Acanthocephalan Parasites of Slimy Sculpin, *Cottus cognatus*, and Ninespine Stickleback, *Pungitius pungitius*, from Lake Michigan, U.S.A

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Acanthocephalan Parasites of Slimy Sculpin, *Cottus cognatus,* and Ninespine Stickleback, *Pungitius pungitius,* from Lake Michigan, U.S.A.

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ABSTRACT: In total, 288 slimy sculpins, *Cottus cognatus,* were collected in September 2003 from 6 Lake Michigan, U.S.A., ports, along with 220 ninespine sticklebacks, *Pungitius pungitius,* from 3 ports. The ports included Waukegan, Illinois; Port Washington (PW) and Sturgeon Bay (SB), Wisconsin; and Manistique (MS), Frankfort (FF), Ludington (LD), and Saugatuck, Michigan. *Echinorhynchus salmonis* infected sculpins from 6 ports, *Acanthocephalus dirus* infected sculpins from 4 ports, and *Neoechinorhynchus pungitius* infected sculpins from 3 ports. *Echinorhynchus salmonis* infected significantly more sculpins at PW and at FF than at MS and LD. There were several significant differences in the intensities and abundances of *E. salmonis* among ports. *Acanthocephalus dirus* significantly infected more sculpins and had significantly higher abundances at FF than at PW, MS, and LD. *Echinorhynchus salmonis*, *A. dirus*, and *N. pungitius* infected sticklebacks from SB, MS, and FF. *Neoechinorhynchus pungitius* significantly infected more sculpins and more sticklebacks, and it had significantly higher abundances at MS than at FF. *Neoechinorhynchus pungitius* was the most common acanthocephalan in *C. cognatus* and *P. pungitius* at MS. These acanthocephalan species infecting *C. cognatus* and *P. pungitius* corresponded in their occurrence to those organisms that serve as their intermediate hosts found in the stomachs of both fish species. Potential changes in the diet of *C. cognatus* played a role in significant differences found for *E. salmonis* and *N. pungitius* at MS. One of these acanthocephalan species was always the most numerous helminth species found in the digestive tracts of *P. pungitius* and *C. cognatus* from these Lake Michigan ports.

KEY WORDS: Acanthocephala, *Echinorhynchus salmonis*, *Acanthocephalus dirus*, *Neoechinorhynchus pungitius*, *Cottus cognatus*, *Pungitius pungitius*, Lake Michigan.

Echinorhynchus salmonis (Muller, 1784) (Acanthocephala: Echinorhynchidae) has been found in 17 fish species from Lake Michigan, U.S.A. (Pearse, 1924; DeGiusti, 1965; Amin and Burrows, 1977; Amin, 1985; Muzzall and Peebles, 1988; Muzzall, 1989, 1993). Amin (1985) and Muzzall (1989, 1993) reported that *E. salmonis* had high prevalences and intensities in 5 salmonid species. *Acanthocephalus dirus* (Van Cleave, 1931) Van Cleave and Townsend, 1936 (Acanthocephala: Echinorhynchidae) has been found in 13 fish species in Lake Michigan (Amin, 1977, 1985; Muzzall, 1989; Camp et al., 1999). Amin (1977) suggested that white suckers, *Catostomus commersonii,* and slimy sculpins, *Cottus cognatus* Richardson, 1836 (Cottidae) supported *A. dirus* populations in southwestern Lake Michigan and also found that infections of *E. salmonis* were relatively heavier than *A. dirus* in sculpins.

The presence of *E. salmonis* and *A. dirus* in smaller fish species in Lake Michigan has not been studied except by Amin (1977) and Amin and Burrows (1977), who reported on these acanthocephalans in *C. cognatus* Richardson, 1836 (Cottidae). There are no published studies on acanthocephalans from the ninespine stickleback, *Pungitius pungitius* (Linnaeus, 1758) (Gasterosteidae), another small fish species in Lake Michigan. Other published studies on the parasites of *C. cognatus* and *P. pungitius* from Lake Michigan (Yeo, 1985; Hudson et al., 1994; Cone et al., 1996; French and Muzzall, 2008) did not report on parasites from their digestive tracts. Furthermore, *Neoechinorhynchus pungitius* Dechtiar, 1972 (Acanthocephala: Neoechinorhynchidae) has not been reported from fish in Lake Michigan. The objectives of the present study were as follows: 1) to report on the occurrence of *E. salmonis*, *A. dirus*, and *N. pungitius* in *C. cognatus* and *P. pungitius* in September 2003 from several ports in Lake Michigan; 2) to determine whether the prevalences, intensities, and abundances of these acanthocephalan species in each fish species were significantly different among ports; and 3) to explore how the diet of *C. cognatus* and *P. pungitius* affects the occurrence of these acanthocephalan species.

MATERIALS AND METHODS

Cottus cognatus and *P. pungitius* were collected at Waukegan [WK], Illinois; Port Washington [PW] and

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Sturgeon Bay [SB], Wisconsin (western Lake Michigan); and Manistique [MS] (northern Lake Michigan), Frankfort [FF], Ludington [LD], and Saugatuck [SG], Michigan (eastern Lake Michigan) (Fig. 1) in September 2003 by using a bottom trawl (12-m, 15.5-m footrope, and 13-mm mesh in the cod end) towed for 10 min. Fish were frozen immediately after capture. They were measured (total length in millimeters) and sexed as each was examined. The digestive tract and associated mesenteries of each fish were examined for acanthocephalans.

Specimens of acanthocephalans from frozen fish varied in their usefulness for species identification. Some individuals had well-established morphological and categorical data, e.g., specimens were fully extended, overall body shape good, proboscis and copulatory bursa everted, ganglion and lemnisci visible, whereas others were fair to poor specimens, e.g., contorted, partially to fully inverted proboscis or copulatory bursa, or various structures unobservable. Most specimens were stained with Grenacher's borax carmine with concentrated hydrochloric acid (1 drop for each 5 ml of stain) added approximately 8 hr after the specimens were placed in the stain. All specimens of acanthocephalans were examined and could be assigned to 1 of the 3 identified species. Prevalence (percentage of fish infected), mean intensity (mean number of acanthocephalans per infected fish), and mean abundance (mean number of acanthocephalans per examined fish) of infections are reported in accordance with the definitions provided by Bush et al. (1997). Voucher specimens have been deposited in the United States National Parasite Collection (USNPC), Beltsville, Maryland, U.S.A. (*E. salmonis* [103424], *A. dirus* [103425], and *N. pungitius* [103426, 103437]).

Lengths of *C. cognatus* and *P. pungitius* were compared among ports by using analysis of variance (ANOVA), or the Kruskal–Wallis test, if the data were not normally distributed. Statistical comparisons of acanthocephalan data for *C. cognatus* involved only ports where 30 or more fish were examined and included PW, MS, FF, and LD. Acanthocephalan data comparisons of *P. pungitius* involved SB, MS, and FF. A chi-square test was used to determine whether there was a significant difference in numbers of infected and uninfected female and male *C. cognatus*, and female and male *P. pungitius* at MS and FF, where 100 fish of each species were examined. Yates correction factor was used in some chi-square comparisons due to multiple tests on the same data. Comparisons of abundances and intensities of infection with each acanthocephalan species involved Student's *t*-test or Mann–Whitney *U*-test with respect to host gender where 100 fish were examined. Intensities, abundances, or both of each acanthocephalan species were compared among ports (ANOVA), followed by Tukey's highly significant difference test. A Mann–Whitney *U*-test was used if the data were not normally distributed.

Where 100 fish were examined, the intensities and abundances of *E. salmonis* and *A. dirus* were correlated with the length of *C. cognatus* at FF, and the intensities and abundances of *N. pungitius* were correlated with the length of *C. cognatus* and of *P. pungitius* at MS. Also, the intensities and abundances of *E. salmonis* and *A. dirus* at FF, and those values of *N. pungitius* in *C. cognatus* and in *P. pungitius* at MS were correlated to fish collection depths (37, 46, 55, 64, 73, 82, and 110 m). The relationships between abundance and intensity of each acanthocephalan species and host total length and collection depths were examined using Spearman's rank correlation analysis. All analyses were performed using MINITAB, and significance was set at $\alpha = 0.05$.

Based on known information on the life cycles of species in the genera *Echinorhynchus*, *Acanthocephalus*, and *Neoechinorhynchus*, we made observations on the food items in the stomachs of *C. cognatus* and *P. pungitius* from the Lake Michigan ports. These observations were made to help understand the occurrence of the acanthocephalan species found in relation to fish diet. Food items observed and noted, but not specifically counted, were as follows: copepods (Copepoda), ostracods (Ostracoda), isopods (Isopoda), the burrowing amphipod *Diporeia* (=*Pontoporeia*) *hoyi* (Amphipoda: Pontoporeiidae), and opossum shrimp *Mysis relicta* (Mysida: Mysidae).

RESULTS

Host demographics

The numbers and mean lengths (range) of the 288 *C. cognatus* and 220 *P. pungitius* examined from 7 Lake Michigan ports are presented in Table 1. There were no significant differences in the lengths of *C. cognatus* for WK, PW, MS, FF, LD, and SG (ANOVA) and in the lengths of *P. pungitius* for SB, MS, and FF (Kruskal–Wallis test).

Acanthocephalans: general

Gravid females of *E. salmonis*, *A. dirus*, and *N. pungitius* were found in the intestines of both *C. cognatus* and *P. pungitius*. The acanthocephalan communities in *C. cognatus* were dominated numerically by *E. salmonis* at WK, FF, LD, and SG (Table 2). *Neoechinorhynchus pungitius* dominated numerically the community of *C. cognatus* at MS. All 3 acanthocephalan species infected *C. cognatus* from MS and FF.

The prevalences of *E. salmonis*, *A. dirus*, and *N. pungitius* were similar in *P. pungitius* at SB, but the mean intensity of *N. pungitius* was highest at this port (Table 3). Similar to *C. cognatus*, *N. pungitius* dominated numerically the acanthocephalan community of *P. pungitius* at MS. All 3 acanthocephalan species occurred in *P. pungitius* from SB, MS, and FF. There were no significant differences in the numbers of infected and uninfected female and male *C. cognatus*, and female and male *P. pungitius* (chi-square analysis) or in the intensity of infection (Student's *t*-test) with respect to host gender with each acanthocephalan species at MS and FF.

The numbers and percentages of *C. cognatus* and *P. pungitius* concurrently infected with 2 acanthocephalan

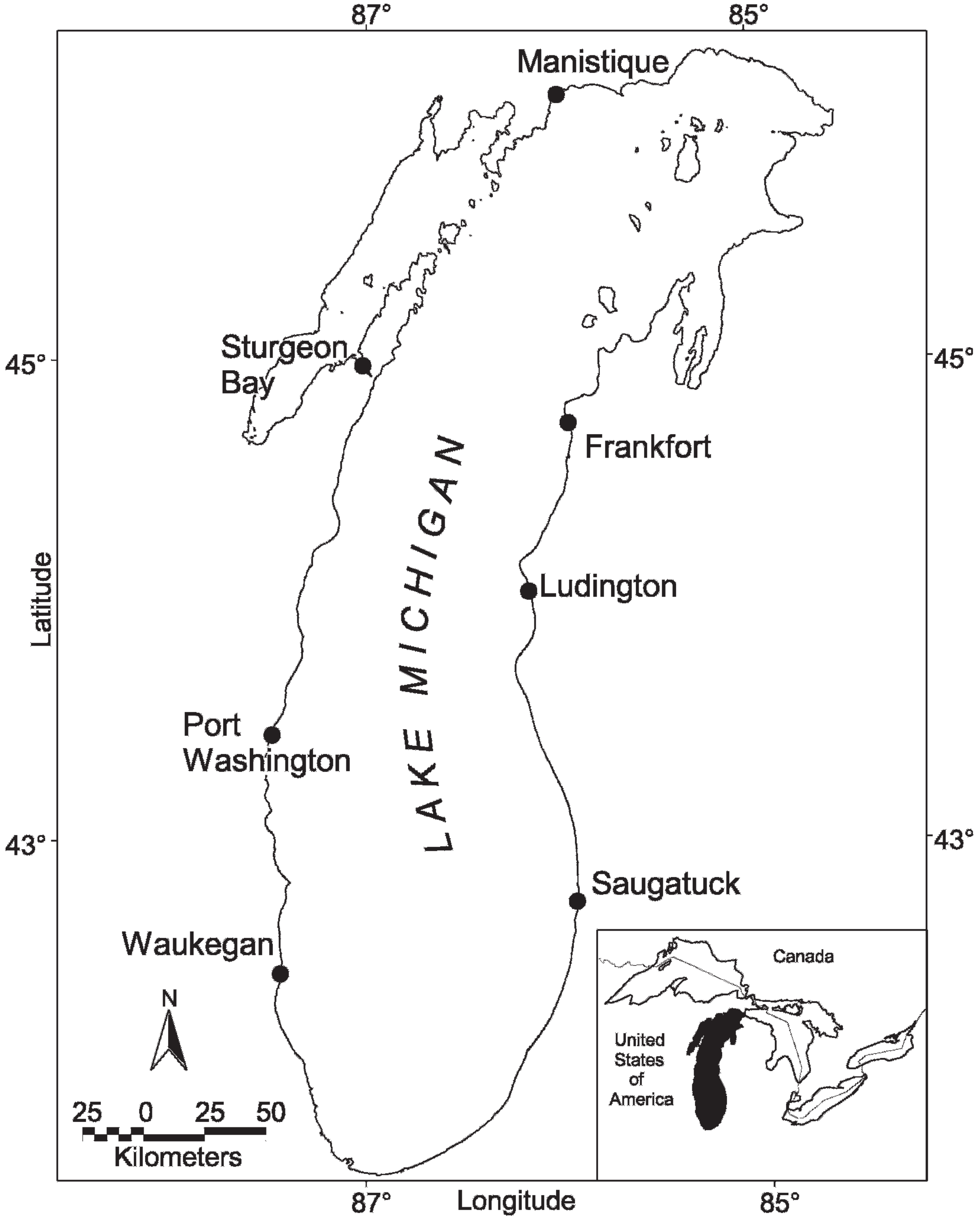

Figure 1. Lake Michigan ports where *Cottus cognatus* and *Pungitius pungitius* were examined for acanthocephalans in September 2003. Inset map, Lake Michigan in context with the Great Lakes system and international boundaries.

species at MS and FF were as follows: *C. cognatus* at MS (*E. salmonis* and *A. dirus*, 1 and 1%; *E. salmonis* and *N. pungitius*, 4 and 4%; *A. dirus* and *N. pungitius*, 1 and 1%), *C. cognatus* at FF (*E. salmonis* and *A. dirus*, 36 and 36%), and *P. pungitius* at FF (*E. salmonis* and *A. dirus*, 2 and 2%). None of the *C. cognatus* and *P. pungitius* was infected with all 3 acanthocephalan species.

Table 1. Mean total length (mm) ± SD (range) and numbers of *Cottus cognatus* and *Pungitius pungitius* examined from 7 Lake Michigan, U.S.A., ports in September 2003.

	Fish species	
Port,* latitude/longitude	*C. cognatus*	*P. pungitius*
WK, 42°26′69″; 87°40′88″	63.4 ± 10.2 (52–82), 16†	—‡
PW, 43°23′50″; 87°45′91″	71.6 ± 15.6 (49–97), 30	—
SB, 44°40′64″; 87°14′83″	—	65.9 ± 4.5 (54–76), 50
MS, 45°48′79″; 86°02′03″	67.1 ± 10.3 (42–93), 100	66.9 ± 7.1 (46–78), 70
FF, 44°29′35″; 86°18′94″	68.2 ± 11.9 (41–102), 100	66.5 ± 5.2 (55–76), 100
LD, 43°55′81″; 86°36′43″	68.5 ± 16.9 (42–125), 33	—
SG, 42°41′63″; 86°20′43″	72.1 ± 8.6 (61–85), 6	—

* WK, Waukegan, Illinois; PW, Port Washington, Wisconsin; SB, Sturgeon Bay, Wisconsin; MS, Manistique, Michigan; FF, Frankfort, Michigan; LD, Ludington, Michigan; SG, Saugatuck, Michigan.
† Number of fish examined.
‡ Fish not examined from port.

Echinorhynchus salmonis

The prevalences, mean intensities, and mean abundances of *E. salmonis*, *A. dirus*, and *N. pungitius* in *C. cognatus* from 6 Lake Michigan ports are presented in Table 2. There were significant differences in the numbers of infected and noninfected *C. cognatus* with *E. salmonis* at PW and MS (χ^2 = 76.44, $P < 0.0001$) and PW and LD (χ^2 = 20.11, $P < 0.0001$), with more sculpins infected at PW; and MS and FF (χ^2 = 86.50, $P < 0.0001$) and FF and LD (χ^2 = 18.01, $P < 0.0001$), with more sculpins infected at FF. The intensities of *E. salmonis* were significantly higher at LD than at the other 3 ports (ANOVA: F = 5.85, $P < 0.001$), followed by Tukey's highly significant difference test with intensities of *E. salmonis* at LD being significantly higher than that at PW (q = 4.68, $P < 0.005$), at MS (q = 4.06, $P < 0.05$), and at FF (q = 5.08, $P < 0.05$) (Table 2). There were several significant differences in the abundances of *E. salmonis* among the ports (ANOVA: F = 25.97, $P < 0.001$). Tukey's highly significant difference test indicated abundances of *E. salmonis* at PW were significantly higher than at MS (q = 5.56, $P < 0.05$), with the abundances at FF being significantly higher than at MS (q = 7.54, $P < 0.05$), and the abundances at LD being significantly higher than those found at PW (q = 4.80, $P < 0.05$), at MS (q = 11.79, $P < 0.05$), and at FF (q = 6.48, $P < 0.05$). Spearman's rank correlation coefficients between *E. salmonis* abundances (r_s = 0.45, $P < 0.001$) and intensities (r_s = 0.54, $P < 0.001$) and lengths of *C. cognatus* at FF were significant. Furthermore, coefficients between *E. salmonis* abundances (r_s = 0.56, $P < 0.001$) and intensities (r_s =

Table 2. Prevalence (P), mean intensity (MI ± SD) (maximum), and mean abundance (MA ± SD) of *Echinorhynchus salmonis*, *Acanthocephalus dirus*, and *Neoechinorhynchus pungitius* in *Cottus cognatus* from 6 Lake Michigan, U.S.A., ports.

	Acanthocephalan species†								
	Es			Ad			Np		
Port*	P (%)	MI ± SD	MA ± SD	P (%)	MI ± SD	MA ± SD	P (%)	MI ± SD	MA ± SD
WK (16)‡	81	3.9 ± 3.0 (10)	3.2 ± 3.1	—§	—	—	19	1.0 (1)	0.18 ± 0.4
PW (30)	87	3.4 ± 2.7 (13)	2.9 ± 2.8	20	4.0 ± 3.0 (9)	0.8 ± 2.0	—	—	—
MS (100)	6	1.2 ± 0.45 (2)	0.06 ± 0.3	4	1.8 ± 0.96 (3)	0.07 ± 0.3	28	13.2 ± 23.3 (116)	3.7 ± 13.5
FF (100)	71	3.8 ± 3.9 (25)	2.7 ± 3.7	56	3.6 ± 2.8 (13)	2.0 ± 2.7	2	2.0 ± 1.4 (3)	0.04 ± 0.3
LD (33)	26	7.5 ± 7.1 (27)	5.9 ± 7.0	15	4.0 ± 4.0 (11)	0.6 ± 2.0	—	—	—
SG (6)	83	4.6 ± 6.4 (16)	3.8 ± 6.0	—	—	—	—	—	—

* WK, Waukegan, Illinois; PW, Port Washington, Wisconsin; MS, Manistique, Michigan; FF, Frankfort, Michigan; LD, Ludington, Michigan; SG, Saugatuck, Michigan.
† Es, *Echinorhynchus salmonis*; Ad, *Acanthocephalus dirus*; Np, *Neoechinorhynchus pungitius*.
‡ Number of fish examined.
§ Acanthocephalan species not found.

Table 3. Prevalence (P), mean intensity (MI ± SD) (maximum), and mean abundance (MA ± SD) of *Echinorhynchus salmonis*, *Acanthocephalus dirus*, and *Neoechinorhynchus pungitius* in *Pungitius pungitius* from 3 Lake Michigan, U.S.A., ports.

	Acanthocephalan species†								
	Es			Ad			Np		
Port*	P (%)	MI ± SD	MA ± SD	P (%)	MI ± SD	MA ± SD	P (%)	MI ± SD	MA ± SD
SB (50)‡	6	1.3 ± 0.6 (2)	0.08 ± 0.3	8	2.5 ± 2.4 (6)	0.20 ± 0.9	6	5.0 ± 6.1 (12)	0.30 ± 1.7
MS (70)	1	1.0	0.01 ± 0.1	1	1.0	0.01 ± 0.1	21	15.9 ± 27.1 (100)	3.4 ± 13.8
FF (100)	8	1.6 ± 0.9 (3)	0.13 ± 0.1	6	2.5 ± 1.8 (13)	0.15 ± 0.7	1	1.0	0.01 ± 0.1

* SB, Sturgeon Bay, Wisconsin; MS, Manistique, Michigan; FF, Frankfort, Michigan.
† Es, *Echinorhynchus salmonis*; Ad, *Acanthocephalus dirus*; Np, *Neoechinorhynchus pungitius*.
‡ Number of fish examined.

0.58, $P < 0.001$) and *C. cognatus* collection depths were significant at FF.

Although prevalence, mean intensity, and mean abundance of *E. salmonis* in *P. pungitius* were highest at FF, these values were not significantly different (chi-square analysis and ANOVA) from those at SB and MS (Table 3). Correlation coefficients between abundances and intensities of *E. salmonis* and lengths of *P. pungitius* were not performed because so few fish were infected.

Acanthocephalus dirus

The chi-square pairwise comparisons for the number of infected and noninfected *C. cognatus* with *A. dirus* involved PW and FF ($\chi^2 = 10.59$, $P < 0.005$), MS and FF ($\chi^2 = 61.93$, $P < 0.0001$), and LD and FF ($\chi^2 = 15.07$, $P < 0.001$), with significantly more sculpins infected at FF than at the other ports (Table 2). There were no significant differences in the intensities of *A. dirus* in *C. cognatus* among PW, MS, FF, and LD (ANOVA). However, the abundances of *A. dirus* were significantly higher at FF than at the other ports (ANOVA: $F = 16.64$, $P < 0.001$). Tukey's highly significant test indicated abundances of *A. dirus* at FF were significantly higher than that at PW ($q = 4.19$, $P < 0.05$), at MS ($q = 9.82$, $P < 0.05$), and at LD ($q = 5.03$, $P < 0.05$). The only significant Spearman's rank correlation coefficient involved the abundances of *A. dirus* and *C. cognatus* lengths at FF ($r_s = 0.40$, $P < 0.001$).

The prevalence of *A. dirus* in *P. pungitius* was highest at SB, and mean intensity was highest at both SB and FF (Table 3). Prevalences, intensities, and abundances of *A. dirus* in *P. pungitius* were not significantly different (chi-square test and ANOVA) among SB, MS, and FF. Correlation coefficients involving the abundances and intensities of *A. dirus* and lengths and collection depths of *P. pungitius* were not performed because so few infected fish were found.

Neoechinorhynchus pungitius

Chi-square pairwise comparisons for the number of infected and noninfected *C. cognatus* with *N. pungitius* involved 1 significant difference with more fish infected at MS than that at FF ($\chi^2 = 24.51$, $P < 0.0001$) (Table 2). Abundances of *N. pungitius* in *C. cognatus* were significantly higher at MS than at FF (Mann–Whitney *U*-test: $U = 6{,}313$, $P < 0.05$). Although the intensities of *N. pungitius* were much higher at MS than at FF, they were not significantly different (Mann–Whitney *U*-test). Spearman's correlation coefficients between *N. pungitius* abundances ($r_s = 0.04$) and intensities ($r_s = 0.11$) and lengths of *C. cognatus*, and coefficients between *N. pungitius* abundances ($r_s = 0.10$) and intensities ($r_s = -0.16$) with *C. cognatus* collection depths were nonsignificant at MS.

The prevalence of *N. pungitius* in *P. pungitius* was highest at MS, followed by SB (Table 3). Chi-square pairwise comparisons for the number of infected and noninfected *P. pungitius* with *N. pungitius* were significant with more fish infected at MS than SB ($\chi^2 = 4.3$, $P < 0.05$) and at MS than that at FF ($\chi^2 = 17.83$, $P < 0.0001$). Although the intensities of *N. pungitius* in *P. pungitius* were highest at MS, they were not significantly different among these 3 ports (Mann–Whitney *U*-test). The abundances were significantly higher at MS than at the other 2 ports (ANOVA: $F = 4.21$, $P < 0.05$), followed by Tukey's highly significant difference test with abundances of *N. pungitius* at MS being significantly higher than those found at FF ($q = 3.9$, $P < 0.05$). The

Spearman's correlation coefficient between *N. pungitius* intensities and lengths of *P. pungitius* was significant at MS ($r_s = 0.62$, $P < 0.05$).

DISCUSSION

The first report of *Echinorhynchus salmonis* in fish from Lake Michigan was Pearse (1924). Thereafter, this acanthocephalan has been reported in numerous fish species, representing several families, in Lake Michigan (e.g., Amin and Burrows, 1977; Muzzall, 1989). Based on this information, *E. salmonis* is a very common and numerous parasite of salmonids, and some other fish species in Lake Michigan. Furthermore, *E. salmonis* was the most common acanthocephalan species in *C. cognatus*, a small fish species, at WK, PW, FF, LD, and SG in the present study.

Amin and Burrows (1977) found that 73% of the *C. cognatus* collected in southwestern Lake Michigan were infected with *E. salmonis*, with a mean abundance of 6.8. In the present study, *E. salmonis* infected *C. cognatus* from all ports, with prevalences varying from 6% to 87%. The mean abundances of *E. salmonis* in *C. cognatus* were lower at most ports than the mean abundance in the same fish host reported by Amin and Burrows (1977).

French et al. (2010) found that *D. hoyi* and *M. relicta* were the most important prey items in the diets of *C. cognatus* from most ports in Lake Michigan in September 2003. Both *C. cognatus* and *P. pungitius* that we examined for acanthocephalans in the present study were from the same samples of fish that French et al. (2010) examined for their diet study. Furthermore, our observations on the stomach contents of *C. cognatus* from most Lake Michigan ports also indicated that sculpins commonly ingested *D. hoyi* and *M. relicta*. *Echinorhynchus salmonis* uses *D. hoyi* as an intermediate host in Lake Michigan (Amin, 1978). The presence of *D. hoyi* in many areas of Lake Michigan and it being a common food item of *C. cognatus* probably account for the common occurrence of *E. salmonis* in *C. cognatus* in the present study.

The intensities and abundances of *E. salmonis* significantly increased with an increase in the length of *C. cognatus* and also significantly increased with collection depths of fish at FF. The a posteriori Spearman's correlation coefficient between length of *C. cognatus* and collection depths at FF was significant ($r_s = 0.56$, $P < 0.001$). Albeit speculation, there may be more (infected?) amphipods and larger *C. cognatus* at deeper depths at this port in Lake Michigan. Consequently, larger *C. cognatus* that occur at deeper depths may eat more (infected?) amphipods, possibly explaining why intensities and abundances of *E. salmonis* are higher in larger *C. cognatus* occurring in deeper waters at FF.

French et al. (2010) reported that the diet of *C. cognatus* at MS changed over time beginning around 1990 from *D. hoyi* to other food items; they did not find *D. hoyi* in fish at depths of ≤46 m, but they did find *D. hoyi* in them at greater depths. None of the 18 *C. cognatus* examined from depths of ≤46 m in the present study was infected with *E. salmonis*, whereas 6 of the 82 fish examined at depths >46 m were infected with *E. salmonis*. The infrequency of *D. hoyi* at MS may account for the lowest prevalence, mean intensity, and mean abundance of *E. salmonis* in *C. cognatus* found at this port.

Most acanthocephalans found in *C. cognatus* and *P. pungitius* at MS were *N. pungitius*. *Neoechinorhynchus pungitius* was described by Dechtiar (1971) from specimens collected from *P. pungitius* in South Bay, Lake Huron, U.S.A. He found that 67% of the *P. pungitius* examined were infected with *N. pungitius* and obtained additional specimens from brook stickleback *Culaea inconstans* and yellow perch *Perca flavescens*. Muzzall and Bowen (2002) reported that the prevalence, mean intensity, and mean abundance of *N. pungitius* in *C. cognatus* from Lake Huron in June 1995 were 52%, 3.9%, and 2.1%, respectively. Amin (1977), Amin and Burrows (1977), Muzzall (1994), and Muzzall et al. (1997) did not find *N. pungitius* in the 1,229 fish representing 19 fish species they examined in Lake Michigan, indicating *N. pungitius* has recently colonized Lake Michigan and is now well established.

French et al. (2010) reported that *D. hoyi* and *M. relicta* were not the dominant prey found in *C. cognatus* from the shallow MS sites (depth, ≤46 m) but that other organisms, including copepods and ostracods, were dominant prey. Furthermore, our observations indicated that copepods and ostracods were more numerous than amphipods and opossum shrimp in the stomach contents of *C. cognatus* and *P. pungitius* at MS. Also, these microcrustaceans were more common in the stomachs of both fish species at MS compared with the other ports. *Neoechinorhynchus* spp. use copepods or ostracods as intermediate hosts (Hoffman, 1999). It is therefore suggested that *N. pungitius* also uses copepods or ostracods as an intermediate host. The high prevalence, mean intensity, and mean abundance of *N. pungitius* in *C. cognatus* at MS compared with the other ports reflect the diet of this fish species, i.e., more microcrustaceans than amphipods and opossum shrimp.

The high prevalences and intensities of *N. pungitius* and low values of *E. salmonis* in *C. cognatus* at MS compared with other ports imply there has been a reduction in the number of *D. hoyi*, causing the diets of sculpins to change and increase their feeding on other organisms, including copepods and ostracods. *Diporeia hoyi* has recently been declining in some areas in Lake Michigan, and its decline is hypothesized to be due to the establishment of zebra mussels *Dreissena polymorpha* (see Nalepa et al., 2005, 2009). Perhaps a switch in diet of *C. cognatus* due to a reduction in the number of *D. hoyi* at MS accounts for the numerical results observed for infrapopulations in these acanthocephalan species.

The first report of *A. dirus* in fish from Lake Michigan was that of Amin (1977), who noted that 38% of the *C. cognatus* examined in March 1974 were infected in southwestern Lake Michigan. In the present study, *A. dirus* infected *C. cognatus* from 4 ports, with prevalences and mean abundance varying from 4% to 56% and 0.6 to 2.0, respectively. Therefore, *A. dirus*, in general, commonly infected *C. cognatus* but occurred in low intensities at various ports in Lake Michigan.

Acanthocephalus dirus uses isopods as intermediate hosts (Muzzall, 1984). In the present study, 2 partially digested isopods infected with cystacanths of *A. dirus* were found in the stomachs of 1 *C. cognatus* from FF and 1 *P. pungitius* from SB. However, the somewhat high prevalences of *A. dirus* in *C. cognatus* at PW and FF in the present study are surprising because French et al. (2010) found isopods to be very infrequent in the stomachs of *C. cognatus* from the ports where fish were examined for acanthocephalans. Our observations also demonstrated that isopods were infrequent in the stomachs of *C. cognatus* and *P. pungitius* examined from these ports. Amin (1978) found a cystacanth of *A. dirus* in 1 *D. hoyi* from 7,990 examined from Lake Michigan and another cystacanth of the same species in 1 *D. hoyi* examined from the stomach of *C. cognatus*. Therefore, *A. dirus* uses isopods and *D. hoyi* as intermediate hosts in Lake Michigan. Amin (1978) also reported that none of the 2,156 *M. relicta* examined from Lake Michigan was positive for acanthocephalans.

In summary, *E. salmonis*, *A. dirus*, and *N. pungitius* were the most common and numerous helminths found in the digestive tracts of *C. cognatus* and *P. pungitius* collected in September 2003 from several ports in Lake Michigan. However, the prevalences and intensities of *E. salmonis* in *C. cognatus* and *P. pungitius* were much lower than the values in salmonids and other larger fishes, as reported in other studies from this lake. Furthermore, few *C. cognatus* (except from FF) and *P. pungitius* were concurrently infected with more than 1 acanthocephalan species in the present study, suggesting that there are differences in numbers of species that serve as intermediate hosts at each port, that these fish feed on different food items at different ports, and that there have been potential changes in the diets of fish.

Although all *C. cognatus* and *P. pungitius* examined in September 2003 were not significantly different in length among several Lake Michigan ports, *E. salmonis*, *A. dirus*, and *N. pungitius* exhibited some significant difference in prevalences, intensities, and abundances in the same fish species among ports. Therefore, these acanthocephalan species are not uniformly distributed in Lake Michigan. The acanthocephalan species infecting *C. cognatus* and *P. pungitius* in the present study, corresponded in their occurrence to those organisms that serve as their intermediate hosts found in the stomachs of both fish species, based on our observations and those made by French et al. (2010). This is the first study on the occurrence of 1 or more acanthocephalan species in the same fish species collected at the same time among 3 or more ports in Lake Michigan.

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