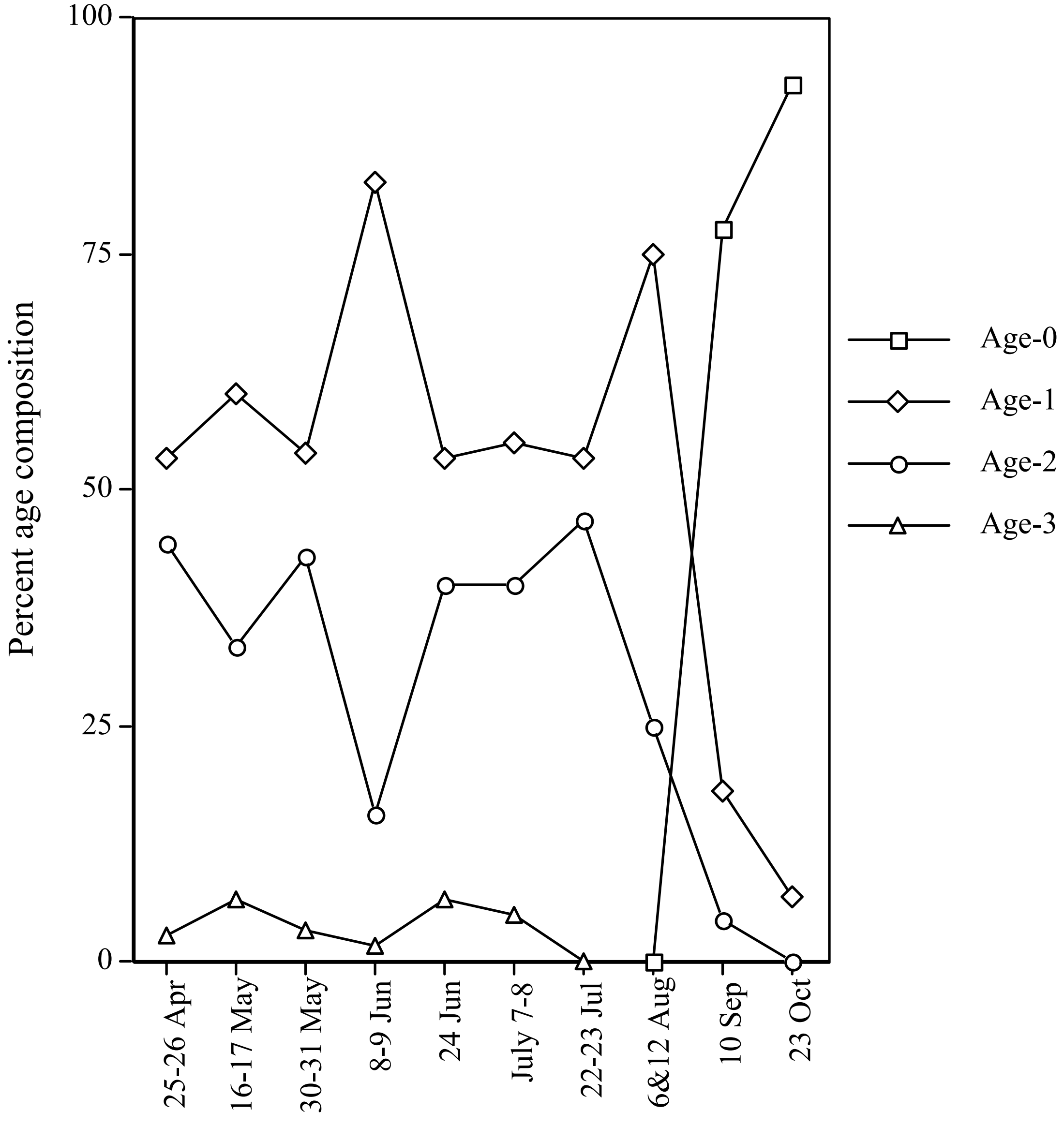

Figure 2.2: Percent age composition of Topeka shiners collected from 21 sites in southwestern Minnesota during 1998.

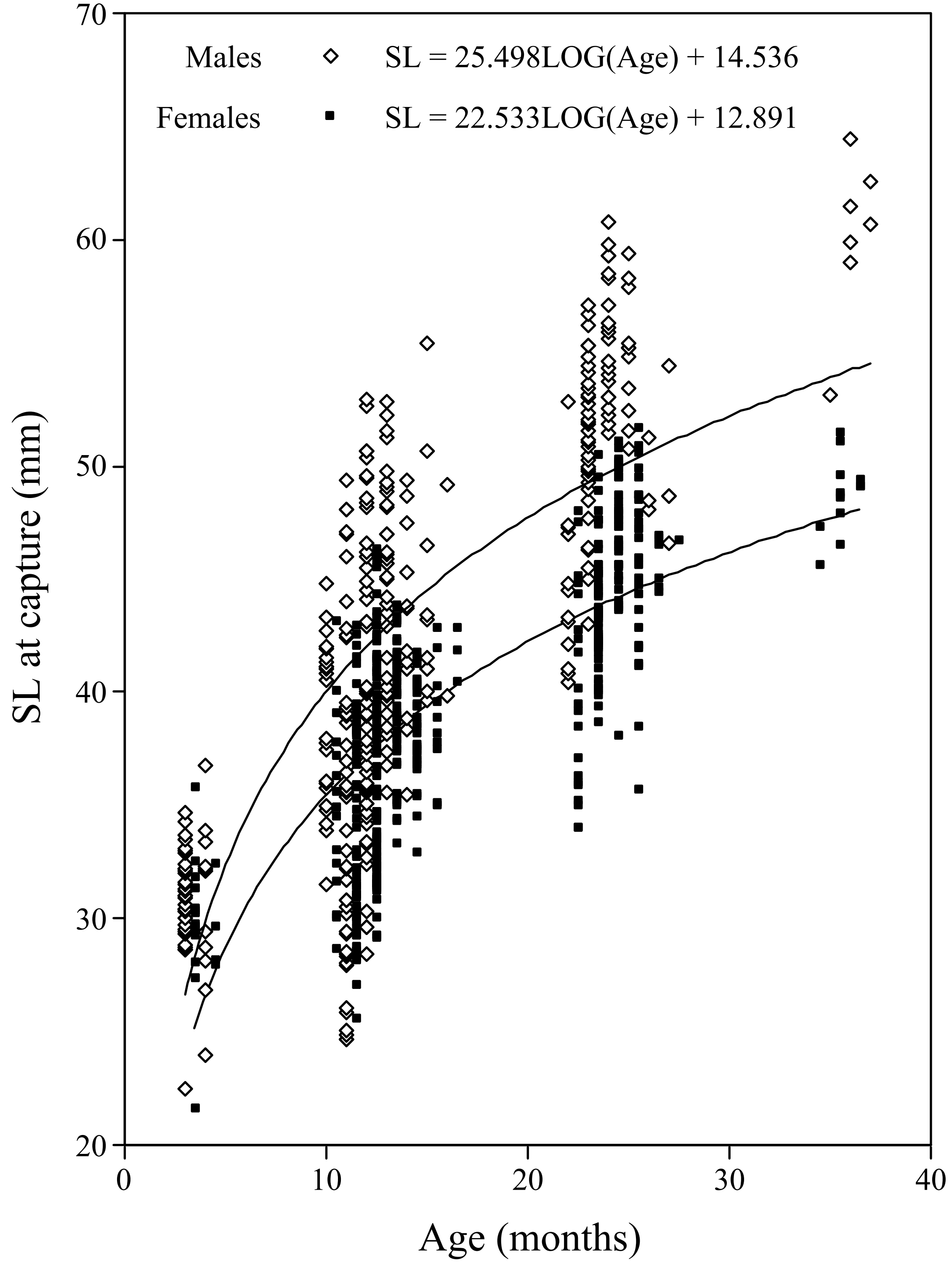

Figure 2.3: Growth curves of standard length (SL) at-capture for male and female Topeka shiners collected from 21 sites in southwestern Minnesota during 1998 and 1999.

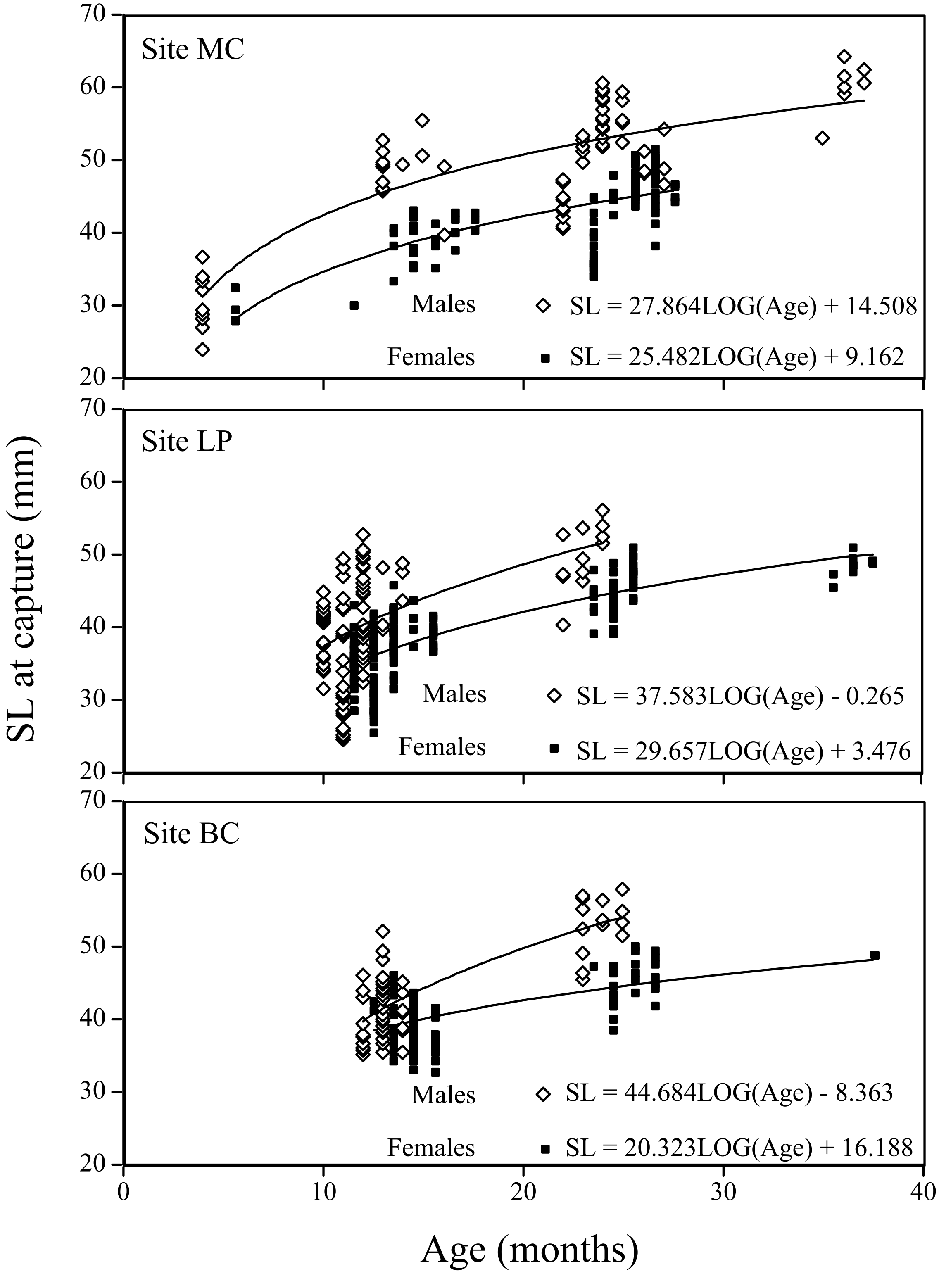

Figure 2.4: Growth curves of standard length (SL) at-capture for male and female Topeka shiners collected from three sites in southwestern Minnesota during 1998 and 1999.

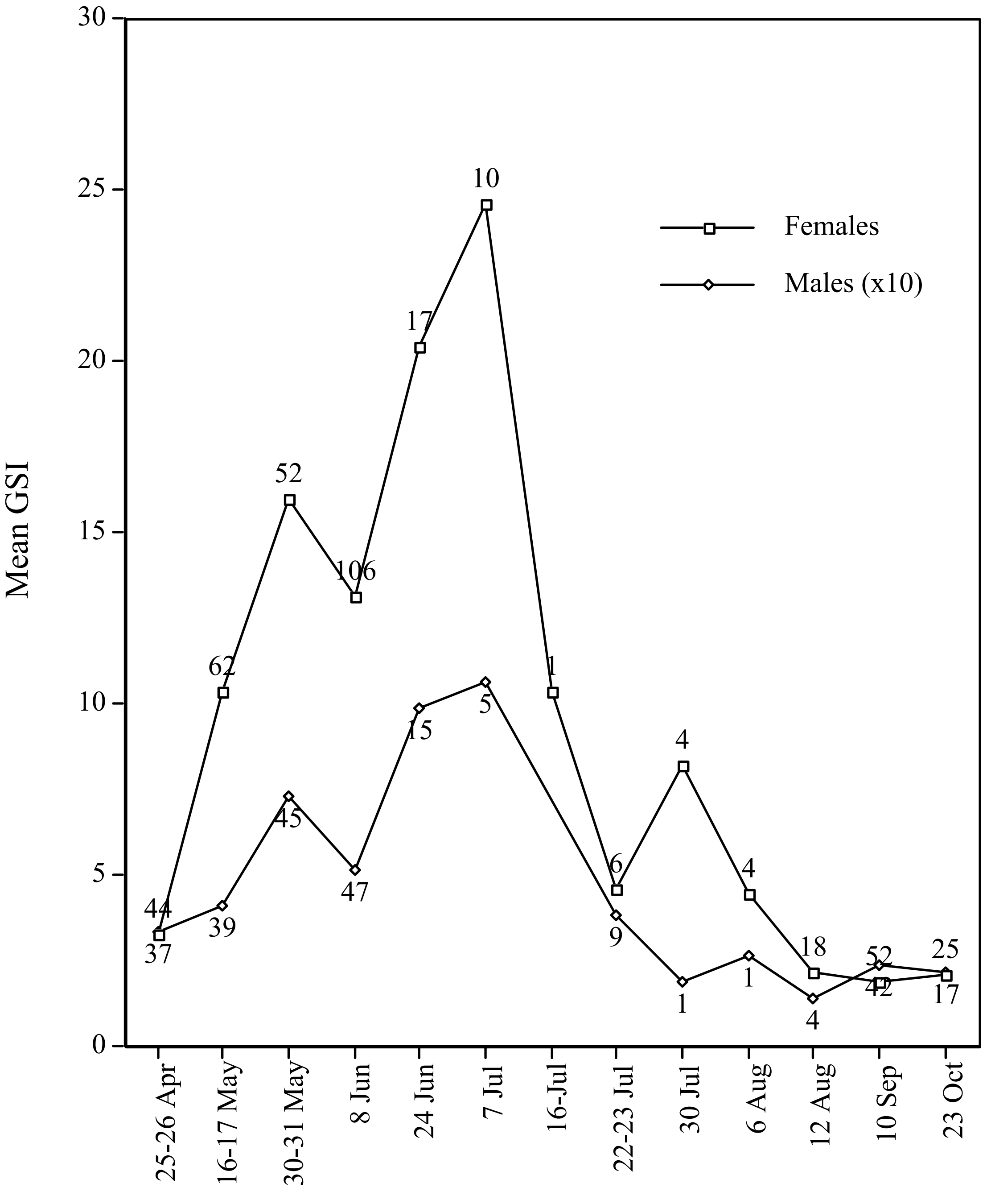

Figure 2.5: Mean gonadosomatic indices (GSI) for female and male Topeka shiners collected from 21 sites in southwestern Minnesota during 1998. Sample sizes for each mean are given. Male GSIs were multiplied x 10 to enhance visual comparisons.

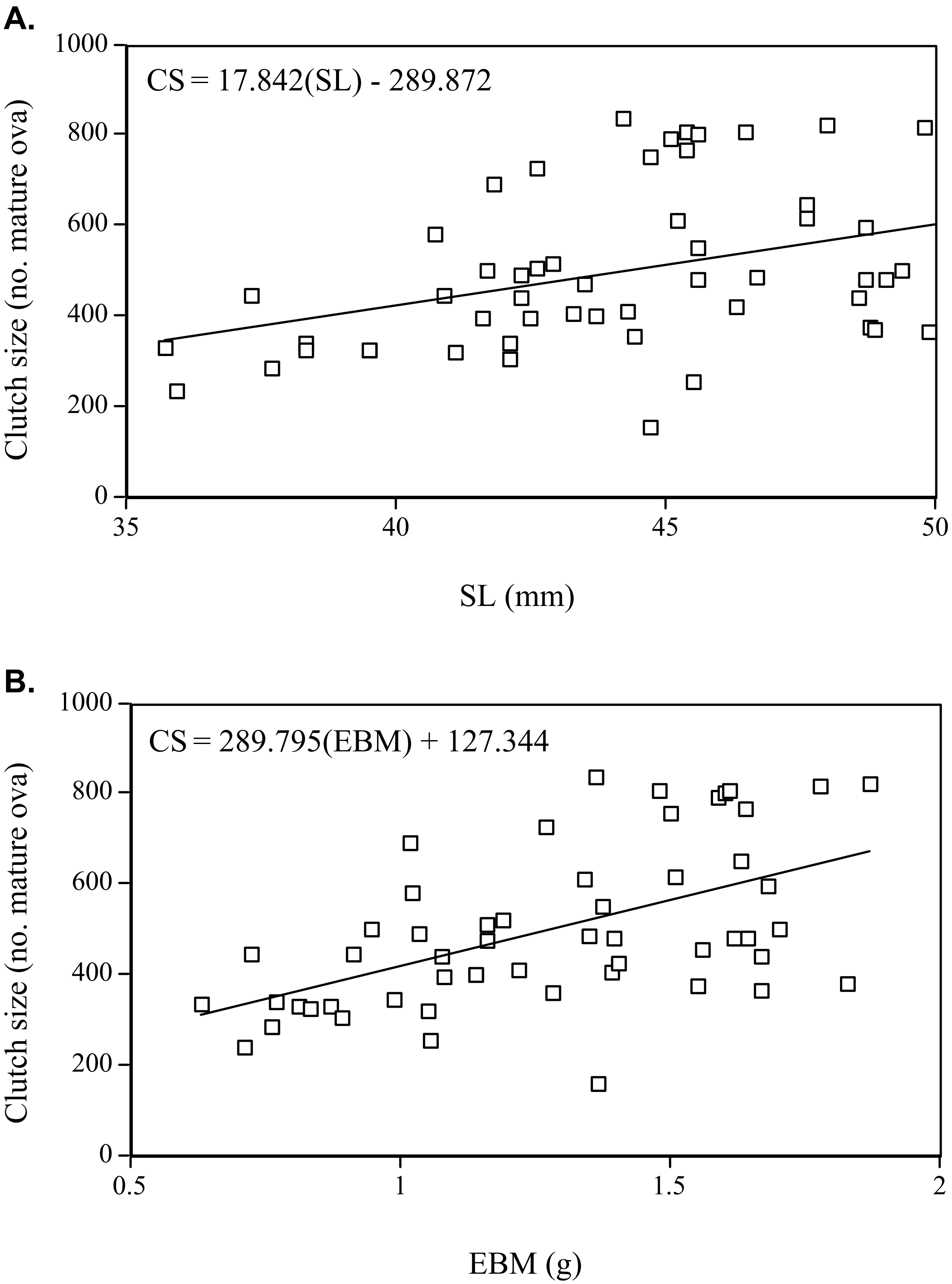

Figure 2.6: Linear regressions of clutch size (CS) by A. standard length (SL) and B. eviscerated body mass (EBM) for mature female Topeka shiners collected from 21 sites in southwestern Minnesota during 1998.

CHAPTER 3

Volumetric Analysis of Topeka Shiner Diet in Southwestern Minnesota

Introduction

The Topeka shiner (*Notropis topeka*) is a small, stout minnow found in low-order prairie streams from central Missouri and Kansas to southern Minnesota and southeastern South Dakota (Bailey and Allum 1962). In Minnesota, this species inhabits pools, slow runs, and off-channel habitats (e.g., oxbows, cutoff tributaries, and excavated ponds) of intermittent headwater streams in the southwestern corner of the state (Chapter 1). Topeka shiners live for a maximum of three years, during which males attain total lengths up to 80 mm and females up to 65 mm (Chapter 2). Adult females produce and spawn multiple-clutches of mature ova during the spawning season from about mid-May to early August (Chapter 2). During the past century, the Topeka shiner has experienced a rangewide decline in distribution and abundance, which led to its listing as federally endangered on January 14, 1999 (Tabor 1998). At present, Topeka shiners appear to be maintaining viable populations in Minnesota ; these may represent the largest, most stable population complex remaining in this species' range (Chapter 1).

Until recently, there have been no detailed published reports regarding the food habits of the Topeka shiner. Churchill and Over (1938) indicated that this species consumed "vegetation and small insects and their larvae" in South Dakota. Pflieger (1975 and 1997) suggested that it was "probably carnivorous" in Missouri. In Kansas, Cross and Collins (1995) noted "midge larvae and other aquatic insects" and invertebrates in their diet, and Kerns (1983) reported that Topeka shiners fed diurnally and were "primarily insectivorous." Hatch and Besaw (2001) concluded that this species is an opportunistic omnivore, which feeds on a variety of both benthic and nektonic food items in Minnesota.

The objective of this study was to determine the types and importance of food items in the diet of Topeka shiners from three sites in Minnesota. Dietary importance of food items was based on their percent composition by volume and frequency of occurrence in gut samples collected seasonally. This information was used to classify the Topeka shiner by feeding guild so that its ecological relationships could be discussed. This study represents the only completely quantitative analysis of Topeka shiner food habits to date.

Methods

Topeka shiners were sampled at three sites within the Big Sioux and Rock watersheds of southwestern Minnesota (Figure 3.1). Most of the streams in these watersheds were low to medium gradient, headwater streams that meandered through highly agriculturalized lands. Two sites (Sites MC and BC) were instream sites that contained pool and slow run habitats. The other site (Site LP) was a small farm pond (excavated in 1992) where Topeka shiners were accidentally introduced. The locations of the instream sites were chosen because they were known to contain relatively large populations of Topeka shiners, and the farm pond site was chosen because it represented the only known occurrence of Topeka shiners in a closed-basin system. Seining was conducted between 0800-1600 hrs CDT at two to three week intervals during the study period (i.e., April-October 1998 at Site MC, April-August 1998 at Site LP, and April-August 1999 at Site BC). For each sample from Sites MC and BC, a random subsample of 21 individuals (or all if $N < 21$) with standard length > 28 mm was anesthetized with a 0.2 g/l buffered solution of MS222. Gut contents were lavaged using a stomach pump developed for use with small fishes. A small, plastic tube attached to a syringe needle was placed in the fish's mouth and water from a syringe was slowly pumped through the gut tract, expelling gut contents through the vent. Gut contents were transferred to a small vial and preserved in 5% formalin. Fish were allowed to revive and released alive. In independent tests, this procedure was effective at removing 90% of the gut contents of nine Topeka shiners, and 15 Topeka shiners held for one week experienced a 13% mortality rate after this procedure was applied. Samples from Site LP were euthanized in the field with MS222 and preserved in 10% formalin. In the laboratory, gut contents were collected from a random subsample of 11 individuals (or all if $N < 11$) by dissection, transferred to a small vial, and preserved in 5% buffered formalin.

A volumetric technique modified from Hellawell and Abel (1971) was used to determine the bulk of each food group in the diet. A sheet of adhesive laminating paper (0.1 mm thick) was applied to a 50 x 75 mm glass plate. A 15 x 30 mm piece of laminating paper was cut out of the middle of the plate, creating a "cell" of known height. Gut contents were transferred from each vial to the cell using a micropipet. Under magnification (6-25 x), food items were sorted into piles in the cell using small mounting pins. Food items were identified to the lowest possible taxon using Eddy et al. (1982), Merritt and Cummins (1984), Pennak (1989), and Thorp and Covich (1991). Fish and invertebrates were typically identified to family or genus; however, they were grouped into higher taxa to simplify reporting. Because of difficulty in distinguishing between the two, eggs from both fish and invertebrates were lumped into one group. Plants were identified to the general groupings of filamentous algae or vascular plant matter. Vascular plant matter included whole or parts of seeds, stems, or leaves of vascular plants. Although sand did not have any nutritional value, it could not be separated from the detritus, so both were lumped into one group. Once all food items were sorted and identified, excess liquid was wicked away with a tissue and a 22 x 40 mm glass coverslip was placed over the cell to "squash" the piles to a uniform height. Hard food items were crushed with a metal probe until they were squashable. The area of each food group was enlarged (23 x) using an overhead microprojector and its outline was traced onto tracing paper. These areas were measured using an optical planimeter (± 0.001 vernier units) and converted into square millimeters. Because each food group was assumed to have uniform height (0.1 mm), volume (mm^3) could be directly calculated from the area. Using a similar method, Hellawell and Abel (1971) reported an overall error of only 3.5% for well macerated materials and up to 8% for “hard-bodied” food items. Percent composition by volume and frequency of occurrence of each food group was examined during the study period at each site to determine its relative importance in the Topeka shiner’s diet.

Results

At all three sites, a variety of both terrestrial and aquatic insects of various life-stages were consumed; however, the predominant order was Diptera, of which, the vast majority were chironomid larvae and pupae. Only the dormant stages of bryozoans and poriferans were consumed, namely statoblasts and gemmules, respectively.

Site MC.—Gut samples were examined from 137 Topeka shiners ranging from 28.1 to 62.6 mm SL. Two gut samples did not contain food. The other gut samples contained 25 different food groups including fish, a snail, insects, water mites, microcrustaceans, worms, bryozoans, poriferans, fish and invertebrate eggs, vascular plant matter, algae, and sand/detritus (Table 3.1). Five Topeka shiners consumed fish larvae, including one percid, one cyprinid, two centrarchids, and a group of 18 unidentified larvae. Fish larvae were not found in gut samples at the other two sites. The four most common food groups (*Daphnia*, Diptera, *Bosmina*, and Copepoda) comprised 83% of the total food volume. Five other food groups (sand/detritus, vascular plant matter, Bryozoa, eggs, and *Ceriodaphnia*) occurred in at least 10% of the gut samples but comprised only 11% of the total volume. The remaining 16 food groups were consumed infrequently (i.e., each occurred < 10% of the gut samples) and comprised only 6% of the total volume.

The amount and type of food consumed varied significantly during the study (Figure 3.2). Mean volume peaked during late May to early June with a second minor peak in mid-September. These peaks corresponded with influxes of microcrustaceans (*Daphnia* in particular) in the diet. Mean volume was lowest when insects were eaten most and *Daphnia* were uncommon. Microcrustaceans (which comprised 71% of the total volume) were consistently the most important food group for Topeka shiners at Site MC, followed by insects (16%), sand/detritus (4%), plants/algae (4%), eggs (2%), fish (2%), and snails (1%). All other food groups combined comprised < 1% of the total volume.

Site LP.—Gut samples were examined from 72 Topeka shiners ranging from 26.1 to 56.1 mm SL. Two guts samples did not contain food. The other gut samples contained 16 different food groups including insects, water mites, microcrustaceans, fish and invertebrate eggs, bryozoans, poriferans, vascular plant matter, algae, and sand/detritus (Table 3.2). The four most common food groups (*Bosmina*, vascular plant matter, sand/detritus, and Diptera) comprised 81% of the total food volume. Two other food groups (*Ceriodaphnia* and Copepoda) occurred in at least 10% of the gut samples but comprised only 8% of the total volume. The remaining 10 food groups were consumed infrequently and comprised only 11% of the total volume.

The type of food consumed varied during the study period at Site LP; however, mean volume did not change significantly (Figure 3.3). The food group responsible for the bulk of the diet was insects in late April, microcrustaceans in late May and mid-August, and plants/algae in late June. Microcrustaceans (which comprised 39% of the total volume) were consistently the most important food group for Topeka shiners at Site LP, followed by plants/algae (26%), sand/detritus (20%), and insects (14%). All other food groups combined comprised < 1% of the total volume.

Site BC.—Gut samples were examined from 134 Topeka shiners ranging from 33.0 to 57.9 mm SL. Three gut samples did not contain food. The other gut samples contained 25 different food groups including fish scales, clams, a snail, insects, water mites, microcrustaceans, worms, bryozoans, poriferans, fish and invertebrate eggs, vascular plant matter, algae, and sand/detritus (Table 3.3). Four of the most common food groups (Diptera, sand/detritus, vascular plant matter, and algae) comprised 79% of the total food volume. Four other food groups (*Chydorus*, parts of unidentified insects, Hydracarina, and *Bosmina*) occurred in at least 10% of the gut samples, but comprised only 8% of the total volume. The remaining 17 food groups were consumed infrequently and comprised only 13% of the total volume.

The types of food consumed varied during the study period; however, mean volume remained fairly constant except for an early June sample which was significantly lower than most of the others (Figure 3.4). Insects comprised the majority of the total volume except during early May when plants/algae were dominant and late July when sand/detritus were dominant. Insects (which comprised 51% of the total volume) were consistently the most important food group for Topeka shiners at Site BC, followed by sand/detritus (19%), plants/algae (18%), microcrustaceans (6%), worms (3%), and eggs (2%). All other food groups combined comprised < 1% of the total volume.

Discussion

In total, 75% of the Topeka shiner's diet consisted of microcrustaceans and insects; therefore, previous classifications of this species as a planktivore/insectivore were essentially correct. However, since they also consumed substantial amounts of vascular plant matter, algae, and sand/detritus, as well as various fish and other invertebrates (which consisted of at least three trophic levels), Topeka shiners should more accurately be considered generalized omnivores (Horowitz 1978), as was suggested by Hatch and Besaw (2001).

Although seasonal food availability and abundance were not measured in the field, the results suggested that Topeka shiners were probably feeding opportunistically. At Sites MC and LP, the volumetric composition of microcrustaceans peaked during late May/early June, was low during most of the summer, and peaked again in early August and early September. This pattern corresponded with expected fluctuations in the seasonal abundance of cladocerans (Pennak 1989). Site BC did not show this pattern, probably because microcrustaceans are not abundant in lotic environments (Pennak 1989). Although Site MC was a flowing system, it was located directly downstream of a large impoundment, where microcrustaceans were surely plentiful. The high variation in seasonal diet composition across populations was also indicative of opportunistic feeding. This plasticity in feeding habits is likely beneficial in the fluctuating environments of headwater prairie streams, where competition for periodically scarce food resources would be otherwise necessary (Starrett 1950).

Hatch and Besaw (2001) noted similarities in the general feeding patterns between Topeka shiners and their sister-species, the sand shiner (*N. ludibundus*), a species Starrett (1950) considered “quite omnivorous.” These two species often occurred syntopically in southwestern Minnesota streams; therefore, the opportunity for interspecific competition existed. Several studies have proposed that omnivores that feed from the same food chain (termed same-chain) should be uncommon in food webs (Hubbell 1973; May et al. 1979; Pimm 1982). Vadas (1990), however, provided several cases in which same-chain omnivory was not destabilizing in food webs, and instead, suggested three ways in which it may be favored by natural selection: 1) omnivory allows fish to feed at lower trophic levels where greater biomass and energy are available, 2) omnivores may increase food web stability by effectively shortening the length of food chains, and 3) fluctuating environments may favor generalists over specialists, thereby selecting for omnivory. If these hypotheses are true, then the co-existence of sand shiners and Topeka shiners was not necessarily detrimental. A comparative analysis of this food web may be required for a definitive answer.

Literature Cited

Bailey, R. M. and M. O. Allum. 1962. Fishes of South Dakota. Miscellaneous Publications of the Museum of Zoology, University of Michigan. 119: 68-70.

Churchill, E. P. and W. H. Over. 1938. Fishes of South Dakota. South Dakota Department of Fish and Game, Pierre. 87 pp.

Cross, F. B. and J. T. Collins. 1995. Fishes in Kansas. University of Kansas Natural History Museum, University Press of Kansas, Lawrence. 315 pp.

Eddy, S., A. C. Hodson, J. C. Underhill, W. D. Schmid, and D. E. Gilbertson. 1982. Taxonomic keys to the common animals of the north central states. Burgess Publishing Company, Minneapolis. 205 pp.

Hatch, J. T. and S. Besaw. 2001. Food use in Minnesota populations of the Topeka shiner (*Notropis topeka*). Journal of Freshwater Ecology. 16(2): 229-233.

Hellawell, J. M. and R. Abel. 1971. A rapid volumetric method for the analysis of the food of fishes. Journal of Fish Biology. 3: 29-37.

Horowitz, R. J. 1978. Temporal variability patterns and the distributional patterns of stream fishes. Ecological Monographs. 48: 307-321.

Hubbell, S. P. 1973. Populations and simple food webs as energy filters. II. Two-species systems. American Naturalist. 107: 122-151.

Kerns, H. A. 1983. Aspects of the life history of the Topeka shiner, *Notropis topeka* (Gilbert), in Kansas. Unpublished thesis. Museum of Natural History, University of Kansas, Lawrence. 32 pp.

May, R. M., J. R. Beddington, C. W. Clark, S. J. Holt, and R. M. Laws. 1979. Management of multispecies fisheries. Science. 205: 267-277.

Merritt, R. W. and K. W. Cummins (editors). 1984. An introduction to the aquatic insects of North America. Kendall/Hunt Publishing Company, Dubuque. 772 pp.

Pennak, R. W. 1989. Fresh-water invertebrates of the United States: Protozoa to Mollusca. John Wiley & Sons, Inc., New York. 628 pp.

Pflieger, W. L. 1997. The fishes of Missouri. Missouri Department of Conservation. 382 pp.

Pflieger, W. L. 1975. The fishes of Missouri. Missouri Department of Conservation. 343 pp.

Pimm, S. L. 1982. Food webs. Chapman and Hall, New York. 219 pp.

Starrett, W. C. 1950. Food relationships of the minnows of the Des Moines River, Iowa. Ecology. 31(2): 216-233.

Tabor, V. M. 1998. Final rule to list the Topeka shiner as endangered. Federal Register. 63: 69008-69021.

Thorp, J. H. and A. P. Covich (editors). 1991. Ecology and classification of North American freshwater invertebrates. Academic Press Inc., San Diego. 911 pp.

Vadas, R. L. Jr. 1990. The importance of omnivory and predator regulation of prey in freshwater fish assemblages of North America. Environmental Biology of Fishes. 27: 285-302.

Table 3.1: Summary of total volume (mm^3) and frequency of occurrence (numbers in parentheses) of food items consumed by Topeka shiners at Site MC during 1998.

Food Item	26-Apr	31-May	9-Jun	24-Jun	8-Jul	23-Jul	12-Aug	11-Sep	23-Oct	All Samples
Fish	2.1 (01)	2.3 (01)	-	-	-	-	3.8 (03)	-	-	8.1 (005)
Gastropoda	-	-	-	-	-	-	-	5.0 (01)	-	5.0 (001)
Diptera	19.5 (12)	13.1 (14)	0.4 (03)	4.9 (10)	5.8 (12)	18.2 (18)	14.0 (15)	2.7 (07)	2.3 (12)	81.0 (103)
Coleoptera	-	0.3 (01)	-	-	-	-	-	-	-	0.3 (001)
Lepidoptera	-	-	-	-	-	-	<0.1 (01)	-	-	<0.1 (001)
Trichoptera	1.1 (01)	-	-	-	-	-	0.7 (02)	-	-	1.7 (003)
Ephemoptera	0.5 (01)	-	-	-	-	-	-	-	-	0.5 (001)
Plecoptera	-	-	-	-	-	-	0.9 (01)	-	-	0.9 (001)
Collembola	-	-	<0.1 (01)	<0.1 (01)	-	-	-	-	-	<0.1 (002)
Hydracarina	0.2 (03)	<0.1 (01)	<0.1 (01)	<0.1 (01)	<0.1 (01)	-	-	-	-	0.3 (007)
Amphipoda	-	-	-	-	0.2 (01)	-	-	0.5 (01)	-	0.7 (002)
Copepoda	1.5 (05)	34.9 (12)	12.0 (11)	4.6 (11)	0.4 (07)	12.6 (11)	0.4 (15)	0.7 (08)	0.4 (07)	67.5 (087)
Diaphanosoma	-	0.7 (01)	-	<0.1 (01)	-	0.1 (02)	-	0.7 (04)	-	1.5 (008)
Daphnia	-	84.4 (13)	72.6 (11)	14.6 (09)	0.2 (05)	0.3 (08)	0.9 (09)	29.0 (13)	0.5 (08)	202.6 (076)
Ceriodaphnia	-	5.8 (04)	0.1 (02)	0.1 (01)	-	0.2 (02)	6.7 (04)	0.2 (01)	-	13.1 (014)
Bosmina	<0.1 (01)	3.0 (12)	20.6 (11)	18.3 (01)	1.1 (14)	4.6 (17)	4.0 (16)	25.2 (13)	0.8 (14)	77.6 (099)
invert. parts[1]	0.1 (02)	-	-	-	-	-	0.3 (03)	-	-	0.4 (005)
Annelida	-	-	-	1.7 (02)	1.0 (01)	-	-	0.2 (01)	-	2.9 (004)
Nematoda	-	-	-	-	-	0.5 (01)	-	-	-	0.5 (001)
Bryozoa	0.2 (03)	1.0 (11)	<0.1 (03)	<0.1 (04)	0.2 (05)	<0.1 (02)	<0.1 (01)	-	<0.1 (03)	1.5 (032)
Porifera	-	<0.1 (01)	-	<0.1 (02)	-	-	-	-	-	<0.1 (003)
eggs[2]	1.6 (08)	0.3 (01)	-	3.7 (09)	-	2.9 (03)	0.3 (02)	-	-	8.8 (023)
plant matter[3]	0.5 (04)	-	0.7 (04)	2.5 (05)	1.8 (06)	1.2 (05)	2.0 (08)	0.2 (05)	0.3 (03)	9.1 (040)
algae	0.3 (04)	-	-	9.4 (02)	-	<0.1 (01)	-	0.2 (01)	0.1 (01)	9.9 (009)
sand/detritus	10.2 (12)	0.8 (07)	0.1 (05)	4.0 (06)	1.5 (12)	0.5 (09)	0.9 (06)	2.2 (09)	<0.1 (03)	20.3 (069)
All Food Items	37.7 (12)	146.6 (14)	106.6 (11)	63.8 (14)	12.2 (17)	41.1 (19)	34.8 (19)	66.9 (13)	4.6 (16)	514.3 (135)
No. guts sampled	12	14	11	15	18	19	19	13	16	137
No. items eaten	13	13	10	15	10	12	14	12	8	25

[1] included fragmentary parts of unidentified invertebrates

[2] included eggs of unidentified fish or invertebrates

[3] included whole or parts of seeds, stems, or leaves of unidentified vascular plants

Table 3.2: Summary of total volume (mm³) and frequency of occurrence (numbers in parentheses) of food items consumed by Topeka shiners at Site LP during 1998.

Food Item	25-Apr	16-May	30-May	8-Jun	24-Jun	23-Jul	12-Aug	All Samples
Diptera	6.2 (09)	1.6 (05)	3.1 (07)	1.7 (06)	2.0 (06)	0.3 (02)	<0.1 (01)	14.8 (36)
Trichoptera	2.1 (02)	-	-	-	-	-	0.3 (01)	2.4 (03)
Ephemoptera	1.1 (01)	0.8 (02)	-	0.6 (01)	0.2 (01)	0.7 (01)	-	3.4 (06)
Hydracarina	<0.1 (01)	-	<0.1 (01)	<0.1 (02)	<0.1 (01)	<0.1 (01)	-	0.1 (06)
Copepoda	0.2 (02)	-	<0.1 (01)	0.1 (03)	0.1 (04)	-	<0.1 (01)	0.5 (11)
Diaphanosoma	-	-	-	-	-	-	0.1 (01)	0.1 (01)
Daphnia	-	-	-	-	-	-	0.1 (01)	0.1 (01)
Ceriodaphnia	-	-	0.1 (01)	0.7 (06)	0.2 (02)	0.5 (02)	9.5 (09)	10.9 (20)
Bosmina	1.9 (11)	8.6 (06)	9.4 (10)	3.7 (10)	1.6 (08)	9.5 (06)	6.7 (11)	41.5 (62)
invert. parts[1]	2.4 (01)	-	0.7 (01)	-	-	0.3 (01)	-	3.4 (03)
eggs[2]	0.4 (01)	<0.1 (01)	-	-	-	-	-	0.4 (02)
Bryozoa	-	-	<0.1 (01)	-	-	<0.1 (02)	-	<0.1 (03)
Porifera	-	-	-	-	-	<0.1 (01)	-	<0.1 (01)
plant matter[3]	2.1 (03)	6.2 (04)	1.5 (04)	3.5 (07)	16.1 (07)	2.2 (01)	-	31.5 (26)
algae	-	-	-	1.2 (01)	-	4.4 (02)	-	5.6 (03)
sand/detritus	2.9 (08)	8.7 (06)	3.3 (06)	3.6 (05)	1.3 (01)	9.7 (08)	-	29.5 (34)
All Food Items	19.2 (11)	26.0 (10)	18.2 (10)	15.1 (10)	21.4 (08)	27.6 (10)	16.7 (11)	144.3 (70)
No. guts sampled	11	10	10	10	10	10	11	72
No. items eaten	10	6	9	9	8	11	7	16

[1] included fragmentary parts of unidentified invertebrates

[2] included eggs of unidentified fish or invertebrates

[3] included whole or parts of seeds, stems, or leaves of unidentified vascular plants

Table 3.3: Summary of total volume (mm^3) and frequency of occurrence (numbers in parentheses) of food items consumed by Topeka shiners at Site BC during 1999.

Food Item	24-Apr	6-May	22-May	4-Jun	22-Jun	8-Jul	21-Jul	3-Aug	All Samples
Fish scales	-	-	-	-	<0.1 (01)	-	-	-	<0.1 (01)
Pelecypoda	-	-	-	-	-	-	-	0.2 (01)	0.2 (01)
Gastropoda	-	-	-	-	0.5 (01)	-	-	-	0.5 (01)
Hymenoptera	-	-	0.7 (01)	-	-	2.4 (02)	1.6 (04)	-	4.7 (07)
Diptera	15.7 (11)	2.0 (04)	26.3 (18)	2.7 (09)	11.5 (12)	12.6 (13)	1.9 (07)	12.5 (17)	85.3 (91)
Coeloptera	-	-	-	-	-	-	1.1 (03)	-	1.1 (03)
Trichoptera	-	-	0.9 (01)	2.0 (01)	-	0.1 (01)	-	-	3.1 (03)
Hemiptera	-	-	-	-	-	-	0.4 (01)	-	0.4 (01)
Ephemoptera	-	-	-	-	-	0.2 (01)	-	-	0.2 (01)
Collembola	<0.1 (01)	-	-	-	-	-	-	-	<0.1 (01)
insect parts[1]	0.1 (02)	-	2.8 (05)	-	0.6 (03)	1.4 (06)	3.8 (07)	2.4 (05)	11.1 (28)
Hydracarina	-	-	0.1 (01)	<0.1 (01)	<0.1 (03)	0.1 (03)	0.2 (05)	0.5 (04)	0.9 (17)
Amphipoda	-	-	-	-	2.1 (03)	0.5 (02)	-	0.4 (01)	2.9 (06)
Ostracoda	-	-	-	-	-	-	-	1.3 (01)	1.3 (01)
Copepoda	<0.1 (01)	-	-	0.1 (01)	-	-	-	1.4 (02)	1.4 (04)
Daphnia	-	-	-	-	0.1 (01)	-	-	-	0.1 (01)
Bosmina	0.1 (02)	0.1 (03)	<0.1 (01)	<0.1 (01)	<0.1 (03)	0.1 (02)	<0.1 (01)	-	0.3 (13)
Chydorus	-	-	-	-	<0.1 (01)	2.4 (10)	0.6 (05)	3.2 (13)	6.2 (29)
Annelida	-	-	-	-	3.4 (06)	0.7 (01)	2.6 (04)	-	6.7 (11)
Nematoda	-	0.1 (02)	0.1 (02)	-	<0.1 (01)	-	-	0.1 (01)	0.3 (06)
Bryozoa	-	-	-	-	-	-	0.1 (02)	-	0.1 (02)
eggs[2]	0.2 (01)	-	0.6 (04)	0.5 (01)	0.2 (01)	1.8 (04)	0.4 (01)	-	3.7 (12)
plant matter[3]	-	0.2 (01)	0.3 (02)	0.5 (02)	1.0 (08)	11.0 (15)	1.4 (08)	6.2 (12)	20.5 (48)
algae	6.2 (03)	5.9 (04)	0.2 (03)	0.2 (04)	2.7 (02)	0.8 (05)	1.9 (07)	0.1 (01)	17.9 (29)
sand/detritus	3.7 (05)	-	12.4 (15)	2.3 (12)	2.3 (08)	1.8 (07)	15.0 (11)	1.8 (05)	39.3 (63)
All Food Items	26.1 (14)	8.1 (05)	44.5 (21)	8.2 (14)	24.4 (17)	36.2 (19)	30.7 (20)	29.9 (21)	208.2 (131)
No. guts sampled	14	5	21	16	18	19	20	21	134
No. items eaten	8	5	11	9	15	14	14	12	25

[1] included fragmentary parts of unidentified insects

[2] included eggs of unidentified fish or invertebrates

[3] included whole or parts of seeds, stems, or leaves of unidentified vascular plants

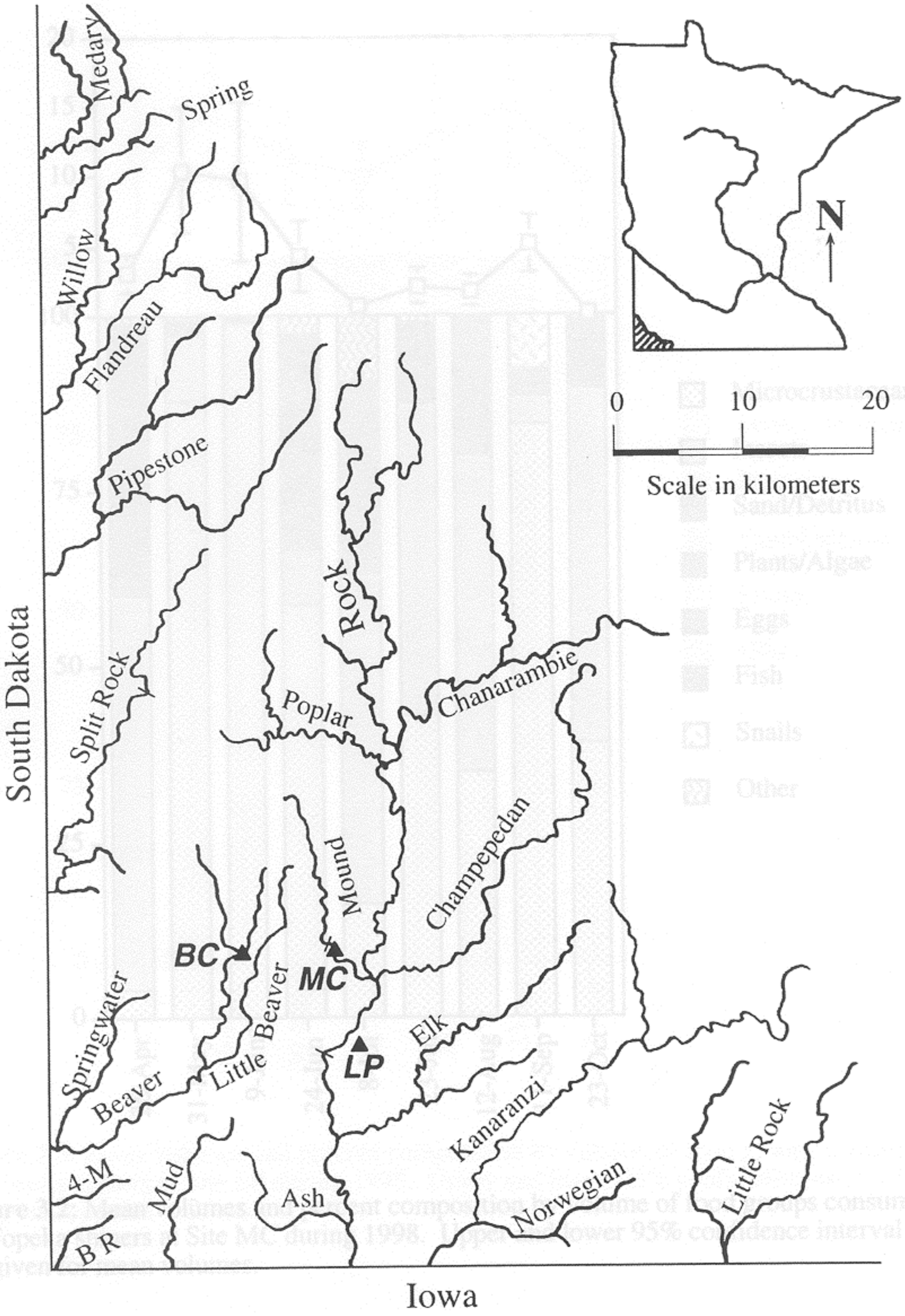

Figure 3.1: Location of food habits study sites (Sites MC, LP, and BC) in southwestern Minnesota during 1998 and 1999.

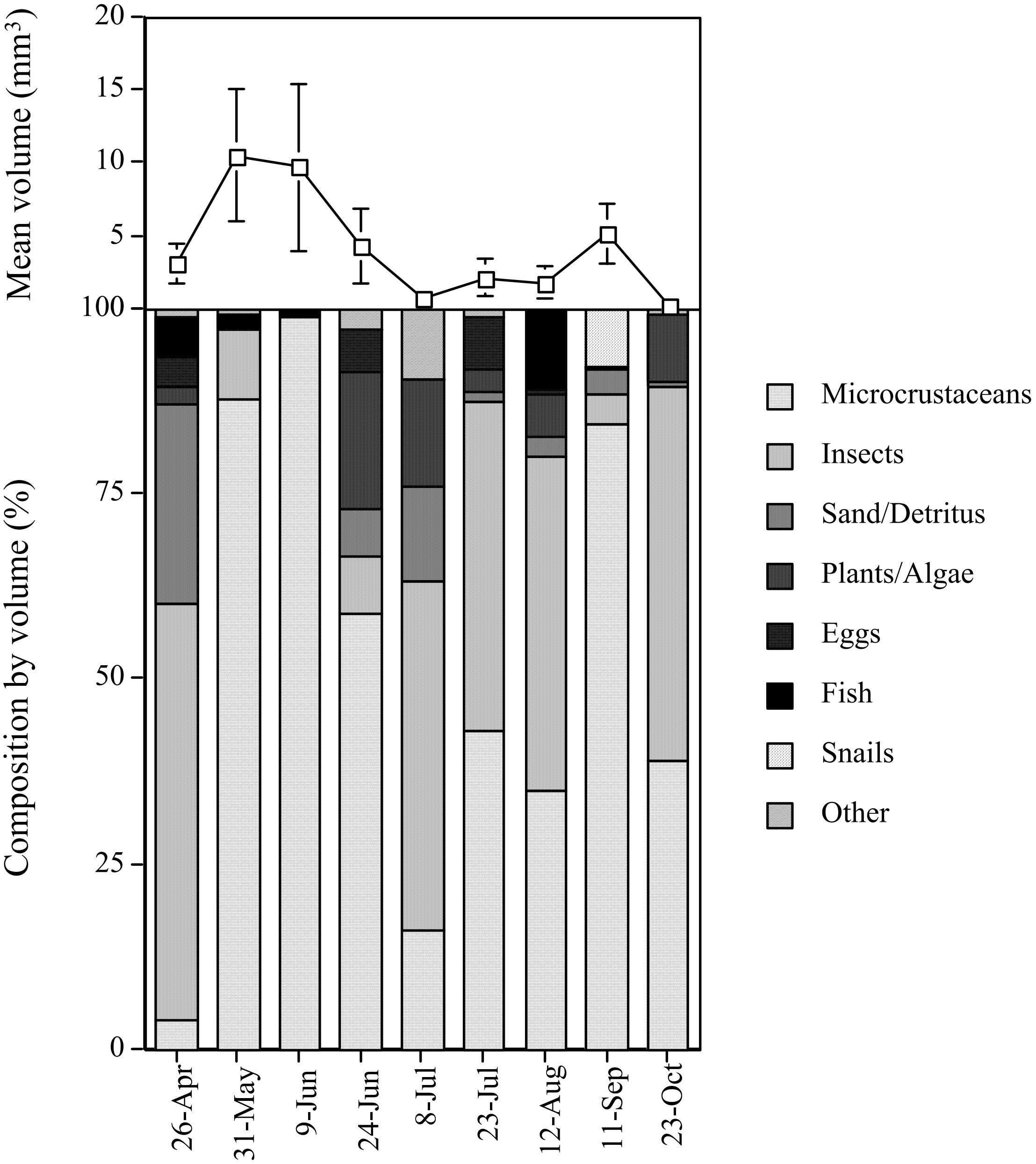

Figure 3.2: Mean volumes and percent composition by volume of food groups consumed by Topeka shiners at Site MC during 1998. Upper and lower 95% confidence interval bars are given for mean volumes.

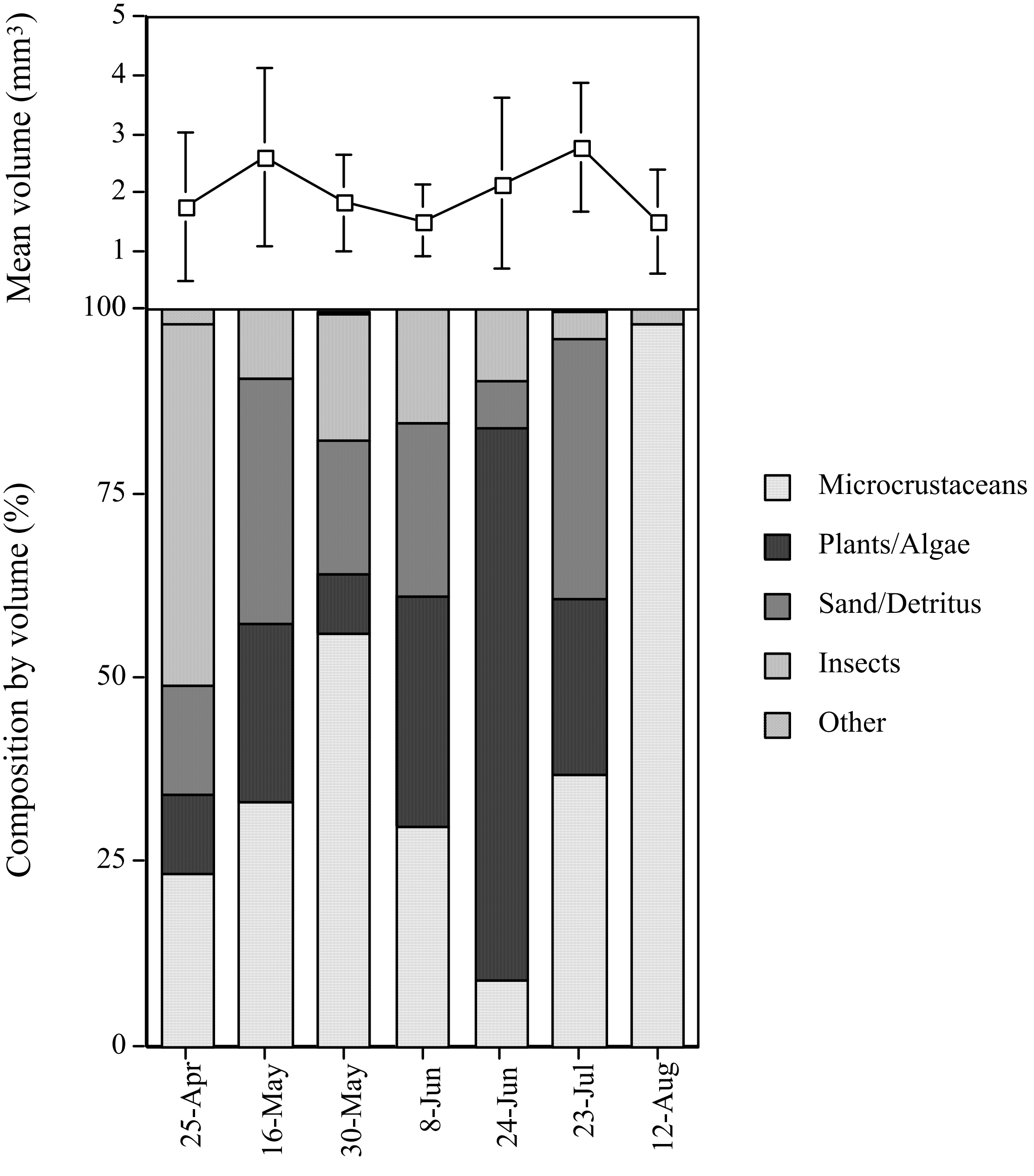

Figure 3.3: Mean volumes and percent composition by volume of food groups consumed by Topeka shiners at Site LP during 1998. Upper and lower 95% confidence interval bars are given for mean volumes.

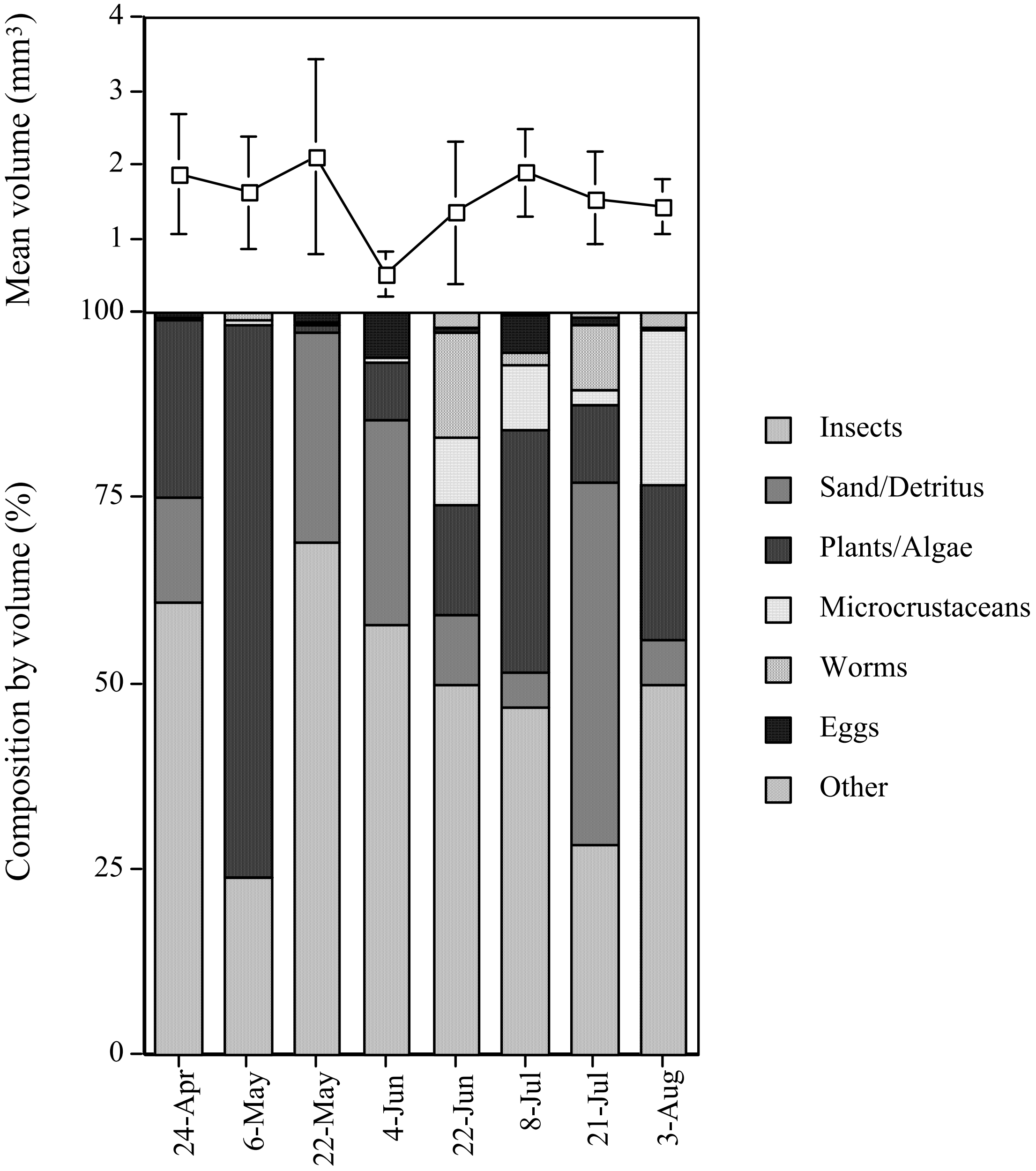

Figure 3.4: Mean volumes and percent composition by volume of food groups consumed by Topeka shiners at Site BC during 1999. Upper and lower 95% confidence interval bars are given for mean volumes.