

UNIVERSITY OF WISCONSIN-LA CROSSE

Graduate Studies

PARASITES OF CATOSTOMID FISHES FROM NAVIGATION POOLS 8 AND 9 OF
THE UPPER MISSISSIPPI RIVER (IOWA, MINNESOTA, WISCONSIN)
AND THE LOWER MISSOURI NATIONAL RECREATIONAL RIVER
(NEBRASKA, SOUTH DAKOTA)

A Manuscript Style Thesis Submitted in Partial Fulfillment of the Requirements for the
Degree of Master of Science in Biology

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(Aquatic Science Concentration)

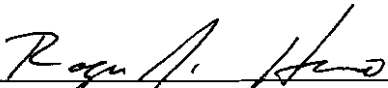
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By Jennifer L. Walker

We recommend acceptance of this thesis in partial fulfillment of this candidate's
requirements for the degree Master of Science in Biology
(Aquatic Science Concentration)

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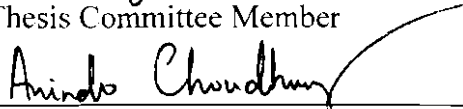
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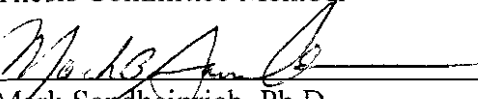
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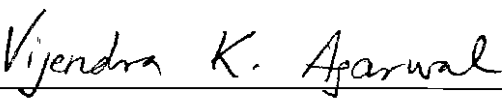
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ABSTRACT

Walker, J.L. Parasites of catostomid fishes from Navigation Pools 8 and 9 of the upper Mississippi River (Iowa, Minnesota, Wisconsin) and the lower Missouri National Recreational River (Nebraska, South Dakota). MS in Biology, May, 2007, 45 pp. R. Haro

The Mississippi River System has undergone severe alterations for navigation and flood control, and has suffered from point and non-point source pollution throughout modern times. Though parasite communities can be important indicators of habitat destruction and change, the parasite fauna of the Mississippi River System is largely unknown. In this study the parasite fauna of catostomid fishes was identified and compared between Navigation Pools 8 and 9 of the upper Mississippi River and the lower portion of the Missouri National Recreational River. A total of 141 catostomid (sucker) fishes was examined for parasites in 2003. At least 41 distinct parasitic taxa in 20 genera were identified. Suckers in Navigation Pools 8 and 9 of the upper Mississippi River harbored at least 38 different parasite species, while suckers in the Missouri National Recreational River harbored at least 18 parasite species. Two previously undescribed parasite species were recovered, and many previously described species were new records for these hosts. Results from this study provide a basis for future studies on parasites occurring in catostomids from the upper Mississippi and middle Missouri rivers.

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INTRODUCTION

Fish parasites can be sensitive indicators of the state of aquatic environments (Pietroock et al. 2001). Habitat fragmentation and degradation, the presence of toxicants, and distribution patterns of parasite hosts can be estimated by the occurrence and population structures of parasites (Marcogliese et al. 1990, Barger and Esch 2000, Weichman and Janovy 2000, Pietroock et al. 2001). Though little is known about the parasite fauna of the Mississippi and Missouri rivers, the entire Mississippi River System (MRS) has been subject to severe habitat degradation and alterations throughout modern times.

The upper Mississippi River (UMR), located between St. Anthony Falls, MN, and the Mississippi River's confluence with the Missouri River near St. Louis, MO, has been channelized and impounded by 29 locks and dams since the 1930s, and has been subject to pollution from point and non-point sources before and since (Wiener et al. 1984). Though the Missouri River supports only 6 major dams in its upper reaches, the entire watershed is used heavily for agriculture, and the lower portion of the river is channelized from Ponca, NE to its confluence with the Mississippi River near St. Louis, MO (Pflieger and Grace 1987).

A 94-km (58 mi) segment of river, located between Yankton, SD, and Ponca, NE, makes up the lower portion of the Missouri National Recreational River (MNRR) (Berry

and Young 2004). This river segment is located downstream from the last impoundment on the Missouri River and is connected to downstream parts of the Missouri and Mississippi rivers, allowing for migration of fish between these areas. Although natural flow patterns have been altered from their original state by water-level control upstream, much of the original habitat remains in this portion of the river, and this river segment remains unchannelized.

The MRS supports at least 250 fish species, 132 of which have been reported from the UMR (Fremling et al. 1989), and about 100 species have been reported from the Missouri River (Berry and Young 2004). The UMR and Missouri River support numerous species in the family Catostomidae (Appendix A). This family of fishes has been present in North America for at least 55 million years (Becker 1983). Many of the 59 catostomid species present in North America are indigenous to the MRS, often representing the majority of species in commercial catches (Becker 1983). Catostomids have become extremely diverse in the MRS; each species has adapted over thousands of years to 1 of the wide range of habitats this unique river system contains. Although this family of fishes contains both numerous and common species, such as *Moxostoma macrolepidotum* (shorthead redhorse) and *Minytrema melanops* (spotted sucker), it also includes relatively rare representatives such as *Cycleptus elongatus* (blue sucker) and *Carpiodes velifer* (highfin carpsucker) (Becker 1983, Hoffman 1999).

Catostomids are omnivorous, feeding on a wide variety of aquatic plants and animals including mollusks, small crustaceans, and insect larvae (Pflieger 1975, Becker 1983, Hoffman 1999). Most of these animals make excellent intermediate hosts for trematode, acanthocephalan, cestode, and nematode parasites, and transmission is likely

to occur through ingestion or by close proximity to these alternate hosts (Szalai et al. 1992, Hoffman 1999). Many species of catostomids attain large sizes. *Ictiobus cyprinellus* (bigmouth buffalo) commonly reaches 38-69 cm (15-27 in) and attains 14 kg (30 lbs), and *C. elongatus*, while only weighing 1-3 kg (3-5 lbs), may grow to 61 cm (24 in) or more (Pflieger 1975, Becker 1983). Host body size has been positively correlated with parasite load of individual hosts (Buchmann 1989, Lo et al. 1998, and Poulin 2000). This relationship can be expected to be very strong for intestinal parasites of catostomid fishes. As omnivores, catostomids have an intestinal tract of 2 to 3 times the length of the body. A 61-cm (24 in) fish may provide 158 cm (62 in) of mucosal habitat for various intestinal parasites. In addition to omnivorous habits, the migratory habits of catostomids are also likely to increase parasitism. Migratory fish exposed to a variety of environmental conditions exhibit higher species richness of parasites than sedentary species of fish (Caro et al. 1997, Raibaut et al. 1998). Many catostomids migrate long distances to spawning grounds through complex habitats (Pfleiger 1975). For example, *I. cyprinellus* may travel over 370 km (230 mi) during spawning migration (Becker 1983).

A wide variety of parasites have been reported from catostomid fishes (Hoffman 1999). The cestode Family Caryophyllaeidae parasitizes catostomid and cyprinid fishes, and has become highly diversified in North American catostomid fishes. In a key to 18 caryophyllaeid species from Wisconsin fishes, 14 were described from catostomid hosts (Williams 1977). Also diverse in catostomids is the trematode Family Lissorchiidae in which 18 distinct species have been described from catostomid hosts (Christensen et al. 1982, Choudhury and Nelson 1998, Hoffman 1999). Most catostomid parasite species are described from hosts that were not collected from the MRS, and many are described

from hosts collected as far away as Kentucky, California, and Manitoba (Christensen et al. 1982, Choudhury and Nelson 1998). With the abundance and availability of catostomid hosts in the MRS, it is expected that many species of parasites occur in MRS catostomids that have yet to be described.

Previous studies of the parasite fauna of the UMR and the MOR have been limited. Several historical records exist from parts of the UMR and MOR. Pearse (1924) surveyed the fish parasites in Lake Pepin (Navigation Pool 4) of the UMR. Essex and Hunter (1926) surveyed other parts of the Mississippi and Missouri rivers for fish parasites. Huggins (1959) studied parasites from fishes in South Dakota, including parts of the MOR. More recently, surveys have been conducted in southeast Wisconsin (Amin 1975, 1977, 1982), Navigation Pool 20 of the UMR (Robinson and Jahn 1980), and the upper MOR in North Dakota and northern South Dakota (Kritsky et al. 1972). While many of these surveys include a variety of host fish species, most included only a few or no catostomid host species. Kritsky et al. (1972) surveyed parasites of *Carpiodes carpio* from the Missouri River in North Dakota. Hoffman (1999) lists parasites reported from catostomid species that occur in MOR and Mississippi River tributaries, though most of these parasites were reported from hosts that were not collected in the upper Mississippi or Missouri rivers.

Catostomid fishes are widely accepted as good biological indicators (Simon and Lyons 1995). While some species are hardy and can tolerate poor environmental conditions, others are extremely sensitive to changes in habitat or water quality. Because of their sensitivity to environmental change or quality, many catostomid populations are in decline (Berry and Young 2004). Changes in parasite communities may indicate a

change in the environment well before effects become apparent in hosts. A survey of the fish parasite fauna from catostomids of the UMR and MOR was considered timely and appropriate.

Due to the abundance and species richness of catostomid fishes in the UMR and MOR, parasite species richness was expected to be high (Caro et al. 1997; Raibaut 1998). Given the catostomid family's long evolutionary history in the MRS, their parasites should have had a long evolutionary history as well, and parasite species could be expected to have diversified in parallel with their hosts. The UMR supports a high species richness of catostomids, which should have encouraged more lateral transfers of parasites between hosts and increased speciation of parasites. The UMR may also support a higher species richness of suitable intermediate hosts for catostomid parasites than the MNRR. However, the lower MNRR may serve as a refuge for some parasite species that may have been extirpated from other parts of the MRS, and may act as a refuge for intermediate hosts as well. Therefore, while higher parasite species richness was expected in the UMR, the lower MNRR was expected to support parasite species that were not found in the UMR. Unfortunately, the original distributions of parasite species from these areas will remain unknown. This study can serve as a baseline for future studies.

The goal of this study was to identify the parasite fauna occurring in catostomid fish species from Navigation Pools 8 and 9 of the UMR and the lower portion of the MNRR. Additional goals were to examine host-parasite relationships, and to compare parasite communities between host species and river systems.

MATERIALS AND METHODS

Fish were collected from Navigation Pools 8 and 9 of the UMR near La Crosse and Genoa, WI, and the lower portion of the MNRR between Ponca, NE and Yankton, SD (Figures 1 and 2). Navigation Pools 8 and 9 were chosen because of their mid-location within the lock and dam system and wide variety of habitats, including braided channels and extensive backwaters. Navigation Pool 8 has been monitored for a range of parameters since the 1980s by staff of the Upper Midwest Environmental Sciences Center (UMESC) as part of the Long Term Resource Monitoring Program (<http://www.umesc.usgs.gov/ltrmp.html>). The lower portion of the MNRR is located downstream from the last river impoundment on the MOR (Gavin's Point Dam) and contains remnants of native habitat while maintaining a connection to all parts of the river downstream.

Catostomids were collected from 2 pools of the UMR and the lower MNRR in 2003 (Table 1). Fish were collected from Navigation Pool 9 in April 2003 with fyke nets and hoop nets. Collections from Navigation Pool 8 were made in October 2003 by electroshocking, except for 7 *Ictiobus bubalus* (smallmouth buffalo) which were purchased from a commercial fisherman in December 2003. Fish were collected from the lower MNRR in June 2003 with hoop nets and by electroshocking. Identifications of host species were confirmed by keys in Becker (1983) and Pfeleger (1975). Fish from Navigation Pools 8 and 9 were transported live in plastic tubs containing river water to a laboratory and maintained in a tank with aerated well water until necropsy. All fish were

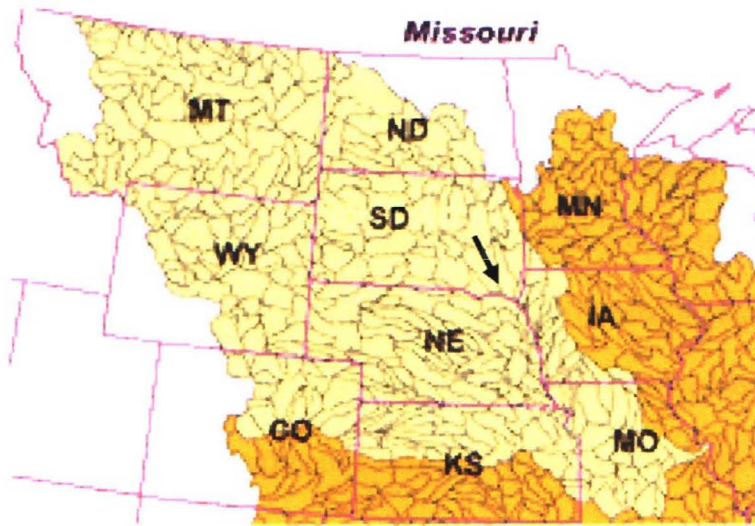


Figure 1. Drainages of the Missouri River Basin. Arrow indicates sampling area. (www.epa.gov)

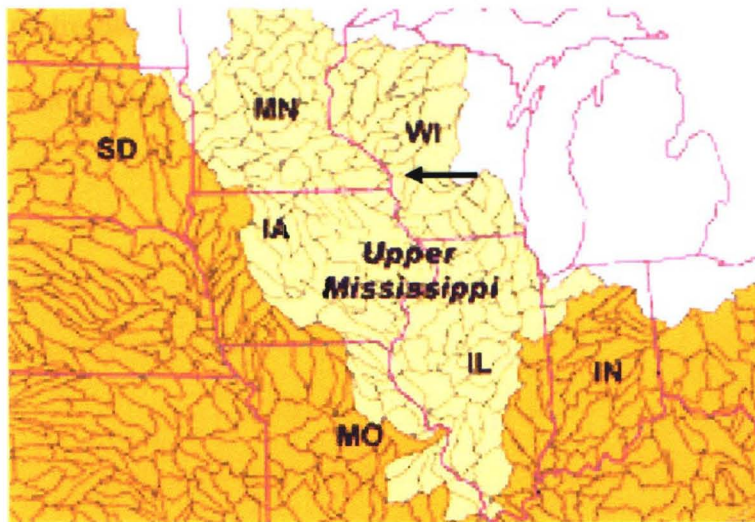


Figure 2. Drainages of the upper Mississippi River Basin. Arrow indicates sampling area. (www.epa.gov)

euthanized with an overdose of 10 mg/L to 1000 mg/L methane-tricaine sulfonate (MS-222). Fish from the MNRR were immediately examined visually for ecto- and endoparasites not found in the gills and gastrointestinal tract, respectively. Gills and gastrointestinal tracts were removed and flash frozen in supercooled ethanol (-80° C), and kept frozen until examination at a later date (Bush and Holmes 1986).

Necropsies for extracting parasites followed standard techniques described by Post (1987) and Hoffman (1999). Each fish was measured for total length and sex was recorded. External body surfaces, including fins, mouth, and gills were examined for ectoparasites. Skin and muscle tissues were examined for encysted metacercariae. The location of each parasite was recorded. Liver, heart, swim bladder, kidney, and urinary bladder were examined under a stereomicroscope for internal parasites after removal of gastrointestinal tracts. Gastrointestinal tracts were cut length-wise and examined in tap water under a stereomicroscope.

Table 1. Catostomid species collected from the upper Mississippi River Navigation Pools 8 and 9, and the lower Missouri National Recreational River

Collection site	Catostomid species	Sample size (n)
Upper Mississippi River		
Navigation Pool 8		
	<i>Carpiodes cyprinus</i> (quillback)	3
	<i>Hypentelium nigricans</i> (northern hogsucker)	1
	<i>Ictiobus bubalus</i> (smallmouth buffalo)	7
	<i>Ictiobus cyprinellus</i> (bigmouth buffalo)	3
	<i>Minytrema melanops</i> (spotted sucker)	10
	<i>Moxostoma anisurum</i> (silver redhorse)	9
	<i>Moxostoma carinatum</i> (river redhorse)	9
	<i>Moxostoma erythrurum</i> (golden redhorse)	11
	<i>Moxostoma macrolepidotum</i> (shorthead redhorse)	14
Navigation Pool 9		
	<i>Ictiobus bubalus</i> (smallmouth buffalo)	4
	<i>Minytrema melanops</i> (spotted sucker)	10
	<i>Moxostoma macrolepidotum</i> (shorthead redhorse)	10
Missouri National Recreational River		
	<i>Carpiodes carpio</i> (river carpsucker)	12
	<i>Carpiodes cyprinus</i> (quillback)	1
	<i>Carpiodes velifer</i> (highfin carpsucker)	1
	<i>Cycleptus elongatus</i> (blue sucker)	10
	<i>Ictiobus bubalus</i> (smallmouth buffalo)	3
	<i>Ictiobus cyprinellus</i> (bigmouth buffalo)	10
	<i>Moxostoma macrolepidotum</i> (shorthead redhorse)	13

Parasites were identified to genera by using keys in Hoffman (1999). Species identifications were made by using original species descriptions and reviews of genera including keys to some species (Lincicome and Van Cleave 1949, Van Cleave 1949, Van Cleave and Timmons 1951, Bullock 1963, Rogers 1966, Rogers 1967, Mackiewicz 1968, Chien 1969, Roberts 1970, Moravec and Arai 1971, Williams 1977, Cressey 1978, Williams 1978, Baker 1979, Barnhart and Powell 1979, Christensen et al. 1982, Mergo and White 1982, Amin 1985, Doyle and Gleason 1991, Hoffman 1999). Sample representatives of each species were fixed and mounted with methods described by Cable (1977) and Hoffman (1999).

The Shannon-Wiener diversity index was used to measure the diversity of parasite communities in *M. macrolepidotum* and *M. melanops* in collections where samples size was greater than 10 (Krebs 1989). The formula for the Shannon-Wiener diversity index is:

$$H' = -\sum_{i=1}^S (p_i) (\log_2 p_i)$$

where H' = the index of community diversity, S = the number of species in the community for that host, and p_i = the proportion of the relative abundance of the parasite species. Relative diversity was then calculated:

$$J = H'/H'_{\max}$$

where J = Shannon evenness, and $H'_{\max} = \log_2 S$.

Prevalence of parasites was defined as the percent of hosts infected with a species of parasite within a population (Hoffman 1999). Parasite species with greater than or equal to 50% prevalence were considered ecological core species for that host.

Ecological satellite species were parasite species occurring at a prevalence of less than

10%. Mean intensity was defined as the mean number of individuals of a parasite species per infected host (Roberts and Janovy 2000). Abundance was defined as the mean number of individuals of a parasite species in all hosts of that species examined (Hoffman 1999).

RESULTS

A total of 5,395 individual parasites was recovered from 141 catostomid fishes, ranging from 1 parasite in an individual *Carpionodes cyprinus* (quillback) collected from Pool 9 UMR, to 501 in an individual *C. elongatus* collected from the MNRR. Parasite fauna in 91 catostomid fishes from the UMR consisted of 530 (14.60%) monogeneans, 300 (8.27%) digeneans, 762 (21.00%) cestodes, 1,291 (35.57%) nematodes, 483 (13.31%) acanthocephalans, 223 (6.14%) crustaceans, 32 (0.88%) glochidia, and 8 (0.22%) leeches. Average parasite load for catostomids from the UMR was 39.9 parasites per fish host. Parasite fauna in 50 catostomids from the lower MNRR consisted of 66 (3.7%) monogenes, 319 (18.1%) digenes, 44 (2.5%) cestodes, 1282 (72.6%) nematodes, 47 (2.7%) acanthocephalans, and 7 (0.4%) crustaceans. The average parasite load for catostomids from the MNRR was 35.3 parasites per fish host.

At least 33 parasite species in 24 genera infected the 9 species of catostomid fishes representing 5 genera from Pool 8 UMR; when samples from Pool 9 are included, at least 38 parasite species occurred in these hosts from the UMR (Table 2). Host species that supported the highest parasite species richness in the UMR were *M. melanops* and *M. macrolepidotum*, with 15 and 14 distinct species, respectively (Appendix B). At least 12 distinct parasite species were found in *M. anisurum*. *Carpionodes cyprinus* and *Moxostoma carinatum* (river redhorse) each harbored at least 6 distinct parasite species in Pool 8, while *I. bubalus* harbored 6 distinct parasites from the 2 UMR pools. An individual *Hypentelium nigricans* (northern hogsucker) collected from Pool 8 supported only 1

Table 2. Parasites occurring in the Mississippi River System; prevalence in bold type indicates an ecological core species ($\geq 50\%$ prevalence) (n = host sample size)

Parasite	Host	n	Collection site	Prevalence	Mean intensity (min-max)	Abundance
Monogenea						
<i>Myzotrema cyclepti</i>	<i>Cycleptus elongatus</i>	10	MNRR	50.0	10.8 (1-26)	5.4
<i>Neodiscocotyle carpioditis</i>	<i>Carpiodes carpio</i>	12	MNRR	8.3	1.0 (1)	0.1
	<i>C. cyprinus</i>	3	Pool 8	66.7	7.5 (3-12)	5.0
	<i>C. velifer</i> *	1	MNRR	100.0	11.0 (11)	11.0
<i>Pellucidhaptor planacrus</i>	<i>Ictiobus bubalus</i>	4	Pool 9	25.0	1.0 (1)	0.25
<i>Pseudomurraytrema</i> sp.	<i>Moxostoma carinatum</i>	9	Pool 8	22.2	2.5 (1-4)	0.6
<i>Pseudomurraytrema alabarrum</i>	<i>Minytrema melanops</i>	10	Pool 8	40.0	3.5 (1-8)	1.4
		10	Pool 9	20.0	3.5 (2-5)	0.7
	<i>Moxostoma macrolepidotum</i> *	14	Pool 8	42.9	11.5 (2-41)	4.9
		10	Pool 9	60.0	3.0 (1-6)	1.8
<i>Pseudomurraytrema milleri</i>	<i>Moxostoma anisurum</i>	9	Pool 8	77.8	46.7 (2-41)	36.3
<i>Pseudomurraytrema rogersi</i>	<i>Hypentelium nigricans</i>	1	Pool 8	100.0	74.0 (74)	74.0

Table 2. Continued

Parasite	Host	n	Collection site	Prevalence	Mean intensity (min-max)	Abundance
Digenea						
<i>Hysteromorpha</i> sp.	<i>Moxostoma macrolepidotum</i> *	14	Pool 8	7.1	1.0 (1)	7.1
<i>Lissorchis</i> sp. (n. species)	<i>Minytrema melanops</i>	10	Pool 8	70.0	11.4 (2-30)	8.0
		10	Pool 9	50.0	15.4 (4-43)	7.7
<i>Lissorchis gullaris</i>	<i>Ictiobus bubalus</i> *	7	Pool 8	14.3	3.0 (3)	0.4
		4	Pool 9	25.0	1.0 (1)	0.3
	<i>I. cyprinellus</i>	3	Pool 8	66.7	5.5 (3-8)	3.7
		10	MNRR	50.0	3.2 (1-11)	1.6
<i>Lissorchis kritskyi</i>	<i>Carpionodes carpio</i>	12	MNRR	50.0	45.0 (2-127)	22.5
	<i>C. cyprinus</i> *	3	Pool 8	100.0	8.0 (2-18)	8.0
	<i>C. velifer</i> *	1	MNRR	100.0	30.0 (30)	30.0
<i>Lissorchis macropharynx</i>	<i>Moxostoma anisurum</i> *	9	Pool 8	11.1	1.0 (1)	0.1
	<i>M. carinatum</i> *	9	Pool 8	11.1	1.0 ((1)	0.1
	<i>M. macrolepidotum</i>	14	Pool 8	14.3	2.0 (1-3)	0.3
<i>Neascus</i> sp.	<i>Moxostoma macrolepidotum</i>	14	Pool 8	7.1	1.0 (1)	0.1

Table 2. Continued

Parasite	Host	n	Collection site	Prevalence	Mean intensity (min-max)	Abundance
<i>Phyllodistomum lysteri</i>						
	<i>Cycleptus elongatus</i> *	10	MNRR	10.0	2.0 (2)	0.2
	<i>Ictiobus cyprinellus</i> *	10	MNRR	10.0	1.0 (1)	0.1
	<i>Minytrema melanops</i> *	10	Pool 8	30.0	5.7 (2-12)	1.7
		10	Pool 9	30.0	26.3 (3-65)	7.9
	<i>Moxostoma anisurum</i> *	9	Pool 8	11.1	1.0 (1)	0.1
Cestoda						
Larval cestode						
	<i>Minytrema melanops</i>	10	Pool 9	10.0	1.0 (10)	0.1
	<i>Moxostoma anisurum</i>	9	Pool 8	11.1	4.0 (4)	0.4
	<i>M. macrolepidotum</i>	13	MNRR	7.7	1.0 (1)	0.1
Caryophyllaeid spp. (n. species)						
	<i>Ictiobus bubalus</i>	7	Pool 8	71.4	7.4 (1-24)	5.3
		4	Pool 9	75.0	10.3 (6-13)	7.8
		3	MNRR	66.7	2.0 (1-3)	1.3
		3	Pool 8	100.0	3.0 (1-5)	3.0
	<i>I. cyprinellus</i>	10	MNRR	20.0	1.0 (1)	0.2
Caryophyllaeid sp.						
	<i>Minytrema melanops</i>	10	Pool 9	100.0	50.1 (1-269)	50.1
	<i>Moxostoma macrolepidotum</i>	10	Pool 9	20.0	2.5 (1-4)	0.5
Caryophyllaeid spp. (immature)						
	<i>Carpiodes cyprinus</i>	1	MNRR	100.0	1.0 (1)	1.0
	<i>Minytrema melanops</i> §	10	Pool 8	-	-	-
	<i>Moxostoma anisurum</i> §	9	Pool 8	-	-	-
	<i>M. macrolepidotum</i>	13	MNRR	15.4	1.0 (1)	0.2

Table 2. Continued

Parasite	Host	n	Collection site	Prevalence	Mean intensity (min-max)	Abundance
<i>Biacetabulum</i> sp.	<i>Minytrema melanops</i> §	10	Pool 8	-	-	-
		10	Pool 9	-	-	-
	<i>Moxostoma anisurum</i> §	9	Pool 8	-	-	-
<i>Biacetabulum carpiodi</i>	<i>Carpionodes carpio</i> §	12	MNRR	-	-	-
<i>Isoglaridacris</i> sp.	<i>Moxostoma erythrurum</i>	1	Pool 8	36.4	7.5 (1-16)	2.7
<i>Isoglaridacris wisconsinensis</i>	<i>Moxostoma anisurum</i> *§	9	Pool 8	-	-	-
<i>Monobothrium</i> sp.	<i>Moxostoma anisurum</i> §	9	Pool 8	-	-	-
<i>Promonobothrium minytremi</i>	<i>Minytrema melanops</i> §	10	Pool 8	-	-	-
		10	Pool 9	-	-	-
<i>Spartoides wardi</i>	<i>Carpionodes carpio</i> §	12	MNRR	-	-	-
	<i>C. cyprinus</i>	3	Pool 8	66.7	14.5 (10-19)	9.7
	<i>C. velifer</i> *	1	MNRR	100.0	34.0 (34)	34.0

Table 2. Continued

Parasite	Host	n	Collection site	Prevalence	Mean intensity (min-max)	Abundance
Nematoda						
<i>Camallanus ancylostirus</i>						
	<i>Carpiodes carpio</i>	12	MNRR	8.3	1.0 (1)	0.1
	<i>C. cyprinus</i>	3	Pool 8	66.6	4.0 (8-10)	2.7
		1	MNRR	100.0	2.0 (2)	2.0
	<i>Cycleptus elongatus*</i>	10	MNRR	10.0	1.0 (1)	0.1
	<i>Ictiobus bubalus</i>	7	Pool 8	57.1	3.3 (1-7)	1.9
		4	Pool 9	25.0	2.0 (2)	0.5
		3	MNRR	33.3	2.0 (2)	0.7
	<i>I. cyprinellus</i>	10	MNRR	20.0	2.0 (1-3)	0.4
	<i>Moxostoma carinatum*</i>	9	Pool 8	22.2	3.0 (2-4)	0.7
	<i>M. erythrurum</i>	11	Pool 8	9.1	1.0 (1)	9.1
	<i>M. macrolepidotum</i>	14	Pool 8	7.1	2.0 (2)	0.2
		10	Pool 9	30.0	1.3 (1-2)	0.4
		13	MNRR	38.5	2.4 (1-7)	0.9
<i>Rhabdochona milleri</i>						
	<i>Cycleptus elongatus*</i>	10	MNRR	80.0	103.4 (1-501)	82.7
	<i>Moxostoma anisurum*</i>	9	Pool 8	11.1	1.0 (1)	0.1
	<i>M. macrolepidotum</i>	14	Pool 8	35.7	15.8 (7-31)	5.6
		10	Pool 9	80.0	57.5 (12-153)	46.0
		13	MNRR	92.3	30.9 (2-99)	28.5
Nematode sp.						
	<i>Ictiobus bubalus</i>	4	Pool 9	25.0	4.0 (4)	1.0

Table 2. Continued

Parasite	Host	n	Collection site	Prevalence	Mean intensity (min-max)	Abundance
Nematode sp. (encysted)						
	<i>Carpiodes cyprinus</i>	3	Pool 8	66.7	350.0 (300-400)	233.3
	<i>Ictiobus bubalus</i>	3	MNRR	33.3	20.0 (20)	6.7
	<i>I. cyprinellus</i>	10	MNRR	10.0	42.0 (42)	4.2
	<i>Moxostoma macrolepidotum</i>	10	Pool 9	30.0	10.3 (3-15)	3.1
	<i>Minytrema melanops</i>	10	Pool 9	30.0	1.3 (1-2)	0.4
Acanthocephala						
<i>Pomphorhynchus bulbocolli</i>						
	<i>Ictiobus cyprinellus</i>	3	Pool 8	33.3	2.0 (2)	0.7
		10	MNRR	10.0	22.0 (22)	2.2
	<i>Moxostoma anisurum</i> *	9	Pool 8	22.2	2.5 (1-4)	0.6
	<i>M. carinatum</i>	9	Pool 8	100.0	6.6 (1-11)	6.6
	<i>M. erythrurum</i>	11	Pool 8	45.5	14.0 (3-46)	6.4
	<i>M. macrolepidotum</i>	14	Pool 8	78.6	22.9 (1-143)	18.0
		10	Pool 9	30.0	2.3 (1-5)	0.7
<i>Neoechinorhynchus prolixoides</i>						
	<i>Carpiodes carpio</i> §	12	MNRR	-	-	-
	<i>Minytrema melanops</i> §	10	Pool 9	-	-	-
	<i>Moxostoma erythrurum</i> *§	11	Pool 8	-	-	-
	<i>M. macrolepidotum</i> §	10	Pool 9	-	-	-
<i>Neoechinorhynchus prolixus</i>						
	<i>Carpiodes carpio</i> *§	12	MNRR	-	-	-
	<i>Minytrema melanops</i> §	10	Pool 9	-	-	-
	<i>Moxostoma macrolepidotum</i> §	10	Pool 9	-	-	-

Table 2. Continued

Parasite	Host	n	Collection site	Prevalence	Mean intensity (min-max)	Abundance
<i>Neoechinorhynchus distractus</i>						
	<i>Minytrema melanops</i> *	10	Pool 8	10.0	1.0 (1)	0.1
	<i>Moxostoma erythrurum</i> *§	11	Pool 8	-	-	-
	<i>M. carinatum</i> *	9	Pool 8	11.1	1.0 (1)	0.1
<i>Leptorhynchoides thecatus</i>						
	<i>Minytrema melanops</i>	10	Pool 8	10.0	1.0 (1)	0.1
Crustacea						
<i>Argulus appendiculosus</i>						
	<i>Ictiobus cyprinellus</i>	10	MNRR	10.0	1.0 (1)	0.1
	<i>Minytrema melanops</i> *	10	Pool 8	10.0	1.0 (1)	0.1
		10	Pool 9	10.0	3.0 (3)	0.3
	<i>Moxostoma macrolepidotum</i> *	14	Pool 8	7.1	1.0 (1)	0.1
<i>Argulus catostomi</i>						
	<i>Ictiobus cyprinellus</i> *	3	Pool 8	33.3	1.0 (1)	0.3
<i>Ergasilus</i> sp.						
	<i>Cycleptus elongatus</i>	10	MNRR	20.0	1.5 (1-2)	0.3
<i>Ergasilus versicolor</i>						
	<i>Carpionodes cyprinus</i> *	3	Pool 8	33.3	5.0 (5)	1.7
	<i>Ictiobus cyprinellus</i>	3	Pool 8	100.0	5.0 (1-10)	5.0
	<i>I. bubalus</i>	7	Pool 8	71.4	2.0 (1-5)	1.4
	<i>Moxostoma carinatum</i> *	9	Pool 8	100.0	9.3 (1-63)	9.3
	<i>M. macrolepidotum</i>	14	Pool 8	7.1	1.0 (1)	7.1
	<i>M. anisurum</i> *	9	Pool 8	66.7	3.5 (2-7)	2.3
	<i>M. erythrurum</i> *	11	Pool 8	54.5	6.0 (1-16)	3.3
	<i>Minytrema melanops</i>	10	Pool 8	70.0	6.4 (2-15)	4.5

Table 2. Continued

Parasite	Host	n	Collection site	Prevalence	Mean intensity (min-max)	Abundance
<i>Lernaea sp.</i>	<i>Carpiodes velifer</i> *	1	MNRR	100.0	2.0 (2)	2.0
	<i>I. cyprinellus</i>	10	MNRR	10.0	1.0 (1)	0.1
Hirudinea	<i>Moxostoma anisurum</i>	9	Pool 8	22.2	4.0 (1-7)	0.9
Mollusca (glochidia)	<i>Minytrema melanops</i> *	10	Pool 8	10.0	1.0 (1)	0.1
		10	Pool 9	10.0	2.0 (2)	0.2
	<i>Moxostoma macrolepidotum</i>	10	Pool 9	50.0	5.8 (1-21)	2.9

*indicates a new host record for that species according to Hoffman (1999)

§ indicates a mixed fauna of parasite species; individual species parameters were unable to be determined

parasite species. Eighteen parasite species were unique to the UMR. Of these unique species, 11 were recovered from hosts not collected in the lower MNRR.

At least 19 parasite species in 16 genera infected catostomids from 7 species in 4 genera from the lower MNRR (Table 2). Host species supporting the highest number of parasite species were *I. cyprinellus*, with at least 8 distinct taxa, and *Carpiodes carpio* (river carpsucker), supporting at least 6 distinct parasite taxa. Three parasite species were unique to catostomids collected from the MNRR. Of these species, 2 were recovered from hosts that were not found in collections from Pool 8 UMR.

Parasite species richness and number of host species in that host genus were not significantly correlated with one another for Pool 8 UMR ($r = 0.815$, $n = 5$, $p = 0.093$), nor were these factors significantly correlated with one another for the lower MNRR ($r = -0.355$, $n = 4$, $p = 0.645$). Parasite species richness and host length (for species where sample size was 10 or greater) were not significantly correlated with one another for either Pool 8 UMR ($r = 0.120$, $n = 31$, $p = 0.519$), or the lower MNRR ($r = 0.104$, $n = 22$, $p = 0.645$). Although parasite species richness was significantly correlated with the sample size of host species for Pool 8 UMR ($r = 0.717$, $n = 9$, $p = 0.030$), parasite species richness was not significantly correlated with the sample size of host species for the lower MNRR ($r = 0.591$, $n = 7$, $p = 0.162$).

Diversity measures showed similar results in two catostomid species for Pool 8 and Pool 9 UMR (Table 3). Pool 8 UMR had the highest values for the Shannon-Wiener Index (H') and Shannon evenness (J), which demonstrated that parasite communities in these catostomids from Pool 8 were more evenly distributed and higher in species richness than parasites in these species from Pool 9 and the MNRR.

Table 3. Species diversity measures for catostomid parasites in the Mississippi River System

Sampling site	Host species	S ¹ (total # of species)*	H ²	J ³
Pool 8, UMR	<i>M. macrolepidotum</i>	9	2.5	0.788
	<i>M. melanops</i>	9	2.78	0.878
Pool 9, UMR	<i>M. macrolepidotum</i>	8	1.45	0.483
	<i>M. melanops</i>	9	1.49	0.469
Lower MNRR	<i>M. macrolepidotum</i>	4	0.29	0.143

*species were pooled for parasite genera with mixed fauna of parasites

¹number of parasite species in the community for that host

²index of community diversity

³Shannon evenness

While parasite species richness was comparable in catostomids for both Pools 8 and 9, abundance of parasites was more evenly distributed in Pool 8 than in either Pool 9 or the MNRR (Table 2). Species richness and species evenness was lowest for the MNRR. Relative abundance of parasites in *M. macrolepidotum* was more even in Pool 8, while both Pool 9 and the MNRR appeared to be dominated in abundance by a single parasite species. This dominant species was *Rhabdochona milleri* in *M. macrolepidotum* from Pool 9 UMR and the MNRR.

Fifteen ecological core parasite species and 5 satellite species were identified from 9 host species in the UMR. *Camallanus ancyloDIRUS* was a core species in some

hosts and a satellite species in other hosts. The same was true of *Ergasilus versicolor*. The lower MNRR supported 10 core species and 2 satellite species. *Neodiscocotyle carpioditis*, and *C. ancyloides* were both core and satellite species for different hosts. Six species were core parasites in catostomid fishes for both Pool 8 UMR and the lower MNRR: *C. ancyloides*, *Lissorchis gullaris*, *L. kritskyi*, *N. carpioditis*, *Spartoides wardi*, and an unidentified caryophyllaeid species recovered from both *Ictiobus* species. This species was proposed in this study to represent a new species, possibly belonging to the Genus *Hypocaryophyllaeus* (Figures 3 and 4). *Camallanus ancyloides*, *L. gullaris*, and the new caryophyllaeid species were core species for the same hosts in both rivers, although *C. ancyloides* was also a core species for other hosts. All core species occurred in at least 1 other host except *Pseudomurraytrema rogersi*, found only in *H. nigricans*; *Pseudomurraytrema milleri*, found only in *M. anisurum*, and a previously undescribed *Lissorchis* species which appeared to be specific to *M. melanops* (Figure 5). In the UMR, *E. versicolor* was the most prevalent parasite species, infesting 8 host species in 4 genera (Figure 6). Of these 8 host species, 6 species in 3 genera supported *E. versicolor* as a core parasite (greater than 50% prevalence). *Pomphorhynchus bulbocolli* was the second most prevalent parasite infecting 5 host species in 2 genera, and was found in 2 host species as a core parasite (78.6 % prevalence). *Camallanus ancyloides* occurred in 5 host species in 3 genera (Figure 7). This parasite was a core species for *C. cyprinus* (66.6% prevalence) and *I. bubalus* (57.1% prevalence). *Lissorchis* spp., *Pseudomurraytrema* spp., and caryophyllaeid tapeworms also infected a wide range

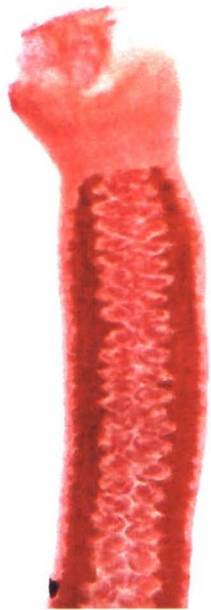


Figure 3. Proposed new
Caryophyllaeidae species – anterior
end of acetocarmine stained
whole mount



Figure 4. Proposed new
Caryophyllaeidae species – posterior
end of acetocarmine stained whole
mount



Figure 5. Proposed new *Lissorchis* species – acetocarmine stained whole mount



Figure 6. *Ergasilus versicolor* – acetocarmine stained whole mount



Figure 7. *Camallanus ancylodirus* - anterior end of whole mount showing chitinous valves

of hosts at moderate to high prevalence, and were often core species for those hosts (Table 2). In the lower MNRR, *C. ancylodirus* was the most prevalent species, infecting 6 host species in 4 genera (Figure 7). Caryophylleid tapeworms were the only other group infecting 5 or more host species. Most core species in the lower MNRR infected only 1 or 2 catostomid species.

The parasite infrapopulation from Pool 8 UMR was made up of 68.7% endoparasites, and 31.3% ectoparasites. Parasites with indirect life cycles were more common in Pool 8 UMR (59.3%) than parasites with direct life cycles (40.7%). Endoparasites dominated in the lower MNRR making up 96.0% of the total infrapopulation, while only 4.0% of total parasites were ectoparasites. Ninety-three percent of the total parasite infrapopulation from the lower MNRR were species exhibiting an indirect life cycle, while 6.6% of parasites had direct life cycles.

This survey identified 2 proposed new species. The first of these was a tapeworm in the Family Caryophyllaeidae collected from both rivers in *I. bubalus* and *I. cyprinellus* (Figures 3 and 4). Its morphological characteristics resembled *Hypocaryophyllaeus* more closely than other caryophyllaeid genera, but did not match the generic description (Hoffman 1999), and did not match any species descriptions (Williams 1977, Williams 1978). Another possible new species was a *Lissorchis* species collected from *M. melanops* (Figure 5). Its morphology resembled *Lissorchis mutabile* described from *Erimyzon succetta* (lake chubsucker) more closely than other lissorchids described from *M. melanops*. No known exotic parasites were identified in this study.

DISCUSSION

Despite alterations from its natural state, the MRS supported a diverse parasite fauna in catostomid fishes. These results are encouraging. One might expect to find fragmented parasite communities with little or no interaction between hosts and parasites (Barger and Esch 2000, Weichman and Janovy 2000). Instead, results were consistent with the hypotheses of species-rich parasite communities with higher species richness occurring in the UMR, and some novel species from the lower MNRR. Parasite communities in both rivers showed evidence of interaction between parasites and host species, suggesting healthy and resilient ecosystems.

Sample size appeared to be the limiting factor in determining species richness for Pool 8 UMR. In addition to small sample sizes for some host species, some catostomids known to occur in these parts of the MRS were not collected. Seven of 8 catostomid species occurring in the lower MNRR were collected. However, 3 of those 7 host species had sample sizes of 3 or fewer. To provide an accurate picture of the catostomid parasite fauna from these areas, all catostomid species occurring in pools of the UMR and the lower MNRR should be examined in adequate sample sizes.

A checklist of catostomid parasites and their hosts for these parts of the MRS has not been previously established. Host collections and examination for parasites, preparation of parasites, and identification to species level are labor intensive, costly, and require a high level of expertise in parasitology. Because the goals of this study were to obtain baseline information about catostomid parasite fauna and begin construction of a

host and parasite checklist for the MRS, larger sample sizes were sacrificed to include more host and parasite species.

High parasite species richness has been correlated with the occurrence of several closely related host species in the same environment (Caro et al. 1997, Raibaut 1998). The UMR supported 5 representative species of *Moxostoma* in this study, all of which were high in parasite species richness. The proximity in Pools 8 and 9 of many species in the same genus likely encouraged speciation of moxostomid parasites through lateral transfers, as well as through coevolution of new parasite and host species. Interestingly, *Minytrema melanops* supported the highest parasite species richness in the UMR, and it is the only species occurring in that genus.

In this study 2 new parasite species were recovered. Both the unidentified *Lissorchis* sp. from *M. melanops* (spotted sucker) and the new species of Caryophyllaeid from *I. bubalus* and *I. cyprinellus* were ecological core species for these hosts. This suggests that these were not accidental host-parasite interactions, and that host associations with these parasites were well established in the MRS. The fact that the lissorchid found in *M. melanops* more closely resembled lissorchids described from *Ermizon* species suggests that these lissorchids shared a common ancestor either in *Ermizon* species or in *M. melanops*. These 2 host species may have had an overlap in diet and/or habitat that allowed this ancestor to exist in both hosts, or allowed the transfer of the parasite from one host species to another. This may also be the case for the new caryophyllaeid species found in both *Ictiobus* (buffalo) species. Caryophyllaeid species were found in all genera of the catostomid family from the MRS. Overlaps in diet and habitat may have encouraged transfer of a parasite and speciation in buffalo. Because

this parasite occurred in both *Ictiobus* species, coevolution of hosts and parasite in conjunction with parasite transfer to a new host species is likely.

Parasites with indirect life cycles that were identified in this survey were nematodes, acanthocephalans, digenetic trematodes, and cestodes. The presence of these parasites indicates the presence of numerous aquatic invertebrates which serve as intermediate hosts in the UMR and in the lower MNRR such as sphaerid (fingernail) clams, ancyloid snails, and numerous types of copepods, aquatic insects, ostracods, amphipods, and oligochaete worms. Several of these intermediate hosts are well known as indicators of a healthy environment. For example, the presence of *R. milleri* in both pools of the UMR and the MNRR shows that trichoptera larvae, which are highly sensitive to environmental change and degradation, were abundant in these environments and that conditions were favorable for transmission.

The intensities and abundance of parasites, together with knowledge of its intermediate hosts can reveal subtle differences between habitats within the same river system. The higher intensities and abundances of *R. milleri* in *C. elongatus* and *M. macrolepidotum* from the lower MNRR, and in *M. macrolepidotum* from Pool 9 UMR show that trichoptera larvae are a major part of the diet of these fish in Pool 9 and the lower MNRR at the time of collection. Perhaps trichoptera larvae were not as readily available as food items in Pool 8 previous to sampling, or conditions were not favorable for transmission of free-living larval stages than in Pool 9 and the MNRR at the times of collection.

Seasonal changes may account for differences in all parasite populations between pools. Pool 8 was sampled in October, while Pool 9 and the lower MNRR were sampled

in spring and early summer. While *R. milleri* was not as highly prevalent and was recovered in lower intensities in Pool 8 when compared to Pool 9 UMR and the MNRR, *E. versicolor* was the most highly prevalent parasite in Pool 8 UMR. This parasite was not found to infest catostomids from Pool 9 earlier in the year, while only 1 ergasilid was recovered from catostomids in June from the MNRR, even though the same hosts were readily available at both locations. Seasonality may be the largest factor in determining differences between Pools in this study.

This study provides a good baseline for comparison of catostomid parasite communities in future studies. Further studies should focus on a few parasite or host species, such as the taxonomic position of the proposed new parasite species discovered in these collections, or the diversity of monostomid parasites found in the UMR. Without previous data on the parasite fauna of the MRS, it was impossible to deduce what effects changing environmental conditions have had on parasite communities and how interactions between hosts and parasites have been affected over time. Having some knowledge of the parasite fauna and communities of the MRS is likely to encourage future exploration of interactions between these hosts and parasites.

REFERENCES

- Amin, O. M. 1975. Intestinal helminths of some Southeastern Wisconsin fishes. *Proceedings of the Helminthological Society of Washington* 42:43-46.
- Amin, O. M. 1977. Distribution of fish parasites from two Southeast Wisconsin streams. *Wisconsin Academy of Sciences, Arts and Letters* 65:225-230.
- Amin, O. M. 1982. Two larval trematodes (Strigeoidea) of fishes in Southeastern Wisconsin. *Proceedings of the Helminthological Society of Washington* 49:207-213.
- Amin, O. M. 1985. Acanthocephala from lake fishes in Wisconsin: *Neoechinorhynchus robertbaueri* n. sp. From *Erimyzon sucetta* (Lacépède), with a key to species of the genus *Neoechinorhynchus* Hamann, 1892, from North American freshwater fishes. *Journal of Parasitology* 71:312-318.
- Bailey, P. A. and R. G. Rada. 1984. Distribution and enrichment of trace metal (Cd, Cr, Cu, Ni, Pb, Zn) in bottom sediments of Navigation Pools 4 (Lake Pepin), 5, and 9 of the Upper Mississippi River. Pages 119-138 in J. G. Wiener, R. V. Anderson, and D. R. Conville, eds. *Contaminants in the Upper Mississippi River*. Butterworth Publishers, Boston, MA.
- Baker, M. R. 1979. Redescription of *Camallanus ancyloDIRUS* Ward and Magath 1916 (Nematoda: Camallanidae) from freshwater fishes of North America. *Journal of Parasitology* 65:389-392.
- Barger, M. A. and G. W. Esch. 2000. Downstream changes in the composition of the parasite community of fishes in an Appalachian stream. *Journal of Parasitology* 87:250-255.
- Barnhart, M. C. and E. C. Powell. 1979. *Lissorchis kritskyi* sp. n. (Digenea: Lissorchiidae) from the river carpsucker, *Carpionodes carpio* (Rafinesque). *Proceedings of the Helminthological Society of Washington* 46:47-51.
- Becker, G. C. 1983. *Fishes of Wisconsin*. The University of Wisconsin Press, Madison, WI. 1052 pp.

- Berry, C. R., Jr. and B. Young. 2004. Fishes of the Missouri National Recreational River, South Dakota and Nebraska. *Great Plains Research* 14:89-114.
- Buchmann, K. 1989. Relationship between host size of *Anguilla anguilla* and the infection level of the monogeneans *Pseudodactylogyus* spp. *Journal of Fish Biology* 35:599-601.
- Bullock, W. L. 1963. *Neoechinorhynchus prolixoides* n. sp. (Acanthocephala) from North American fishes. *Proceedings of the Helminthological Society of Washington* 30:92-96.
- Bush, A.O. and J.C. Holmes. 1986. Intestinal helminthes of lesser scaup ducks: patterns of association. *Canadian Journal of Zoology* 64:132-141.
- Cable, R. M. 1977. *An illustrated lab manual of parasitology*. 5th edition. Burgess Publishing Company. Minneapolis, MN.
- Caro, A., C. Combes, and L. Euzet. 1997. What makes a fish a suitable host for Monogenea in the Mediterranean? *Journal of Helminthology* 71:203-210.
- Chien, S. M. 1969. Monogenean parasites of *Hypentelium nigricans* with description of a new species. *Journal of Parasitology* 55:737-739.
- Christensen, B. M., P. K. Wellner, and L. N. Gleason. 1982. Two new species of *Lissorchis* Magath (Digenea: Lissorchiidae) from the spotted sucker, *Minytrema melanops* (Rafinesque), with a key to species. *Proceedings of the Helminthological Society of Washington* 49:22-27.
- Choudhury, A. and P. A. Nelson. 1998. *Lissorchis macropharynx* n. sp. (Digenea: Lissorchiidae) from the shorthead redhorse, *Moxostoma macrolepidotum* (Lesueur) (Osteichthyes: Catostomidae). *Journal of Parasitology* 84:1196-1202.
- Combes, C. 2001. *Parasitism: the ecology and evolution of intimate interactions*. University of Chicago Press, Chicago, IL.
- Cressey, R. F. 1978. Marine flora and fauna of the Northeastern United States. Crustacea: Branchiura. National Oceanic and Atmospheric Administration Technical Report Circular 413. U.S. Department of Commerce National Marine Fisheries Service. Washington, D.C.
- Doyle, L. R. and L. N. Gleason. 1991. Suckers and other bursal structures of *Pomphorhynchus bulbocolli* and *Acanthocephalus dirus* (Acanthocephala). *Journal of Parasitology* 77:437-440.
- Essex, H. E. and G. W. Hunter, III. 1926. A biological study of fish parasites from the central states. *Transactions of the Illinois State Academy of Science* 19:151-181.

- Fremling, C. R. and T. O. Claflin. 1984. Ecological history of the Upper Mississippi River. Pages 5-24 in J. G. Wiener, R. V. Anderson, and D. R. Conville, eds. Contaminants in the Upper Mississippi River. Butterworth Publishers, Boston, MA.
- Fremling, C. R., J. L. Rasmussen, R. E. Sparks, S. P. Cobb, C. F. Bryan, and T. O. Claflin. 1989. Mississippi River fisheries: a case history. Pages 309-351 in D. P. Dodge, ed. Proceedings of the International Large River Symposium. Canadian Special Publication Fisheries and Aquatic Sciences.
- Hoffman, G. L. 1999. Parasites of North American Freshwater Fishes. Cornell University Press, Ithaca, NY. 539 pp.
- Hughhins, E. 1959. Parasites of fishes in South Dakota. South Dakota Department of Game, Fish & Parks, Agricultural Experiment Station, Bulletin 484.
- Krebs, C. J. 1989. Ecological Methodology. Harper & Row, New York, NY. 654 pp.
- Kritsky, D. C., P. D. Leiby, and M. E. Shelton. 1972. Studies on helminthes of North Dakota. IV. Parasites of the river carpsucker, *Carpiodes carpio*, with descriptions of three new species (Monogenea). Journal of Parasitology 1972:723-731.
- Lo, C. M., S. Morand, and R. Galzin. 1998. Parasite diversity/host age and size relationship in three coral-reef fishes from French Polynesia. International Journal for Parasitology 28:1695-1708.
- Long Term Resource Monitoring Program. 13 Dec. 2005. Upper Midwest Environmental Sciences Center, U.S. Geological Survey, La Crosse, Wisconsin. <<http://www.umesc.usgs.gov/ltrmp.html>>.
- Lincicome, D. R. and H. J. Van Cleave. 1949. Distribution of *Leptorhynchoides thecatus*, a common acanthocephalan parasitic in fishes. American Midland Naturalist 41:421-431.
- MacArthur, R. H. and E. O. Wilson. 1967. The theory of island biogeography. Princeton University Press, Princeton, NJ.
- Mackiewicz, J. S. 1968. Two new caryophyllaeid cestodes from the spotted sucker, *Minytrema melanops* (Raf.) (Catostomidae). Journal of Parasitology 54:808-813.
- Manter, H. W. 1966. Parasites of fishes as biological indicators of recent and ancient conditions. Pages 59-70 in J. E. McCauley, ed. Host-Parasite Relationships:

Proceedings of the Twenty-sixth Annual Biology Colloquium. Oregon State University Press, Corvallis, OR.

- Marcogliese, D. J., T. M. Goater, and G. W. Esch. 1990. *Crepidostomum cooperi* (Allocreadidae) in the burrowing mayfly, *Hexagenia limbata* (Ephemeroptera) related to trophic status of a lake. *American Midland Naturalist* 124:309-317.
- Mergo, J. C. and A. M. White. 1982. Two new species of Dactylogyridae (Monogenea) from the silver redhorse, *Moxostoma anisurum*. *Journal of Parasitology* 68:946-948.
- Moravec, F., and H. P. Arai. 1971. The North and Central American species of *Rhabdochona* Railliet 1916 (Nematoda: Rhabdochonidae) of fishes, including *Rhabdochona canadensis* sp. nov. *Journal of Fisheries Research Board of Canada* 28:1645-1662.
- Pearse, A. S. 1924. The parasites of lake fishes. *Transactions of the Wisconsin Academy of Science, Arts, and Letters* 21:161-194.
- Pfleiger, W. 1975. *The Fishes of Missouri*. Missouri Department of Conservation. 343 pp.
- Pflieger, W.L. and T.B. Grace. 1987. Changes in the fish fauna of the lower Missouri River, 1940-1983. Pages 166-177 in W.J. Matthews and D.C. Heins, eds. *Community and Evolutionary Ecology of North American Stream Fishes*. University of Oklahoma Press, Norman, OK.
- Pietroock, M., T. Meinelt, D. J. Marcogliese, and C. E. W. Steinburg. 2001. Influence of aqueous sediment extracts from the Oder River (Germany/Poland) on survival of *Diplostomum* sp. (Trematoda: Diplostomidae) cercariae. *Archives of Environmental Contamination and Toxicology* 40:327-332.
- Pinnegar, J. K., N. Campbell, and N. V. C. Poulin. 2001. Unusual stable isotope fractionation patterns observed for fish host-parasite trophic relationships. *Journal of Fish Biology* 59:494-503.
- Post, G. 1987. *Textbook of fish health*. T.F.H. Publications, Inc., Neptune City, NJ.
- Poulin, R. 1995. Phylogeny, ecology, and the richness of parasite communities in vertebrates. *Ecological Monographs* 65:283-302.
- Poulin, R. 2000. Variation in the intraspecific relationship between fish length and intensity of parasitic infection: biological and statistical causes. *Journal of Fish Biology* 56:123-137.

- Price, P. W. and K. M. Clancy. 1983. Patterns in number of helminth parasite species in freshwater fishes. *Journal of Parasitology* 69:449-454.
- Raubaut, A., C. Combes, and F. Benoit. 1998. Analysis of the parasitic copepod species richness among Mediterranean fish. *Journal of Marine Systems* 15:185-206.
- Ranta, E. 1992. Gregariousness versus solitude: another look at parasite faunal richness in Canadian freshwater fishes. *Oecologia* 89:150-152.
- Roberts, L. S. 1970. *Ergasilus* (Copepoda: Cyclopoida): revision and key to species in North America. *Transactions of the American Microscopy Society* 89:134-161.
- Roberts, L. S. and J. Janovy, Jr. 2000. *Foundations of Parasitology*, 6th edition. The McGraw Hill Companies, Inc., Boston, MA.
- Robinson, G. L. and L. A. Jahn. 1980. Some observations of fish parasites in Pool 20, Mississippi River. *Transactions of the American Microscopy Society* 99:206-212.
- Rogers, W. A. 1966. Three new species of *Pseudomurraytrema* (Trematoda: Monogenea) from gills of catostomid fishes. *Journal of Parasitology* 52:462-465.
- Rogers, W. A. 1967. *Myzotrema cyclepti* gen. n., sp. n. (Trematoda: Monogenea) from gills of *Cycleptus elongates* (LeSueur) from Alabama. *Proceedings of the Helminthological Society of Washington* 34:3-6.
- Salgado-Maldonado, G., N. Mercado-Silva, G. Cabanas-Carranza, J. M. Caspeta-Mandujano, R. Aguilar-Aguilar, and L. I. Iniguez-Dávalos. 2004. Helminth parasites of freshwater fishes of the Ayuquila River, Sierra de Manantlán Biosphere Reserve, West Central Mexico. *Comparative Parasitology* 71:67-72.
- Simková, A., S. Morand, I. Matejusová, P. Jurajda, and M. Gelnar. 2001. Local and regional influences on patterns of parasite species richness of central European fishes. *Biodiversity and Conservation* 10:511-525.
- Simon, T. P. and J. Lyons. 1995. Application of the index of biotic integrity to evaluate water resource integrity in freshwater ecosystems. Pages 245-262 in W. S. Davis and T. P. Simon, eds. *Biological Assessment and Criteria: Tool for Water Resource Planning and Decision Making*. CRC Press. Boca Raton.
- Szalai, A. J., J. F. Craig, and T. A. Dick. 1992. Parasites of fishes from Dauphin Lake, Manitoba, 1985-1987. Central and Arctic Region Department of Fisheries and Oceans. 25th Technical Report of Fisheries and Aquatic Sciences.
- Van Cleave, H. J. 1949. The acanthocephalan genus *Neoechinorhynchus* in the catostomid fishes of North America, with descriptions of two new species. *Journal of Parasitology* 35:500-512.

- Van Cleave, H. J. and H. F. Timmons. 1951. An additional new species of the Acanthocephalan genus *Neoechinorhynchus*. *Journal of Parasitology* 38:53-56.
- Weichman, M. A. and J. Janovy, Jr. 2000. Parasite community structure in *Pimephales promelas* (Pisces: Cyprinidae) from two converging streams. *Journal of Parasitology* 86:654-656.
- Wiener, J. G., G. A. Jackson, T. W. May, and B. P. Cole. 1984. Longitudinal distribution of trace elements (As, Cd, Cr, Hg, Pb, Se) in fishes and sediments in the upper Mississippi River. Pages 139-170 in J. G. Wiener, R. V. Anderson, and D. R. Conville, eds. *Contaminants in the Upper Mississippi River*. Butterworth Publishers, Boston, MA.
- Williams, D. D. 1977. A key to caryophyllaeid cestodes of Wisconsin fishes. *Iowa State Journal of Research* 51:471-477.
- Williams, D. D. 1978. A key to caryophyllidean cestodes of Iowa fishes. *Iowa State Journal of Research* 52:401-409.

APPENDIX A

**CATOSTOMID FISHES OCCURRING IN THE UPPER MISSISSIPPI RIVER
(FREMLING ET AL. 1989) AND THE LOWER MISSOURI NATIONAL
RECREATIONAL RIVER (BERRY AND YOUNG 2004)**

Appendix A. Catostomid fishes occurring in the upper Mississippi River (Fremling et al. 1989) and the lower Missouri National Recreational River (Berry and Young 2004)

Species		UMR	MNRR
<i>Carpionodes carpio</i>	(river carpsucker)	x	x
<i>Carpionodes cyprinus</i>	(quillback)	x	x
<i>Carpionodes velifer</i>	(highfin carpsucker)	x	x
<i>Catostomus commersoni</i>	(white sucker)	x	x
<i>Cycleptus elongatus</i>	(blue sucker)	x	x
<i>Hypentelium nigricans</i>	(northern hogsucker)	x	
<i>Ictiobus bubalus</i>	(smallmouth buffalo)	x	x
<i>Ictiobus cyprinellus</i>	(bigmouth buffalo)	x	x
<i>Ictiobus niger</i>	(black buffalo)	x	
<i>Minytrema melanops</i>	(spotted sucker)	x	
<i>Moxostoma anisurum</i>	(silver redhorse)	x	
<i>Moxostoma carinatum</i>	(river redhorse)	x	
<i>Moxostoma erythrurum</i>	(golden redhorse)	x	
<i>Moxostoma macrolepidotum</i>	(shorthead redhorse)	x	x
<i>Moxostoma valenciennesi</i>	(greater redhorse)	x	

APPENDIX B

CHECKLIST OF PARASITES OCCURRING IN 67 CATOSTOMID FISHES
COLLECTED FROM POOL 8 AND POOL 9, UPPER MISSISSIPPI RIVER IN 2003.
PARASITES IN BOLD TYPE INDICATE ECOLOGICAL CORE SPECIES
(PREVALENCE $\geq 50\%$) FOR THAT HOST

Appendix B. Checklist of parasites occurring in 67 catostomid fishes collected from Pool 8 and Pool 9, upper Mississippi River in 2003. Parasites in bold type indicate ecological core species (prevalence $\geq 50\%$) for that host

Host	n	Parasite
<i>Carpionodes cyprinus</i> (quillback)	3	Monogenea
		<i>Neodiscocotyle carpioditis</i>
		Digenea
		<i>Lissorchis kritskyi</i>
		Cestoda
		<i>Spartoides wardi</i>
		Nematoda
Eneysted nematodes		
<i>Camallanus ancyloDIRUS</i>		
Crustacea		
<i>Ergasilus versicolor</i>		
<i>Hypentelium nigricans</i> (northern hogsucker)	1	Monogenea
		<i>Pseudomurraytrema rogersi</i>
<i>Ictiobus bubalus</i> (smallmouth buffalo)	7	Monogenea
		<i>Pellucidhaptor planacrus</i>
		Digenea
		<i>Lissorchis gullaris</i>
		Cestoda
		Caryophyllaeidae sp.
		Nematoda
<i>Camallanus ancyloDIRUS</i>		
Nematode sp.		
Crustacea		
<i>Ergasilus versicolor</i>		
<i>Ictiobus cyprinellus</i> (bigmouth buffalo)	3	Digenea
		<i>Lissorchis gullaris</i>
		Cestoda
		Caryophyllaeidae sp.
		Acanthocephala
		<i>Pomphorhynchus bulbocolli</i>
Crustacea		
<i>Argulus catostomi</i>		
<i>Ergasilus versicolor</i>		
<i>Minytrema melanops</i> (spotted sucker)	10	Monogenea
		<i>Pseudomurraytrema alabarrum</i>
		Digenea
<i>Lissorchis sp.</i>		
<i>Phyllodistomum lysteri</i>		

Appendix B. Continued

Host	n	Parasite
		<p>Cestoda</p> <p><i>Biacetabulum</i> sp.</p> <p>Larval cestode (unidentified)</p> <p>Caryophyllaeidae sp.</p> <p><i>Promonobothrium minytremi</i></p> <p>Nematoda</p> <p>Nematode sp. (encysted)</p> <p>Acanthocephala</p> <p><i>Leptorhynchoides thecatus</i></p> <p><i>Neoechinorhynchus distractus</i></p> <p><i>Neoechinorhynchus prolixoides</i></p> <p><i>Neoechinorhynchus prolixus</i></p> <p>Crustacea</p> <p><i>Argulus appendiculosis</i></p> <p><i>Ergasilus versicolor</i></p> <p>Bivalvia</p> <p>Unidentified glochidium</p> <p>Hirudinea sp.</p>
<i>Moxostoma anisurum</i> (silver redhorse)	9	<p>Monogenea</p> <p><i>Pseudomurraytrema milleri</i></p> <p>Digenea</p> <p><i>Lissorchis macropharynx</i></p> <p><i>Phyllodistomum lysteri</i></p> <p>Cestoda</p> <p><i>Biacetabulum</i> sp.</p> <p>Caryophyllaeidae sp.</p> <p><i>Isoglaridacris wisconsinensis</i></p> <p><i>Monobothrium</i> sp.</p> <p>Unidentified plerocercoid</p> <p>Nematoda</p> <p><i>Rhabdochona milleri</i></p> <p>Acanthocephala</p> <p><i>Pomphorhynchus bulbocolli</i></p> <p>Crustacea</p> <p><i>Ergasilus versicolor</i></p> <p>Hirudinea sp.</p>
<i>Moxostoma carinatum</i> (river redhorse)	9	<p>Monogenea</p> <p><i>Pseudomurraytrema</i> sp.</p> <p>Digenea</p> <p><i>Lissorchis macropharynx</i></p> <p>Acanthocephala</p> <p><i>Neoechinorhynchus distractus</i></p> <p><i>Pomphorhynchus bulbocolli</i></p> <p>Crustacea</p> <p><i>Ergasilus versicolor</i></p>

Appendix B. Continued

Host	n	Parasite
<i>Moxostoma erythrurum</i> (golden redhorse)	11	Cestoda
		<i>Isoglaridacris sp.</i>
		Nematoda
		<i>Camallanus ancyloDIRUS</i>
		Acanthocephala
		<i>Neoechinorhynchus distractus</i>
		<i>Neoechinorhynchus prolixoides</i>
<i>Pomphorhynchus bulbocolli</i>		
Crustacea		<i>Ergasilus versicolor</i>
<i>Moxostoma macrolepidotum</i> (shorthead redhorse)	14	Monogenea
		<i>Pseudomurraytrema alabarrum</i>
		Digenea
		<i>Lissorchis macropharynx</i>
		<i>Hysteromorpha sp.</i>
		<i>Neascus sp.</i>
		Cestoda
		Caryophyllaeidae sp.
		Nematoda
		<i>Camallanus ancyloDIRUS</i>
		<i>Rhabdochona milleri</i>
		Unidentified nematode sp. (encysted)
		Acanthocephala
		<i>Neoechinorhynchus prolixoides</i>
		<i>Neoechinorhynchus prolixus</i>
<i>Pomphorhynchus bulbocolli</i>		
Crustacea		<i>Argulus appendiculosis</i>
		<i>Ergasilus versicolor</i>
Mollusca		Unidentified glochidium

APPENDIX C

CHECKLIST OF PARASITES OCCURRING IN 50 CATOSTOMID FISHES
COLLECTED FROM THE LOWER MISSOURI NATIONAL RECREATIONAL
RIVER IN 2003. PARASITES IN BOLD TYPE INDICATE ECOLOGICAL CORE
SPECIES (PREVALENCE $\geq 50\%$) FOR THAT HOST

Appendix C. Checklist of parasites occurring in 50 catostomid fishes collected from the lower Missouri National Recreational River in 2003. Parasites in bold type indicate ecological core species (prevalence \geq 50%) for that host

Host	n	Parasite
<i>Carpiodes carpio</i> (river carpsucker)	12	Monogenea
		<i>Neodiscocotyle carpioditis</i>
		Digenea
		<i>Lissorchis kritskyi</i>
		Cestoda
		<i>Biacetabulum carpiodi</i>
		<i>Spartoides wardi</i>
		Nematoda
		<i>Camallanus ancyloides</i>
Acanthocephala		
<i>Neoechinorhynchus prolixoides</i>		
<i>Neoechinorhynchus prolixus</i>		
<i>Carpiodes cyprinus</i> (quillback)	1	Cestoda
		Caryophyllaeidae sp. (immature)
		Nematoda
<i>Camallanus ancyloides</i>		
<i>Carpiodes velifer</i> (highfin carpsucker)	1	Monogenea
		<i>Neodiscocotyle carpioditis</i>
		Digenea
		<i>Lissorchis kritskyi</i>
		Cestoda
		<i>Spartoides wardi</i>
Crustacea		
<i>Lernaea sp.</i>		
<i>Cycleptus elongatus</i> (blue sucker)	10	Monogenea
		<i>Myzotrema cyclepti</i>
		Digenea
		<i>Phyllodistomum lysteri</i>
		Nematoda
		<i>Camallanus ancyloides</i>
		<i>Rhabdochona milleri</i>
Crustacea		
<i>Ergasilus sp.</i>		
<i>Ictiobus bubalus</i> (smallmouth buffalo)	3	Cestoda
		Caryophyllaeidae sp.
		Nematoda
<i>Camallanus ancyloides</i>		
Nematode sp. (encysted)		

Appendix C. Continued

Host	n	Parasite
<i>Ictiobus cyprinellus</i> (bigmouth buffalo)	10	Digenea <i>Lissorchis gullaris</i> <i>Phyllodistomum lysteri</i> Cestoda Caryophyllaeidae sp. Nematoda <i>Camallanus ancyloides</i> Nematode sp. (encysted) Acanthocephala <i>Pomphorhynchus bulbocollis</i> Crustacea <i>Argulus appendiculosis</i> <i>Lernaea sp.</i>
<i>Moxostoma macrolepidotum</i> (shorthead redhorse)	13	Cestoda Caryophyllaeidae sp. (immature) Cestode (larval) Nematoda <i>Camallanus ancyloides</i> <i>Rhabdochona milleri</i>