

Diversity of metazoan parasites of the African catfish *Clarias gariepinus* (Burchell, 1822) as indicators of pollution in a subtropical African river system

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Abstract

The relationship between parasite species diversity and organic pollution in the upper Manyame catchment, Zimbabwe, was investigated between October 2006 and January 2007. The parasite assemblage comprised 13 species in total. Species richness in the unpolluted sites was high; in the moderately polluted sites, it was low, while in the polluted sites, only one parasite species was encountered. Component community diversity, as measured by the Shannon index (H'), decreased with increase in organic pollution. The distribution and occurrence of ectoparasites (*Dolops ranarum*, *Lamproglana clariae*, *Chonopeltis* sp. and *Macroglyrodactylus* sp.) and one endoparasite (*Lytocestus* sp.) were limited to the unpolluted sites, demonstrating their sensitivity to organic pollution. The prevalence of the nematodes *Paracamallanus cyathopharynx*, *Procamallanus laevionchus* and *Contracaecum* spp. larvae decreased along the pollution gradient, showing their high sensitivity to organic pollution. The platyhelminths *Diplostomum* sp. and *Polyonchobothrium clarias* were the most tolerant and occurred at both polluted and unpolluted sites. *Proteocephalus* sp. and *Caryophyllaeus* sp. were limited to the polluted sites, probably as a result of high abundance of oligochaetes and copepods, their intermediate hosts that thrive in sewage-enriched sediments, at the downstream sites. The observed results assume that the decrease in parasite diversity can be related to increased organic pollution. Some parasites requiring complex life histories were absent along with pollution-related disappearance of their vector hosts. Further studies should address the identification of parasite life stages that are more sensitive to pollutants.

Introduction

Most of the human impacts on the aquatic environment affect the health of the resident fish fauna, eventually causing disease and associated mortalities

(Poulin, 1992). Parasites usually exist in equilibrium with their hosts as a survival strategy (Bush *et al.*, 2001). However, in instances where the hosts are overcrowded, such as in aquaria and fish farms, parasitic diseases can spread very rapidly and cause gross mortalities (Paperna, 1996). This is not usually the case in the wild, natural aquatic environment unless it is disturbed by human interference such as pollution, which can alter the natural distribution of parasite communities

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and infracommunities (Bush *et al.*, 2001). The relative abundance of endo- and ectoparasites of fish in a particular aquatic system can be used as an indicator of environmental stress (Avenant-Oldewage, 2001). Ectoparasites, for instance, are more in contact with water; if they are sensitive to a pollutant, there will be fewer ectoparasites than endoparasites in a polluted system, while the converse is also true (Avenant-Oldewage, 2001).

Virtually, all free-living organisms are hosts to parasites, and parasitism, in its broadest sense, is considered to be the most common lifestyle on Earth (Price, 1980). Thus, healthy ecosystems can be hardly considered disease free. The fact that parasites possess complex life cycles makes them extremely valuable information units about environmental conditions, because their presence/absence tells us a great deal about not only their host ecology but also food web interactions, biodiversity and environmental stress (Overstreet, 1997; Marcogliese, 2003, 2004). Combining different species based on shared patterns of transmission provides a potentially more powerful indicator of prevailing environmental conditions. Hudson *et al.* (2006) argue that many ecological factors affecting fish parasite life cycles and the complexity of aquatic food webs are important in determining ecosystem health, while Blonar *et al.* (2009) investigated associations and responses of specific fish-parasitic taxa to different contaminants to come up with a quantitative approach that will be important in studying parasite–host–pollution interactions.

Each parasite species reflects the presence of different organisms that participate in its life cycle; together, all these parasite species in a host reflect the presence of a plethora of host organisms and trophic interactions in the environment (Marcogliese, 2003). Thus, parasites potentially may be used as surrogate indicators of species diversity and ecosystem diversity, two of the three important levels of biodiversity cited in the Rio Convention on Biological diversity (Marcogliese, 2003). Given that pollution may have impacts on populations and communities of organisms, and thus on food web structure, parasites may be used as natural biological tags of ecosystem health. The species composition of parasite communities is clearly impacted by environmental stress, and species richness tends to decrease under degraded conditions.

Numerous investigators have examined the effects of environmental stress on single species of parasites in temperate aquatic systems (Khan & Thulin, 1991; Overstreet, 1993; MacKenzie *et al.*, 1995; Williams & Mackenzie, 2003; Marcogliese, 2004; Sures, 2004), despite the fact that it is difficult to predict the direction of effects of pollution impacts on parasite communities. Most studies document changes in some aspect of the parasite fauna, and it is clear that pollution has effects on parasite populations and communities and is, however, often associated with a reduction in species richness of parasites (Marcogliese, 2004).

This study intended to establish the relationship between metazoan parasites and pollution levels in the catchment. The specific objectives of this study were to determine the biodiversity of metazoan parasite

communities of *Clarias gariepinus* in the Upper Manyame catchment and to compare the diversity and distribution of metazoan parasite fauna along defined pollution gradients in the Upper Manyame catchment and assess the suitability of using parasites as predictors of environmental change.

Materials and methods

Study area

The upper Manyame River catchment extends over an area of 2227 km² and most of Harare and its dormitory town of Chitungwiza (established in the 1970s) lie within the catchment (Magadza, 1997). About 10% of the catchment comprises urban developments, while 90% is rural, comprising commercial farmland and communal land (Magadza, 1997). The Nyatsime, Manyame and Mukuvisi rivers in the catchment were selected for this study (fig. 1). The three rivers display a gradient in pollution as most of the urban and industrial run-off finds its way into them before draining into Lake Chivero. The city of Harare, with a population of about 3 million people, lies within the catchment and all its domestic and industrial effluents eventually flow into the lake. The lake has been eutrophic since the 1960s (Marshall, 1994, 1997) with serious water quality problems that have led to fish kills in the lake and its feeder tributaries, Nyatsime, Marimba and Manyame (Magadza, 1997; Marshall, 1997; Moyo, 1997).

The Mukuvisi River is severely polluted by poorly treated sewage effluent and industrial discharge (Moyo & Worster, 1997; Staneva, 1997; Zaranyika, 1997). The Nyatsime and Manyame rivers above Lake Chivero are also severely polluted by sewage effluent from Chitungwiza. Lack of resources to upgrade sewage treatment

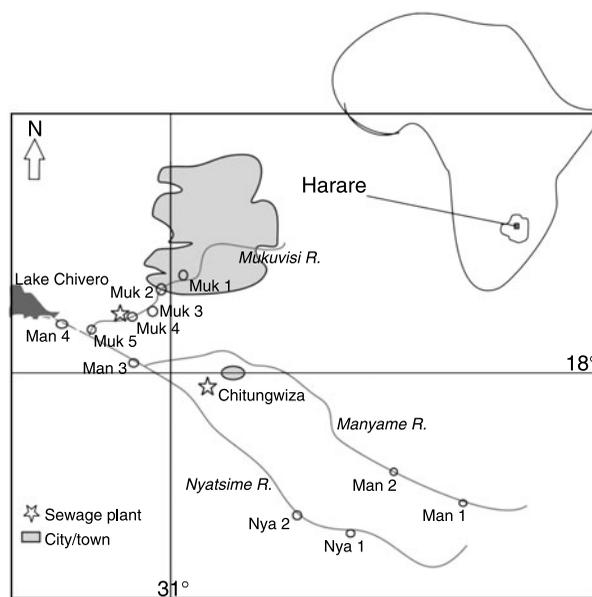


Fig. 1. The Upper Manyame catchment system (Zimbabwe) showing the location of sampling sites on the Manyame (Man), Mukuvisi (Muk) and Nyatsime (Nya) rivers.

works, lack of funding to water quality management and research, overcrowding, bureaucracy and poor management of wetlands have led to the eutrophication of the lake and its feeder tributaries (Magadza, 1997, 2003). Much of the work on aquatic pollution in the Upper Manyame catchment has focused on the analysis of physicochemical conditions of water (Marshall & Falconer, 1973; Mathuthu *et al.*, 1993, 1997; Jarawaza, 1997; Magadza, 1997, 2003; Zaranyika, 1997). The effect on the biota has generally been overlooked with the exception of isolated studies by Moyo & Worster (1997), Moyo & Phiri (2002) and Gratwicke *et al.* (2003).

Fish and parasite collection

Fish were collected over a 3-month period (October–December 2006) using a Smith-Root VI electrofisher powered by a Honda generator producing 750 V DC, although the output varied according to the conductivity of the water. A seine net was used at the confluence of the Manyame River into Lake Chivero. The body surface, fins and buccal cavity of each fish caught were immediately examined for ectoparasites. Ectoparasitic crustaceans from the external surfaces were kept alive in dam water and were then transported to the laboratory for further parasitological examination. In the laboratory, the standard and total lengths (mm), mass (g) and sex of each fish were recorded. The fish were kept in aerated tanks and examined within 12 h after sampling.

The gills were dissected and examined for ectoparasites, of which the crustaceans were cleared in lactic acid and preserved in 70% alcohol. Monogeneans were fixed with Malmberg's solution (ammonium picrate glycerine) before being preserved in 70% alcohol. Portions of the muscles, viscera and the gastrointestinal tract were dissected and examined for internal parasites. Cestodes were relaxed in saline solution, fixed in a hot alcohol-formol-acetic acid (AFA) solution and preserved in 70% alcohol. Encysted digeneans were first excysted, fixed in hot AFA and preserved in 70% alcohol. Nematodes were fixed in glacial acetic acid until they died and stretched, then preserved in 70% alcohol. They were then cleared and mounted in lactophenol. Cestodes and digeneans were stained in aqueous acetocarmine solution.

Surface water temperature and dissolved oxygen content were measured using a HACH oxygen meter; conductivity, using a WTW conductivity meter and pH using a HACH pH meter. Subsurface water samples were collected in 1-litre plastic containers rinsed in deionized water. The samples were taken to the laboratory where they were frozen and analysed for the following micronutrients: reactive phosphate, total phosphorus, total nitrogen and nitrate.

Data analysis

Parasite prevalence, mean intensities and abundance were measured and calculated as defined by Bush *et al.* (2001). Shannon's diversity index (H') was calculated as a measure of community diversity (Magurran, 1988) and the terms 'diversity' and 'diverse' are used to reflect the values of this diversity index. Species richness refers to the number of species. Infracommunity refers to the

community of parasite species in a host individual, component community richness was defined as the number of species present in a sample from a single locality (Sousa, 1994). Hierarchical cluster analysis was used to assess the similarities among (1) parasite component communities of the different sites and (2) sampling sites based on the physicochemical variables.

Principal component analysis (PCA) was performed to determine the pattern of distribution of parasite species among the sites. All infection data were normalized with $\log(x + 1)$ transformations to achieve homoscedasticity or linearity. Environmental data were also $\log(x + 1)$ transformed to suit the multivariate analysis techniques used. All physical variables were standardized to zero mean and unit variance to make them dimensionless. Results were considered significant at the 95% level ($P < 0.05$). Ordination was done using CANOCO version 4 (Ter Braak & Smilauer, 1998), and STATISTICA version 7 (STATSOFT Inc., Tulsa, Oklahoma, USA) was used for correlation, regression and correspondence analysis.

Results

Water quality

The water temperature varied with the time of sampling, ranging from 22.8 to 26.4°C. Dissolved oxygen levels were high at Mukuvisi 3 (6.4 mg/l), Manyame 2 (6.6 mg/l) and Nyatsime 2 (6.5 mg/l), and lowest at Manyame 4 (2.2 mg/l) and Mukuvisi sites 2 and 4 (4 mg/l). Conductivity readings were higher (420–744 $\mu\text{S}/\text{cm}$) than those of the rural sites (100–228 $\mu\text{S}/\text{cm}$). Water pH was neutral to slightly alkaline (range 6.86–8.9) at all the sampling sites. Within the Manyame system, all the nutrients were quite low in the rural sites and higher downstream towards the lake. All the Mukuvisi sites had high levels of nutrients (table 1). The heavily impacted sites in terms of increased level of nitrates, phosphates, conductivity and reduced dissolved oxygen content levels included all the Mukuvisi sites and Manyame sites 3 and 4, while the rural sites (Manyame/Nyatsime) remained comparatively unimpacted (table 1).

Cluster analysis to group sites according to similarities in physicochemical variables showed three distinct clusters (fig. 2). The four rural sites were clustered together because they belong to the same rural catchment and had similar physicochemical variables of low levels of macronutrients and conductivity (fig. 2). These sites are located in the upper reaches of the catchment, which is still pristine. There was evidence of increasing pollution as the rivers progress towards the lake (Manyame 4).

Species composition, diversity and distribution

A total of 72 catfish out of the 110 catfish caught were infected with parasites. Thirteen species of metazoan parasites were encountered in total from 72 infected fish collected from the three rivers in this survey (tables 2 and 3). The endoparasites included two digenean metacercariae (*Tylodelphys* sp. and *Diplostomum* sp.); four adult cestodes (*Proteocephalus* sp., *Polyonchobothrium clarias*, *Caryophyllaeus* sp. and *Lycocestus* sp.); three nematode

Table 1. Physicochemical parameters of water samples from the sampling localities on the Manyame (Man), Mukuvisi (Muk) and Nyatsime (Nya) rivers.

	pH	Cond	DO	TN	TP	NO ₃	PO ₄	T (°C)
Man 1	7.5	99.99	5.9	2.9	0.15	0.15	0.43	22.8
Man 2	7.7	121.5	6.6	3.5	0.23	0.16	0.45	24.9
Man 3	8.9	622	3.9	3.56	5.6	6.9	5.6	24.7
Man 4	6.86	420	2.2	12.9	2.2	1.8	0.84	25.32
Nyat 1	7.2	173	5.8	1.5	0.1	0.12	0.3	26.4
Nyat 2	7.3	228	6.5	3.2	0.14	0.1	0.42	25.6
Muk 1	8	744	4.2	22.15	4.6	4.9	4.5	24.6
Muk 2	8.3	641	4	19.5	4.3	5.2	3.4	24.5
Muk 3	8.5	420	6.4	13.36	2.4	1.9	0.74	26.1
Muk 4	8.18	639	4	18.5	3.2	5.4	3	24.1
Muk 5	8.7	399	5.8	12.25	2	2	0.9	23.6

Cond, conductivity; DO, dissolved oxygen content; TN, total nitrogen; TP, total phosphate, NO₃, nitrate; PO₄, phosphate.

With the exception of pH (no unit) and temperature (°C), all parameters are in mg/l.

species (larval *Contracaecum*, adult *Paracamallanus cyathopharynx* and adult *Procammallanus laevionchus*). The four ectoparasite species encountered include three crustaceans, *Chonopeltis* sp. and *Dolops ranarum* (Branchiura), *Lamproglea clariae* (Copepoda), and a monogenean (*Macrogyrodactylus clarii*). One ectoparasite, *L. clariae*, was found at all the rural sites, while *M. clarii*, *Chonopeltis* sp. and the cestode, *Lytocestus*, were found only at the Nyatsime rural sites. *Dolops ranarum* only occurred at Manyame rural sites.

Parasites were identified as much as possible to species level, but where this was not possible, they were identified to genus level. With reference to a diagnostic compendium by Avenant-Oldewage & Knight (1994), we propose that our *Chonopeltis* sp. could tentatively be *Chonopeltis fryeri* (Van As, 1986), based on morphological similarity. This is one of the only 2 out of 13 *Chonopeltis* species that infest *C. gariepinus* in Africa (the other being *C. inermis* (Thiele, 1900)). If confirmed, our record of this species would be the first in the Zambezi system, since it is only recorded from the Limpopo system to date (Avenant-Oldewage & Knight, 1994). What we refer to as *Proteocephalus* sp. could actually be the new cestode genus

and species, *Barsonella lafoni* (de Chambrier *et al.*, 2009), which all along we have been misidentifying (M. Barson, unpublished MPhil thesis, University of Zimbabwe). It certainly differs from the only confirmed proteocephalid species infecting *C. gariepinus* in southern Africa, *Proteocephalus glanduligerus* (Janicki, 1928) (Mashego, 2001; Barson & Avenant-Oldewage, 2006; Scholz *et al.*, 2009), but, for the purposes of this paper, we retain the use of *Proteocephalus* pending further diagnosis. Caryophyllid cestodes (*Caryophyllaeus* sp. and *Lytocestus* sp.) were also difficult to appreciate and a more detailed taxonomic study is ongoing to resolve these peculiarities.

Parasite species richness decreased as pollution levels increased (table 4). The non-polluted sites had higher species diversity (8–10), dominated by *P. laevionchus* and *D. ranarum*, while the polluted sites had lower species diversity (3–4) and dominated by *Diplostomum* sp. and *P. cyathopharynx*. The lowest species diversity (2–1) was found in the severely polluted sites, and *P. laevionchus* and *Contracaecum* sp. larvae occurred at these sites in very low abundances. The unpolluted sites had the highest diversity ($H' = 0.96$ – 2.00) because they had more unique species. The polluted sites had lower diversity

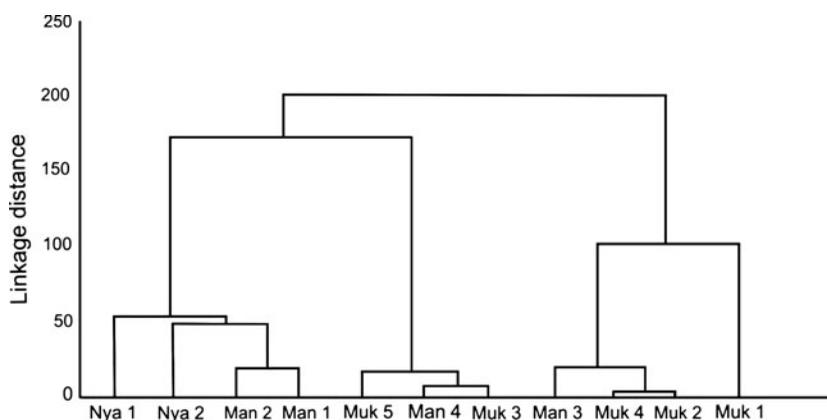


Fig. 2. Cluster analysis showing similarity among 11 sites based on physicochemical variables. Man, Manyame; Muk, Mukuvisi; Nya, Nyatsime.

Table 2. Prevalence (*P*), mean abundance (MA), intensity (range) and mean intensity (MI) of platyhelminth parasites of *Clarias gariepinus* in the upper Manyame catchment.

Parasite species	MAN 1	MAN 2	MAN 3	MAN 4	NYA 1	NYA 2	MUK 1	MUK 2	MUK 3	MUK 4	MUK 5
Trematoda											
<i>Diplostomum</i>											
<i>P</i> (%)	44.4	33.3	–	–	11.8	9.1	–	–	62.5	–	66.7
MA	14.4	13.33			21.4	0.91			74.38		10
MI (range)	32.5 (10–90)	40 (40)			75 (30–120)	10 (10)			19 (20–350)		15 (10–20)
<i>Tylodelphys</i>											
<i>P</i> (%)	–	–	–	–	5.9	18.2	–	–	–	–	–
MA					0.59	0.18					
MI (range)					10 (10)	1 (1)					
Monogenea											
<i>Macrogyrodactylus</i>											
<i>P</i> (%)	–	–	–	–	23.5	18.2	–	–	–	–	–
MA					1.14	0.18					
MI (range)					2 (1–5)	1 (1)					
Cestoidea											
<i>Polyonchobothrium clarias</i>											
<i>P</i> (%)	22.2	33.3	57.1	–	11.8	10	–	–	18.8	–	16.7
MA	0.44	0.67	1.57		0.18	0.1			0.5		0.83
MI (range)	2 (1–2)	2 (1–2)	3.67 (1–6)		1.5 (1–3)	2.67 (1–4)			2.7 (1–4)		5 (5)
<i>Lytocestus</i> spp											
<i>P</i> (%)	22	33.3	–	–	29.4	18.2	–	–	–	–	–
MA	0.221	0.33			0.29	0.18					
MI (range)	1 (1–3)	1 (1)			1 (1)	1 (1)					
<i>Caryophyllaeus</i>											
<i>P</i> (%)	–	–	–	–	–	–	–	–	31.3	–	16.7
MA	–	–	–	–	–	–	–	–	0.94	–	0.83
MI (range)	–	–	–	–	–	–	–	–	3 (2–5)	–	5 (5)
<i>Proteocephalus</i>											
<i>P</i> (%)	–	–	–	33.3	–	–	–	–	–	–	–
MA											
MI (range)	–	–	–	2.5	–	–	–	–	–	–	–

MAN, Manyame River; NYA, Nyatsime River; MUK, Mukuvisi River.

Table 3. Prevalence (*P*), mean abundance (MA), intensity (range) and mean intensity (MI) of nematodes and crustaceans of *Clarias gariepinus* in the Upper Manyame catchment.

Parasite species	MAN 1	MAN 2	MAN 3	MAN 4	NYA 1	NYA 2	MUK 1	MUK 2	MUK 3	MUK 4	MUK 5
Nematoda											
<i>Contracaecum</i>											
<i>P</i> (%)	22.2	33.3	–	33.3	5.9	18.2	14.3	14.3	56.3	–	–
MA	0.22	0.83		1.83	0.06	0.45	0.14	0.1	0.31		
MI (range)	1 (1)	1 (1)		5.5 (4–7)	1 (1)	2.5 (1–4)	1 (1)	1 (1)	1.3 (1–2)		
<i>Procammallanus laevionchus</i>											
<i>P</i> (%)	33.3	66.7	14.3	50	58.8	36.4	–	–	–	14.3	–
MA	0.44	2	0.42	1.3	2.18	0.73				0.29	
MI (range)	1.3 (1–2)	3 (1–5)	3 (3)	3 (1–4)	3.7 (1–7)	2 (1–4)				1.3 (1–2)	
<i>Paracammallanus cyathopharynx</i>											
<i>P</i> (%)	66.7	33.33	–	66.7	52.9	27.3	–	–	–	–	–
MA	1.67	1.33		2.67	1.65	0.64					
MI (range)	2.5 (1–6)	4 (4)		8 (2–8)	3.1 (1–10)	2.3 (1–4)					
Crustacea											
<i>Chonopeltis</i>											
<i>P</i> (%)	–	–	–	–	47.1	27.3	–	–	–	–	–
MA					0.18	0.45					
MI (range)					1.6 (1–4)	1.7 (1–3)					
<i>Lamproglana clariae</i>											
<i>P</i> (%)	55.6	33.3	–	–	41.9	27.3	–	–	–	–	–
MA	0.67	0.33			0.65	1					
MI (range)	1.2 (1–2)	1 (1)			1.6 (1–4)	3.7 (3–4)					
<i>Dolops ranarum</i>											
<i>P</i> (%)	77.8	66.7	–	–	–	–	–	–	–	–	–
MA	0.89	0.67									
MI (range)	1.1 (1–3)	1 (1)									

MAN, Manyame River; NYA, Nyatsime River; MUK, Mukuvisi River.

Parasite diversity as indicators of pollution

Table 4. Diversity measures of metazoan parasite component communities in *Clarias gariepinus* along a pollution gradient.

Pollution class	Sites	N	Species richness	H'	H'E	Dominant species	Prevalence (%)
Non-polluted sites	Nyatsime 1	17	10	1.92	0.9	<i>Procamallanus laevisonchus</i>	58.8
	Nyatsime 2	12	10	2.00	0.9	<i>P. laevisonchus</i>	36.4
	Manyame 1	14	8	0.96	0.5	<i>Dolops ranarum</i>	77.8
	Manyame 2	11	8	1.18	0.7	<i>P. laevisonchus</i>	66.7
Polluted sites	Manyame 4	9	4	0.5	0.5	<i>Paracamallanus cyathopharynx</i>	66.7
	Mukuvisi 3	8	4	0.4	0.1	<i>Diplostomum</i> spp.	62.4
	Mukuvisi 5	8	3	0.1	0.1	<i>Diplostomum</i> spp.	66.7
Severely polluted sites	Manyame 3	8	2	0.1	0.1	<i>Polyonchobothrium clarias</i>	57.1
	Mukuvisi 4	7	1	0	0	<i>P. laevisonchus</i>	14.3
	Mukuvisi 2	7	1	0	0	<i>Contraecum</i> spp.	14.3
	Mukuvisi 1	9	1	0	0	<i>Contraecum</i> spp.	14.3

N represents the number of fish hosts collected from each site, H' represents the Shannon diversity index, and H'E represents Shannon's equitability or evenness.

(H' = 0.1–0.5) indicating that there were no parasites in catfish from severely polluted sites. Evenness (H'E) was highest at Nyatsime sites 1 and 2, suggesting an evenly distributed and an assorted assemblage.

Most species were of intermediate abundance as reflected by the lower prevalence of the constituent species (tables 2–4). The H'E for the other two unpolluted sites (Manyame 1 and 2) had slightly decreased showing that there were taxa that occurred more frequently than others, and in these two sites *D. ranarum* and *P. laevisonchus* outnumbered the other species (tables 2–4). There was no heterogeneity of species in the polluted sites (H'E = 0.1–0.5) and severely polluted sites (H'E = 0), as demonstrated by the occurrence of rare species such as *Proteocephalus* sp. and *Caryophyllaeus* sp., respectively (table 4).

The species that are evidently associated with the pristine sites are the ectoparasites (*D. ranarum*, *Chonopeltis* sp., *M. clarii* and *L. clariae*; tables 2–4). The cammalanids, *P. laevisonchus* and *P. cyathopharynx*, seem to be sensitive to organic pollution as their abundances decrease with increase in organic pollution (tables 3 and 4). Most cestodes and digeneans (*P. clarias*, *Proteocephalus* sp., *Caryophyllaeus* sp. and *Diplostomum* sp. with the exception of *Lytocestus* sp. and *Tylodelphys* sp.) seem to be very

tolerant to organic pollution as they are associated with the polluted sites (tables 2 and 4). *Paracamallanus cyathopharynx* was not encountered in the Mukuvisi River as well as Manyame 3, showing that it is highly sensitive to organic pollution. Although larval *Contraecum* occurred at most sites, its prevalences decreased considerably with increasing pollution levels (table 4).

The four unpolluted rural sites possessed metazoan communities with a greater level of similarity because they had a more varied assemblage of parasite species than the polluted sites (fig. 4). The severely polluted sites also possessed more similar metazoan communities because they had a more impoverished parasitic fauna than the polluted sites (fig. 4). This pattern of similarity also appears to be caused by the patterns of the physicochemical variable measurements obtained (fig. 3).

The eigenvalue for the first axis was 0.5, contributing 50.3% of the variance; while the eigenvalue for the second axis was 0.2, contributing 19% of the variance (fig. 4). The PCA plot shows that *Diplostomum* sp. and *P. clarias* are strongly correlated with the first axis and are more widespread and dominant species among both polluted and unpolluted sites (Nyatsime 1 and 2; Manyame 1 and 2; fig. 4). The distribution of *Proteocephalus* sp. was limited

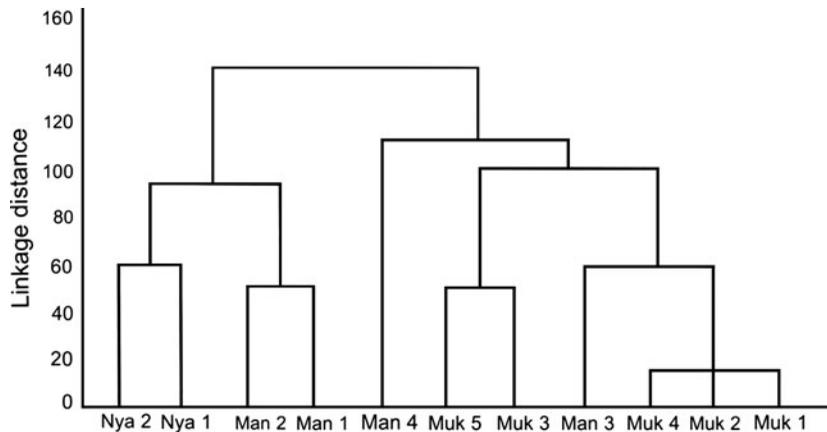


Fig. 3. Cluster analysis showing the patterns of similarity in metazoan parasite communities of test sites in the catchment. Man, Manyame; Muk, Mukuvisi; Nya, Nyatsime.

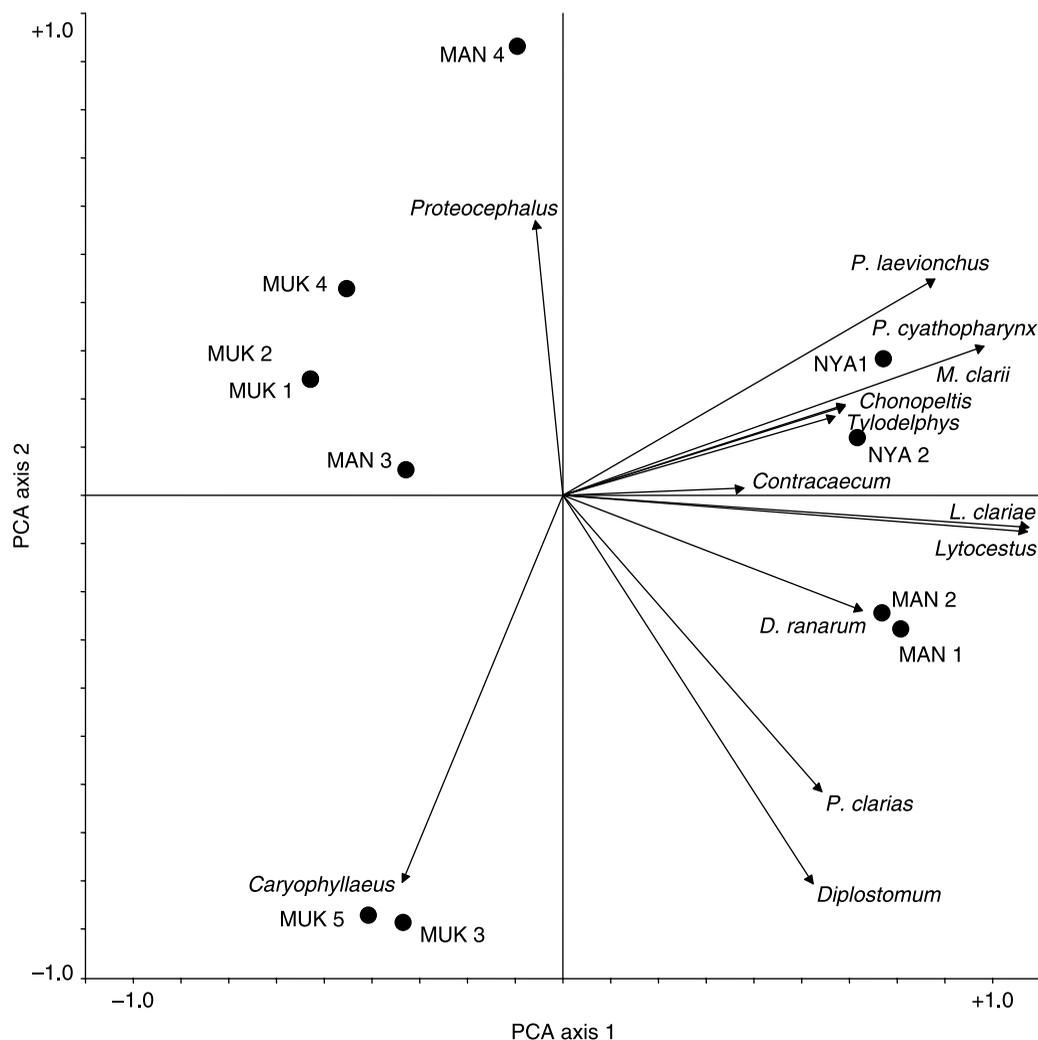


Fig. 4. Principal components analysis (PCA) ordination showing parasite species distribution based on prevalence among sites. MAN, Manyame; MUK, Mukuvisi; NYA, Nyatsime.

to Manyame 4, a lacustrine and polluted environment, while *Caryophyllaeus* sp. was limited to Mukuvisi sites 3 and 5 (polluted sites). The four rural sites are strongly associated with most parasite species. Although *Contracaecum* is weakly correlated with the unpolluted sites, it was a less abundant species (tables 3 and 4; fig. 4). The severely polluted sites (Manyame 3, Mukuvisi 1, 2 and 4) do not demonstrate any close association with any of the parasite species.

Discussion

Water quality

The higher conductivity at Mukuvisi 5 (Pension Farm) and Manyame 3 (Beatrice Road Bridge) may be attributed to sewage effluent saturating the two systems, while the slight decrease in conductivity downstream could be a sign that the ions were precipitating out and settling on the riverbed. The high levels at the Mukuvisi sites may be

due to waste that both the formal (Graniteside) and informal industries (Mbare) deposit in the river. In 1970, the conductivity was around $164 \mu\text{S}/\text{cm}$ (Mitchell & Marshall, 1974). Increased urbanization and poorly treated effluent discharged into the river are implicated in the observed rise in conductivity. From the cluster analysis, it can be concluded that Mukuvisi 3, 5 and Manyame 4 are polluted, while Mukuvisi 1, 2, 4 and Manyame 3 are severely polluted as shown by the high levels of macronutrients and conductivity (fig. 2).

The study shows that a considerably high portion of the fluctuation in the parasite prevalence and diversity was related to change in the physicochemical parameters, particularly nitrates, phosphates and conductivity that increased downstream of the cities of Chitungwiza and Harare, while oxygen levels dropped significantly. It is clear that these three tributaries of Lake Chivero contribute the bulk of the nutrient loading to the lake as they flow through heavily industrialized and densely populated

areas on their way to the lake. The Manyame River carries all the effluent from neighbouring Chitungwiza. The recent large-scale deaths of fish in Lake Chivero indicate a stressed ecosystem due to pollution (Moyo, 1997).

The major drainage system of the rural Manyame and Nyatsime catchments is dominated by commercial and communal farmlands. The area appears to be an ideal locality for rich natural communities of fishes and their parasites based on the assumptions that the waters are relatively uncontaminated; consequently, the rural sites had a flourishing parasitic fauna, while the stressed sites had depauperate fauna.

Species composition, diversity and distribution

Clarias gariepinus hosted high metazoan species richness, comprising 13 species reported. The richest and most diverse metazoan communities were found in the unpolluted sites, while the metazoan communities of the polluted and severely polluted sites were depauperate assemblages with low levels of species richness and diversity and relatively low abundance of most of the constituent species. The study shows that a considerable amount of the fluctuation in the parasite prevalence and diversity was attributed to change in the levels of nutrients, dissolved oxygen and conductivity. Polluted water may also act directly on intermediate hosts and definitive hosts. The results are consistent with the findings of Sulgotowska & Styczynska-Jurewicz (1987) who recorded a reduction in species richness from 12 to 4 due to municipal and industrial sewage.

Chonopeltis sp., *D. ranarum*, *M. clarii*, *L. clariae*, *P. laevionchus* and the cestodes (caryophyllids, proteocephalids and *Polyonchobothrium*) are all autogenic, i.e. they reach maturity in fish. The two digenean taxa reported in this study, *Tylodelphys* and *Diplostomum*, were found in their metacercarial (encysted larval) stage, while *Contracaecum* spp. were found in the juvenile stages, indicating these are allogenic species that reach adult form in other vertebrates such as fish-eating birds. In Zimbabwe, the helminth fauna of piscivorous birds has been recorded by Beverly-Burton (1963), Mettrick (1967), Barson & Marshall (2004) and Barson *et al.* (2008).

The eutrophic nature of Lake Chivero and the Mukuvisi River contributed to the observed helminth community of *C. gariepinus* at the polluted sites only. *Caryophyllaeus* sp. and *Proteocephalus* sp. exhibited distinct distributions in which the former was secluded to Mukuvisi sites 3 and 5, while the latter occurred at Manyame 4 (confluence with the lake). The first intermediate hosts of caryophyllid cestodes are oligochaetes (Tubificidae), particularly *Tubifex* and allied genera (Paperna, 1996). These worms are prevalent in the Mukuvisi River and Lake Chivero (Moyo & Phiri, 2002) and can tolerate organic pollution since they feed on organic particles (Weisberg *et al.*, 1986). Kostarev (1980) found high numbers of *Caryophyllaeus laticeps*, and he attributed this to increased oligochaete populations where household sewage was discharged in reservoirs.

First intermediate hosts of segmented tapeworms such as the proteocephalids are copepods. In *Proteocephalus*, a second larval stage (plerocercoid) develops in fish species that are non-compatible as definitive hosts

(Paperna, 1996). The increased abundance of these intermediate hosts results in part from the sewage outflows and reflects organic enrichment of the sediments, providing excellent habitat for the oligochaete and copepod alternate hosts (Weisberg *et al.*, 1986; Sibley *et al.*, 2000). Data from this study corroborate previous records of increased abundance of tubificid oligochaetes (Moyo & Worster, 1997; Moyo & Phiri, 2002) in the Mukuvisi River. Some freshwater studies have suggested a positive relationship between eutrophication and fish parasitism (Hartman & Numann, 1977; Beer & German, 1993; Lafferty & Kuris, 1999). Eutrophication often raises parasitism because the associated increased productivity can increase the abundance of intermediate hosts (Lafferty & Kuris, 1999), as was observed in the Manyame catchment for *Caryophyllaeus* and *Proteocephalus* sp.

In terms of prevalence *Diplostomum* sp. and *P. clarias* exhibit a high ecological invasiveness, occurring at polluted and unpolluted sites. Cone *et al.* (1993) and Marcogliese & Cone (1996) discovered digeneans to be absent or rare in American eels, and concluded that it was the fish intermediate host and not the parasite that is sensitive to acidification. Acidification impacts most strongly on populations of digeneans. The pH levels in the catchment were found to be within the acceptable range of 6.5–8.5 except for two sites (Mukuvisi 5 and Manyame 3) where *Diplostomum* sp. occurred. The presence of suitable gastropod intermediate hosts is also important in the transmission of digenean parasites (Paperna, 1996). It has nevertheless been shown that some gastropods are extremely sensitive to pollution and were killed on exposure to the polluted Manyame and Mukuvisi sites (B. Masola, personal communication).

Kostarev (1980) found a rise in numbers of *Diplostomum* in sites where industrial effluent was discharged into reservoirs and he attributed this to increased bird populations attracted by dying fish. Massive fish deaths frequently recorded in the Manyame catchment could partly explain the widespread distribution of *Diplostomum*. However, the other digenean, *Tylodelphys* sp., was isolated to the Nyatsime sites, possibly indicating the influence of water quality. Galli *et al.* (2001), however, found no effect of pollution on the prevalence, abundance and mean intensity of *Tylodelphys clavata*.

Polyonchobothrium clarias can withstand harsh conditions, as it has been found in the gall bladder. Wabuke-Bunoti (1980) was the first to report the invasion of the host gall bladder by *P. clarias*. All other environmental conditions being equal, the levels of *P. clarias* infections under organically enriched conditions remained high, as shown by the high prevalence at Manyame 3, a heavily polluted site. Among the four cestode species encountered in this study, three proliferated in polluted water, with only one exception (*Lytocestus*).

Most nematode parasites of *C. gariepinus* were highly sensitive to pollution since they only thrived at unpolluted sites. The presence of the nematodes in the polluted sites is made possible by their possession of a cuticle, which enables them to withstand the harsh conditions. Although *Contracaecum* occurred at eight of the 11 sites, it was less abundant, as characterized by low prevalence. Further studies should address the identification of parasite life stages that are more sensitive to pollutants.

Fish-eating birds also play an important role in the transmission of allogenic parasites (those that do not mature in fish), so their presence is also an important determinant. In our polluted system, fish-eating birds (cormorants, herons, fish eagles, kingfishers and darters) are abundant at Lake Chivero, the ultimate sink of all the pollutants from the rivers. *Contracaecum* has been found to be highly prevalent in both the catfish and the birds (see Barson, 2004; Barson & Marshall, 2004). Larvae might actually survive high pollution load by being encapsulated in a tough sheath inside the body cavity of the fish, and high prevalence in birds could be attributed to easy access to prey in the lake. Along the rivers, however, these birds are very rare to see, and this could also have contributed to the low prevalence observed in the fish.

While the level of water pollution can influence aquatic endoparasites both directly and indirectly by acting on their intermediate hosts, ectoparasites may be more sensitive to contaminants that might reduce their survival and reproduction rates (Khan & Thulin, 1991). Ectoparasites are just as exposed to the environment as their host, such that poor water quality will be expected to adversely affect their diversity to a greater extent than it would endoparasites.

The ectoparasitic crustaceans (*L. clariae*, *D. ranarum* and *Chonopeltis* sp.) and the monogenean (*M. clarii*) were totally absent at polluted sites, a trend also observed by Zharikova (1993). Although these parasites do not require intermediate hosts for completing their life cycles, the results suggest a direct effect of water quality on the parasites. In particular, the abundance of crustacean parasites varies with different environmental conditions and decrease considerably in polluted areas (Kuperman, 1991). For example, Galli *et al.* (2001) provided evidence of the susceptibility of *Lamproglana pulchella* (von Nordmann 1832) to poor water quality. Overstreet & Thulin (1991) found that the prevalence of the copepods *Achtheres percarum* and *Caligulus lacustris* on perch (*Perca fluviatilis*) increased with the distance from the point of effluent discharge, while no parasites were found on fish at the closest location to the effluent discharge. *Chonopeltis* was also absent in the unpolluted Manyame sites (1 and 2), but there is no immediate reason to explain this discrepancy, since this was also the first time this parasite was recorded in the system and its local distribution range has not yet been determined.

Only one monogenean, *M. clarii*, was found in this study only at the unpolluted sites. Similarly, Kostarev (1980) found that industrial waste discharge into two reservoirs had the effect of reducing the number of species of monogeneans. Overstreet & Howse (1977) found the prevalence and intensity of the monogenean, *Macrovalvitrema micropogoni*, on the Atlantic croaker, *Micropogonias undulatus*, to increase with decreasing pollution. The monogenean might be sensitive to high levels of conductivity, nutrients and hypoxia. Ectoparasitic monogeneans have been found to be generally sensitive to pollution in southern Africa (Avenant-Oldewage, 2001). The exposed state of the soft-bodied adult and the delicate, short-lived, free-swimming oncomiracidium may render this parasite and others like it susceptible to harsh environmental conditions (MacKenzie *et al.*, 1995).

In conclusion, the results of this study indicate that the sewage effluent from Firlle and Chitungwiza sewage works affects the metazoan parasite assemblage of *C. gariepinus* in the catchment. This study demonstrates that parasite species composition and richness in catfish communities are influenced by local environmental factors such as conductivity, nutrients and dissolved oxygen, and that parasite assemblages may be good indicators of environmental stress because they reflect the presence of many different types of organisms, based on the variety of complex life cycles displayed by the different parasite taxa.

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