2022. Proceedings of the Indiana Academy of Science 130(2):156–162

A SURVEY OF FRESHWATER FISHES AND THEIR PARASITES THROUGHOUT DELAWARE COUNTY, INDIANA

Jenna P. Ruoss[1] and **Randall J. Bernot:** Department of Biology, Ball State University, Muncie, IN 47306 USA

ABSTRACT. Parasites are ubiquitous within ecosystems and are known to regulate host populations as well as alter trophic interactions, yet their contribution to biodiversity is typically overlooked. More specifically, how parasites may affect fish communities regarding infection intensity and trophic interactions is still misunderstood, with studies showing contradicting results. In this study, fish assemblages and their associated parasite diversity across three different lotic systems: Buck Creek, Halfway Creek, and the West Fork of the White River located in Delaware County, Indiana were examined. Percent prevalence, intensity of infection, and relative abundance of parasites were calculated. Following one sampling season, 89 fish across 21 species were collected. The overall prevalence of parasites was highest for Halfway Creek, followed by Buck Creek, with the White River having the lowest prevalence. Further, it was determined that the mean intensity of parasitic infection was 18.2, 15.9, and 3.3 for Buck Creek, Halfway Creek, and the White River, respectively. Finally, the relative abundance of parasites for Buck Creek, Halfway Creek, and the White River was 11.0, 11.9, and 1.25, respectively. While fish assemblages were not similar among sites, parasite assemblages were relatively similar. Overall, the parasite-host relationships determined in this study may be driven by the surrounding land use, host diet, or host size; future studies could explore these infection and transmission mechanisms in greater detail. Given the importance of how parasites may affect their communities, the subject merits further research.

Keywords: parasitism, host-parasite relationship, aquatic ecosystems

INTRODUCTION

Parasitism occurs when a single organism (the parasite) lives intimately with or on another organism (the host), in which the parasite benefits at the expense of the host, though typically not causing death in the host (Marcogliese & Price 1997). Parasites are ubiquitous, with parasitism being the most common lifestyle among species globally (Bush et al. 2001; Kamiya et al. 2014), and account for approximately 40% of described species (Dobson et al. 2008). Furthermore, Poulin & Morand (2004) have estimated that there are, at minimum, twice as many helminth parasite species (trematodes, cestodes, and nematodes) as there are host species. Parasites have historically been classified by morphology, yet because of similarities in morphology (e.g., cryptic species or morphospecies), species may have been previously classified together (Miura et al. 2005). Thus, current estimates of different species of parasites are likely underestimates. However, with advancing genetic technologies, cryptic species can be distinguished as several genetically unique species (Miura et al. 2005; Dobson et al. 2008; Poulin 2014), thus contributing more to the knowledge of parasite diversity. Understanding the status of the world's parasite diversity is imperative as increasing evidence suggests that as parasite diversity increases, so does the ecosystem functioning (Hudson et al. 2006).

Broadly, parasites may alter host communities within and across ecosystems (Hudson et al. 2006; Lafferty et al. 2008; Bernot & Lamberti 2008; Wood & Johnson 2015). Despite fish serving as potential hosts to many parasitic species, parasites are frequently ignored in fisheries studies (Timi & Poulin 2020). Black spot disease is a visually diagnosable disease caused by the larval fluke *Neascus* spp. and may occur in fishes throughout Indiana (IN DNR 2021). The tell-tale sign of the disease is the appearance of small round black spots on the fish. Once a fish is infected with black spot disease, the fish will increase oxygen consumption and exhibit increased lipid metabolism, consequently increasing energetic demands and stress, possibly leading to population declines (Lemly & Esch 1984). Macro-internal parasites that may infect fishes throughout Indiana include cestodes, nematodes, and acanthocephalans. Infections by macro-internal parasites may induce changes in behavior (Bernot 2003; Sohn et al.

[1] *Corresponding author:* Jenna Ruoss, 402-472-3471 (phone), ruossjp@gmail.com.

2019), reduce growth rates (Mitchum 1995; Grizzle & Goldsby 1996), increase susceptibility to other diseases (Grizzle & Goldsby 1996; Cornet & Sorci 2010), and possibly cause death (Hunt & Cable 2020).

Despite the importance of parasite community effects, parasite biodiversity is understudied and largely unknown (Dobson et al. 2008; Poulin 2014). Specifically, little information exists on the parasites of fishes throughout Indiana (Buckner et al. 1985). The main goals of this investigation were to 1) broadly describe the parasites in fishes collected from three Delaware County, Indiana stream sites, and 2) determine the percent prevalence, intensity, and relative abundance of parasites per site. Further, we aimed to provide baseline data for future studies concerning parasites in Indiana's lotic ecosystems.

METHODS

Fish and parasite communities were sampled at three sites in Delaware County: Buck Creek (40.124173°N, -85.498515°W), Halfway Creek (40.299009°N, -85.236454°W), and White River (40.176764°N, -85.494694°W) (Fig. 1). Fish were collected by seining (3 m wide, 2 m high, 6 mm mesh) for 1-hr at each site, in May through July 2019 (Indiana Scientific Purposes License #19-477). Fish were brought back to the lab and kept alive in tanks if possible or frozen until dissection. Fish were euthanized by tricaine methanesulfonate (MS-222) and given an individual accession number (Hernandez et al. 2007). Before dissection, each fish was examined for cysts formed by *Neascus* spp. (Trematoda: Strigeida; black spot disease) or any other external parasites. Next, fish total length (cm), standard length (cm), and mass (g) were recorded. Necropsies were performed using standard parasitological methods using a Nikon SMZ1500 dissecting scope. The Phylum or Class of each internal parasite was recorded, and parasites were stored in 70% ethanol for further identification due to time constraints. However, we recognize that this general classification limits our understanding of the full extent of the parasitic species present within these ecosystems. The percent prevalence, average intensity with one standard error, and relative abundance per site were determined using the following formulas (Margolis et al. 1982; Mergo & Crites 1986):

1. $$\%\ Prevalence = \frac{\#\ of\ individuals\ of\ a\ host\ spp.\ infected\ with\ a\ particular\ parasite\ spp.}{\#\ of\ hosts\ examined} \times 100$$

2. $$Mean\ intensity = \frac{total\ \#\ of\ individuals\ of\ a\ particular\ parasite\ spp.\ in\ a\ sample\ of\ a\ host\ spp.}{\#\ of\ infected\ individals\ of\ the\ host\ spp.\ in\ the\ sample}$$

3. $$Relative\ abundance = \frac{total\ \#\ of\ indviduals\ of\ a\ particular\ parasite\ species\ in\ a\ sample\ of\ hosts}{total\ \#\ of\ host\ species\ (infected + uninfected)}$$

All parasites were treated as a single species for the above calculations due to the limitations of our data. Shannon diversity (Shannon 1948) was calculated for the fish and parasite assemblages at each site. Further, to determine if there were similarities in fish and parasite assemblages among sites, Jaccard's similarity index (Jaccard 1901) was calculated.

RESULTS

A total of 89 fish across 21 species was collected: 32 from Buck Creek, 33 from Halfway Creek, and 24 from the White River (Table 1). The overall prevalence of parasites for Buck Creek, Halfway Creek, and the White River was 56%, 75%, and 38%, respectively. Further, the mean intensity of parasitic infection was 18.2, 15.9, and 3.3 for Buck Creek, Halfway Creek, and the White River, respectively. Finally, the relative abundance of parasites for Buck Creek, Halfway Creek, and the White River was 11.0, 11.9, and 1.24, respectively (Table 2).

Buck Creek and Halfway Creek had the highest fish Shannon diversity scores (Buck and Halfway

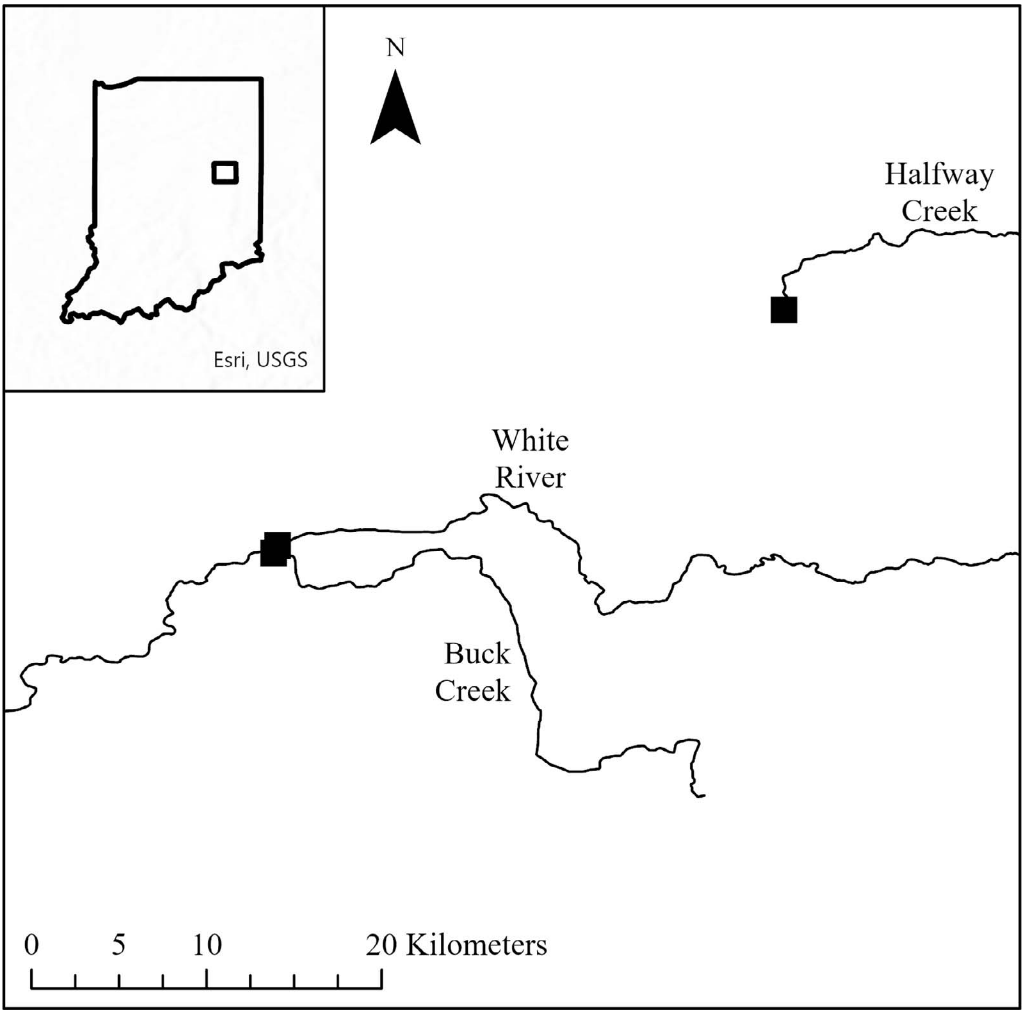

Figure 1.—Map of sampling sites (squares) throughout Delaware County, Indiana (inset map).

Creek H = 2.2), while the White River had the lowest Shannon diversity score (H = 1.5). All three water bodies differed in fish assemblages, though Buck Creek and Halfway Creek were the most similar (J = 0.39). Buck Creek and White River were not similar (J = 0.20), and White River and Halfway Creek were the least similar (J = 0.06). Central Stonerollers (*Campostoma anomalum*) were the only fish species present at all three sites (Table 1).

Buck Creek and White River had the highest parasite Shannon diversity scores (Buck Creek and White River H = 1.0), and Halfway Creek had the lowest (H = 0.9). Buck and Halfway Creek had the most similar parasite assemblages (J = 0.67), followed by Buck Creek and White River (J = 0.60), with White River and Halfway Creek being the least similar (J = 0.33). Black spot disease and trematodes were the only types of parasites found across all the sampling sites (Tables 3–5).

DISCUSSION

High counts of fishes infected with black spot disease, as well as trematodes, acanthocephalans, cestodes, nematodes, and monogeneans were found. Trematodes comprised the majority of internal parasites, and black spot was the only external parasite. The prevalence of helminth taxonomic groups of parasites (e.g., trematodes, cestodes, and nematodes) is consistent with a survey conducted by Buckner et al. (1985), which found a variety of monogenean, digenean,

Table 1.—Abundances of fish species collected from Buck Creek, Halfway Creek, and White River.

Common Name	Scientific Name	Buck Creek	Halfway Creek	White River
Blackstripe Topminnow	*Fundulus notatus*	–	1	–
Bluntnose Minnow	*Pimephales notatus*	3	–	1
Bullhead Minnow	*Pimephales vigilax*	–	2	–
Central Stoneroller	*Campostoma anomalum*	3	4	1
Common Carp	*Cyprinus carpio*	–	1	–
Common Shiner	*Luxilus cornutus*	2	–	3
Creek Chub	*Semotilus atromaculatus*	–	8	–
Emerald Shiner	*Notropis atherinoides*	9	–	10
Johnny Darter	*Etheostoma nigrum*	3	–	–
Northern Hogsucker	*Hypentelium nigricans*	1	–	–
Pumpkinseed	*Lepomis gibbosus*	–	4	–
Rainbow Darter	*Etheostoma caeruleum*	2	–	–
Redfin Shiner	*Lythrurus umbratilis*	–	1	–
River Chub	*Nocomis micropogon*	–	–	2
Rosyface Shiner	*Notropis rubellus*	–	1	–
Silverjaw Minnow	*Notropis buccatus*	3	–	–
Silver Shiner	*Notropis photogenis*	1	–	7
Smallmouth Bass	*Micropterus dolomieu*	3	2	–
Spotfin Shiner	*Cyprinella spiloptera*	1	4	–
Striped Shiner	*Luxilus chrysocephalus*	–	1	–
White Sucker	*Catostomus commersonii*	1	4	–
Total		32	33	24

cestode, and nematode species in fishes throughout southern Indiana.

The host-diversity-begets-parasite-diversity hypothesis suggests that an increase in host diversity should lead to an increase in parasite diversity (Hechinger & Lafferty 2005; Johnson et al. 2016). Kamiya et al. (2014) conducted a meta-analysis of 38 case studies that examined metazoan and protozoan parasites that have an animal host. They found a strong, positive correlation between the species richness of hosts and the species richness of parasites, supporting the host-diversity-begets-parasite-diversity hypothesis. Given that most parasites have a relatively narrow host range, any change in host diversity would be expected to change parasite diversity as well (Johnson et al. 2016). For this study, Buck Creek and Halfway Creek had higher fish species richness and parasite taxonomic richness than the White River, which is consistent with the host-diversity-begets-parasite-diversity hypothesis.

Table 2.—Prevalence, mean intensity (one standard error), and relative abundance of parasites for Buck Creek, Halfway Creek, and the White River.

Variable	Buck Creek	Halfway Creek	White River
Prevalence (%)	56	75	38
Mean Intensity (SE)	18.2 (6.7)	15.9 (3.6)	3.3 (1.2)
Relative Abundance	11.0	11.9	1.25

According to McKenzie (2007), surrounding land-use likely impacts local parasite diversity. For example, row crop agriculture, the dominant land-use in Indiana (Dewitz 2019), may both strengthen and weaken the host-parasite diversity relationship. Agricultural land use may increase nutrients within the surrounding ecosystem, potentially leading to increases in the number of available hosts and, consequently, the richness of parasites (McKenzie 2007). Specifically, nutrient-enriched ecosystems may attract snails that serve as intermediate hosts for many parasites, such as the trematode yellow grub (*Clinostomum complanatum*), which subsequently inhabits a fish host after the snail host (Mitchum 1995; Valtonen et al. 1997; Rohr et al. 2008). In addition, increased nutrients from agricultural run-off leads to increases in algae, which is a food source for aquatic gastropods (Rohr et al. 2008). Therefore, an increase in intermediate hosts may lead to an increase in parasites. For this study, all sites were influenced by agricultural modifications (Holloway 2021), which could explain why fish, such as Creek Chub (*Semotilus atromaculatus*), in which aquatic snails are a primary food source (Bernot 2003), had high counts of trematode infections.

Table 3.—Abundances of trematodes, acanthocephalans, cestodes, nematodes, monogeneans, and black spot occurrences for each fish species collected from Buck Creek. Fish species not listed here but were present in Buck Creek (Table 1) did not have parasites.

Fish Species	Trematoda	Acanthocephala	Cestoda	Nematoda	Monogenea	Black Spot
Bluntnose Minnow	16	0	0	0	0	72
Central Stoneroller	0	0	0	0	0	7
Common Shiner	10	0	0	0	0	10
Emerald Shiner	3	4	0	0	0	11
Northern Hogsucker	0	0	0	0	0	1
Silver Shiner	0	0	0	0	0	11
Silverjaw Minnow	0	0	0	0	0	1
Smallmouth Bass	165	14	3	12	0	1
Spotfin Shiner	0	0	0	0	0	3
Total	194	18	3	12	0	117

Diet, and inherently body-size, may play a role in shaping host-parasite relationships (Bell & Burt 1991; Poulin & Leung 2011; Gaeta et al. 2018). For example, Smallmouth Bass (*Micropterus dolomieu*) are larger piscivores and previous studies show that piscivores tend to have more helminth parasites than non-piscivores (Bell & Burt 1991). Similarly, for this study, Smallmouth Bass had high counts of trematodes at the sites they were present, as well as infections of cestodes and nematodes. Contrarily, fish that consume detritus as their main food source, such as White Sucker (*Catostomus commersoni*), are at less risk of becoming infected by parasites transmitted by predation (Ahlgren 1990; Ahlgren 1996). Parasites were not found in or on any White Suckers collected in this study, which is consistent with the literature that suggests their diet makes them less vulnerable of becoming infected.

Black spot disease is prevalent in many fishes such as cyprinids, catostomids, centrarchids, and ictalurids (Hoffman 1967; Mitchum 1995). Overall, the metacercariae, or the larval forms of trematodes that cause black spot disease, are generally regarded as having low host-specificity (Paperna 1995). Perhaps the observed prevalence of black spot disease across fish species with different diets and sizes at all our sites was due to its low host specificity. Our results are similar to Berra & Au (1978), who reported 89% of their 4,175 fishes sampled were infected with black spot disease in Cedar Fork Creek, Ohio. Notably, Berra & Au (1978) observed that Creek Chub, Central Stonerollers, and Eastern Blacknose Dace (*Rhinichthys atratulus*) had the highest infection prevalence.

Given the implications that parasites may have on ecosystem and human health, further research on parasites and the systems they inhabit is warranted (McKenzie 2007; Wood et al. 2018). This study provides a baseline documentation of some of the parasites for fish assemblages of

Table 4.—Abundances of trematodes, acanthocephalans, cestodes, nematodes, monogeneans, and black spot occurrences for each fish species collected from Halfway Creek. Fish species not listed here but were present in Halfway Creek (Table 1) did not have parasites.

Name	Trematoda	Acanthocephala	Cestoda	Nematoda	Monogenea	Black Spot
Bullhead Minnow	21	0	0	0	0	3
Central Stoneroller	1	0	0	0	0	12
Common Carp	0	0	0	0	0	1
Creek Chub	198	0	0	0	5	33
Pumpkinseed	1	0	0	2	0	0
Smallmouth Bass	36	0	26	0	0	0
Spotfin Shiner	1	0	0	7	0	26
Striped Shiner	6	0	0	0	0	2
Total	264	0	26	9	5	77

Table 5.—Abundances of trematodes, acanthocephalans, cestodes, nematodes, monogeneans, and black spot occurrences for each fish species collected from White River. Fish species not listed here but were present in White River (Table 1) did not have parasites.

Name	Trematoda	Acanthocephala	Cestoda	Nematoda	Monogenea	Black Spot
Central Stoneroller	0	0	0	0	0	1
Emerald Shiner	7	5	0	0	0	3
River Chub	1	1	0	0	0	0
Silver Shiner	8	0	0	0	0	4
Total	16	6	0	0	0	8

Delaware County, Indiana. Future investigations might include expanding this study to a state-wide survey of parasites as well as identify parasites to lower taxonomic groups in order to fully examine what drives the relationship between parasite diversity and host diversity. Further, trends relating parasite load or communities to host size, trophic level, water quality, or other abiotic factors may provide more insight on parasite dynamics and ecology for Indiana lotic ecosystems.

ACKNOWLEDGMENTS

We thank Jessica Weir, Daniel Cassel, Emily Dewig, and Lauren Wines for their assistance in the field. Further, we extend our appreciation to Dr. Mark Pyron, Dr. Adam Berland, and Dr. Amy Gregg for their help with developing this project. This research was approved by the Institutional Animal Care and Use Committee at Ball State University (IACUC #595754-1).

LITERATURE CITED

Ahlgren, M.O. 1990. Diet selection and the contribution of detritus to the diet of juvenile white sucker (*Catostomus commersoni*). Canadian Journal of Fisheries and Aquatic Sciences 47:41–48.

Ahlgren, M.O. 1996. Selective ingestion of detritus by a north temperate omnivorous fish, the juvenile white sucker, *Catostomus commersoni*. Environmental Biology of Fishes 46:375–381.

Bell, G. & A. Burt. 1991. The comparative biology of parasite species diversity: internal helminths of freshwater fish. Journal of Animal Ecology 60:1047–1064.

Bernot, R.J. 2003. Trematode infection alters the antipredator behavior of a pulmonated snail. Journal of the North American Benthological Society 22:241–248.

Bernot, R.J. & G.A. Lamberti. 2008. Indirect effects of a parasite on a benthic community: an experiment with trematodes, snails and periphyton. Freshwater Biology 53:322–329.

Berra, T.M. & R.J. Au. 1978. Incidence of black spot disease in fishes in Cedar Fork Creek, Ohio. Ohio Journal Academy of Sciences 78:318–322.

Buckner, R.L., M.W. Denner, D.R. Brooks & S.C. Buckner. 1985. Parasitic endohelminths from fishes of southern Indiana. Proceedings of the Indiana Academy of Science 94:615–620.

Bush, A.O., J.C. Fernandez, G.W. Esch & J.R. Seed. 2001. Parasitism – The Diversity and Ecology of Animal Parasites. Cambridge University Press, Cambridge, United Kingdom. 566 pp.

Cornet, S. & G. Sorci. 2010. Parasite virulence when the infection reduces the host immune response. Proceedings of the Royal Society B: Biological Sciences 227:1929–1935.

Dewitz, J. 2019. National Land Cover Database (NLCD) 2016 Products: U.S. Geological Survey Data release. At: https://www.sciencebase.gov/catalog/item/5dadee41e4b09fd3b0c9d8ed (Accessed 9 August 2019).

Dobson, A., K.D. Lafferty, A.M. Kuris, R.F. Hechinger &W. Jetz. 2008. Homage to Linnaeus: how many parasites? How many hosts? PNAS 105:11482–11489.

Gaeta, J.W., T.D. Ahrenstorff, J.S. Diana, W.W. Fetzer, T.S. Jones, Z.J. Lawson, M.C. McInerny, V.J. Santucci & M.J. Vander Zanden. 2018. Go big…or don't? A field-based diet evaluation of freshwater piscivore and prey fish size relationships. PLoS ONE 13:e0194092.

Grizzle, J.M. & M.T. Goldsby, Jr. 1996. White grub *Posthodiplostomum minimum* centrarchid metacercariae in the liver of largemouth bass: quantification and effects on health. Journal of Aquatic Health 8:70–74.

Hechinger, R.F. & K.D. Lafferty. 2005. Host diversity begets parasite diversity: bird final hosts and trematodes in snail intermediate hosts. Proceedings of the Royal Society B: Biological Sciences 272:1059–1066.

Hernandez, A.D., J.F. Bunnell & M.V.K. Sukhdeo. 2007. Composition and diversity patterns in metazoan parasite communities and anthropogenic disturbance in stream ecosystems. Parasitology 134:91–102.

Hoffman, G.L. 1967. Parasites of North American Freshwater Fishes. University of California Press, Berkeley, California. 486 pp.

Holloway, D. 2021. Bureau of Water Quality Annual Fish Community Report 2020. Muncie Sanitary District. Muncie, Indiana. (Accessed 30 November 2022).

Hudson, P.J., A.P. Dobson & K.D. Lafferty. 2006. Is a healthy ecosystem one that is rich in parasites? Trends in Ecology and Evolution 21:381–385.

Hunt, R. & J. Cable. 2020. Life in the fast lane: temperature, density and host species impact survival and growth of the ectoparasite *Argulus foliaceus*. Journal of Thermal Biology 92:1102687.

IN DNR (Indiana Department of Natural Resources). 2021. Fish Disease. Indianapolis, Indiana. (Accessed 20 November 2021).

Jaccard, P. 1901. Distribution of the Alpine flora in the Dranse's Basin and some neighbouring regions. Bulletin de la Societe vaudoise des Sciences Naturelles 37:241–272.

Johnson, P.T., C.L. Wood, M.B. Joseph, D.L. Preston, E. Sarah & Y.P. Springer. 2016. Habitat heterogeneity drives the host-diversity-begets-parasite diversity relationship: evidence from experimental and field studies. Ecology Letters 19:752–761.

Kamiya, T., K. O'Dwyer, S. Nakagawa & R. Poulin. 2014. Host diversity drives parasite diversity: meta-analytical insights into patterns and causal mechanisms. Ecography 37:689–697.

Lafferty, K.D., A.P. Dobson & A.M. Kuris. 2008. Reef fishes have higher parasite richness at unfished Palmyra Atoll compared to fished Kiritimati Island. Ecohealth 5:338–345.

Lemly, A.D. & G.W. Esch. 1984. Effects of the trematode *Uvulifer ambloplitis* on juvenile bluegill sunfish, *Lepomis macrochirus*: ecological implications. The Journal of Parasitology 70:475–492.

Marcogliese, D.J. & J. Price. 1997. The paradox of parasites. Global Biodiversity 7:7–15.

Margolis, L., G.W. Esch, J.C. Holmes, A.M. Kuris & G.A. Schad. 1982. The use of ecological terms in parasitology. Journal of Parasitology 68:131–133.

McKenzie, V.J. 2007. Human land use and patterns of parasitism in tropical amphibian hosts. Biological Conservation 137:102–116.

Mergo, J.C. & J.L. Crites. 1986. Prevalence, mean intensity, and relative density of *Lintaxine cokeri* Linton 1940 (Monogenea: Heteraxinidae) on Freshwater drum (*Aplodinotus grunniens*) in Lake Erie 1984. Ohio Journal of Science 86:101–105.

Mitchum, D.L. 1995. Digenetic trematodes. Pp. 88–90. *In* Parasites of Fishes in Wyoming. Wyoming Game and Fish Department, Cheyenne, Wyoming.

Miura, O., A.M. Kuris, M.E. Torchin, R.F. Hechinger, E.J. Dunham & S. Chiba. 2005. Molecular-genetic analyses reveal cryptic species of trematodes in the intertidal gastropod, *Batillaria cumingi* (Crosse). International Journal for Parasitology 35:793–801.

Paperna, I. 1995. Digenea (phylum Platyhelminthes). Pp.329–389. *In* Fish Diseases and Disorders: Protozoan and Metazoan Infections. (P.T.K.Woo, Ed.). CAB International, Wallingford, United Kingdom.

Poulin, R. 2014. Parasite biodiversity revisited: frontiers and constraints. International Journal for Parasitology 44:581–589.

Poulin, R. & S. Morand. 2004. Parasite Biodiversity. Smithsonian Institution Books, Washington, D.C. 216 pp.

Poulin, R. & T.L.F. Leung. 2011. Body size, trophic level, and the use of fish as transmission routes by parasites. Oecologia 166:731– 738.

Rohr, J.R., A.M. Schotthoefer, T.R. Raffel, H.J. Carrick, N. Halstead, J.T. Hoverman, C.M. Johnson, L.B. Johnson, C. Lieske, M.D. Piwomi, P.K. Schoff & V.R. Beasley. 2008. Agrochemicals increase trematode infections in a declining amphibian species. Nature 455:1235–1240.

Shannon, C.E. 1948. A mathematical theory of communication. The Bell System Technical Journal 27:379–423.

Sohn, W., B. Na, S.G. Jung & K.H. Kim. 2016. Mass death of predatory carp, *Chanodichthys erythropterus*, induced by plerocercoid larvae of *Ligula intestinatlis* (Cestoda: Diphyllobothriidae). Korean Journal of Parasitology 54:363–368.

Timi, J.T. & R. Poulin. 2020. Why ignoring parasites in fish ecology is a mistake. International Journal for Parasitology 50:755–761.

Valtonen, E.T., J.C. Holmes & M. Koskivaara. 1997. Eutrophication, pollution, and fragmentation: effects on parasite communities in roach (*Rutilus rutilus*) and perch *(Perca fluviatilis*) in four lakes in central Finland. Canadian Journal of Fisheries and Aquatic Sciences 54:572–585.

Wood, C.L. & P.T. Johnson. 2015. A world without parasites: exploring the hidden ecology of infection. Frontiers in Ecology and the Environment 13:425–434.

Wood, C.L., B.J. Zgliczynski, A.J. Haupt, A.S. Guerra, F. Micheli & S.A. Sandin. 2018. Human impacts decouple a fundamental ecological relationship – the positive association between host diversity and parasite diversity. Global Change Biology 24:3666–3679.

Manuscript received 16 August 2022, revised 8 December 2022.